Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Architecture and Design
Department of Architecture and Technology

Irene González Fernández

Sustainable renovation of nursing homes in Norway

LCA and LCCA of low-impact dementia-friendly measures in Trondhjems Hospital

Master's thesis in Sustainable Architecture
Supervisor: Patricia Schneider-Marin
Co-supervisor: Sara A. Sharbaf, Lucía C. Pérez-Moreno
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(NTNU, Norway)

Co-supervisor:
Sara A. Sharbaf
(NTNU, Norway)

Co-supervisor:
Lucía C. Pérez-Moreno
(UNIZAR, Spain)

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Abstract

European countries are facing social, architectural and environmental challenges. The population is increasingly over-aged and dependent due to demographic ageing. By 2050, 200,000 Norwegians will have dementia and need round-the-clock care in nursing homes. However, COVID-19 severely impacted care homes in Europe. Norway was one of the most resilient countries in the pandemic, but today the staff still handles an increased workload and patients are dealing with depression. Norwegian nursing homes need to be transformed into dementia-friendly high energy-efficient, zero-emissions environments, considering the current context of climate change and global warming. According to the EU's climate-neutral objective, the building stock must be transformed into zero-energy buildings to achieve climate neutrality by 2050.

Given the previous context, an ambitious and holistic strategy is needed to renovate the long-term care stock in Norway. This thesis aims to investigate the environmental, economic and social impacts of renovating nursing homes in Norway to achieve the zero emissions building (ZEB) ambition level while transforming care homes into dementia-friendly environments. In particular, the goal is to minimise the embodied carbon emissions and reduce the operational energy use of a case study in Trondheim (Trondhjems Hospital) by proposing low-impact but meaningful renovation measures.

The methodology involves a life cycle assessment (LCA) of the embodied and operational energy emissions, net energy use and net energy delivered of two units (*sykehjem* and dementia wings) in the nursing home. The research method also performs a life cycle cost analysis (LCCA) to evaluate the construction and operational energy costs and an environmental quality assessment (EQA) to estimate the social impacts of the renovation measures on the comprehensive well-being of the residents with dementia. The LCA, LCCA and EQA consider a diverse range of insulation materials (wood fibre and mineral wool), cladding materials (wood and brick) and energy standards (Passive house and TEK17), with the purpose of generating a reference document for practitioners to renovate nursing homes with a dementia-friendly and sustainable approach. The scenarios assessed are externally insulating, internally insulating, changing windows, and transforming the unit into a dementia-friendly environment.

The results show 1.1-1.7 $kgCO_2eq/yr/m^2_{GFA}$ of embodied emissions in the *sykehjem* unit and 1.9-3.3 $kgCO_2eq/yr/m^2_{GFA}$ in the dementia wings. The operational energy emissions are 10.1-13.1 $kgCO_2eq/yr/m^2_{GFA}$ in the *sykehjem* and 10.9-15.6 $kgCO_2eq/yr/m^2_{GFA}$ in the dementia wings. Compared to the baseline scenario, the net energy use and delivered energy are reduced by a 50% approximately. The construction costs are around 7,500-17,000 NOK/$m^{2,}$ and the total costs during 60 years of service life are 16,200-29,300 NOK/m^2. Compared to TEK17, the average payback period of the Passive House standard is two years (emissions) and 25 years (costs). Extrapolating the results for all nursing homes in Norway, the total cost of renovating the building stock to be climate-neutral is between 19.4 and 69 billion NOK, depending on the scenario assumed.

The carbon emissions are below Enova's benchmark for renovated low-energy buildings. However, Trondhjems Hospital cannot reach any ZEB ambition levels because it does not produce enough renewable energy to compensate for the emissions. The nursing home would need around 4,000 m^2 of PV panels to be zero emissions. The case of Trondhjems Hospital shows that it is not feasible to have ZEB nursing homes. In order to reach climate neutrality by 2050, policies should focus on lowering energy emissions and promoting renewable energy production technologies at a neighbourhood level (ZEN).

Keywords: nursing home, renovation, dementia, LCA, zero emissions, zero energy, climate neutrality

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The master's thesis is based on the knowledge and skills obtained in the courses AAR4817 Emissions as Design Drivers and AAR4926 Integrated Energy Design. The contribution to the FME-ZEN Ydalir pilot project as a researcher in the Fall Semester of 2022 built the LCA and LCCA methodology of the thesis. The selection of the topic comes from the research project "Nursing homes after COVID-19" that the author is part of. The project lasts 4 years (2021-2025) and is founded by the Government of Aragón (Spain). The investigation is supported by *T37_17R Grupo de Investigación en Arquitectura* research group, *T37_23R BUILT4LIFE Lab* research group and *MuWo* research project.

I would like to express my sincere gratitude t every person who contributed to the thesis. Many thanks to my supervisor Patricia Schneider-Marin and co-supervisors Sara A. Sharbaf and Lucía C. Pérez-Moreno for their support and valuable feedback throughout the thesis. I would also like to thank Marianne Rose Kjendseth Wiik (SINTEF) for her guidance during the research job in the FME-ZEN last semester. I am also grateful to the staff in Trondhjems Hospital and Trondheim Kommune for providing the case study's baseline information.

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"I am a mosaic of everyone I have ever loved, even for a heartbeat".

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List of Abbreviations

NTNU	Norwegian University of Science and Technology
UNIZAR	University of Zaragoza
LCA	Life cycle assessment
LCCA	Life cycle cost analysis
EU	European Union
ZEB	Zero-emissions/energy building
EQA	Environmental quality assessment
ZEN	Zero emissions neighbourhood
FME-ZEN	Research Centre on Zero Emission Neighbourhoods in Smart Cities
RQ	Research question
T	Task
LCI	Life cycle inventory
WHO	World Health Organisation
HVS	Health and welfare centre (*Helse- og velferssenter*)
SH	*Sykehjem*
O	*Omsorgsbolig*
GNAFCC	Global Network for Age-friendly Cities and Communities
GHG	Greenhouse gas
NZEB	Neary zero-energy building
EPC	Energy performance certificate
PH	Passive house
LEB	Low-energy buildings
net ZEB	Net zero energy building
TEK	TEK17 (*Byggteknisk forskrift*)
CO_2eq	CO_2 equivalent
GWP	Global warming potential
DiBK	Directorate for Building Quality (*Direktoratet for byggkvalitet*)
GFA	Gross floor area
S	Scenario
FBZ	FutureBuit Zero
BIM	Building Information Modeling
EPD	Environmental Product Declaration
HVAC	Heating, ventilation and cooling
DW	Dementia wings
XPS	Expanded polystyrene
PVC	Polyvinyl chloride
WC	Wood cladding
BC	Brick cladding
WF	Wood fibre
MW	Mineral wool
PV	Photovoltaic
NOK	Norwegian kroner
VAT	Value-added tax
EAT-HC	Environmental Audit Tool-High Care
BEAT-D	Building Environmental Assessment Tool-Dementia
RFI	Room for Improvement
CCI	Construction Cost Index
GIA	Gross internal area
SCC	Smart Cities and Communities
C	Building category
Q	Quantity
TD	Transport distance
SF	Service life
W	Wastage

1 Introduction

1.1 Motivation

The master's thesis is connected to an ongoing research project, "Nursing homes after COVID-19", carried out at the University of Zaragoza in Spain. The project has a duration of 4 years (2021-2025) and is founded by the Government of Aragón. The investigation is supported by *T37_17R Grupo de Investigación en Arquitectura* research group, *T37_23R BUILT4LIFE Lab* research group and *MuWo* research project.

The principal motivation to elaborate a master's thesis about renovating nursing homes from a sustainable and dementia-friendly approach comes from some of the biggest challenges that European countries are facing nowadays:

Social challenges. In the current context of demographic ageing, older people are increasingly over-aged, dependent and feminized. The rise in life expectancy has heightened the need of round-the-clock care. While elderly people with physical disabilities can 'age in place' using home-based care services, people with dementia benefit from dementia-friendly environments in nursing homes. 80% of nursing home residents in Norway have dementia. In 2050, more than 200,000 Norwegians will have dementia.

Architectural challenges. Norway has a robust care system with a person-centred approach, but not enough dementia-specific places are available in nursing homes. Although the COVID-19 pandemic did not impact nursing homes in Norway (only 1.3% deaths), the staff is handling an increasing workload and mental stress, and residents are dealing with depression and frailty due to isolation.

Environmental challenges. In the current context of climate change and global warming, the renovation of care facilities has to reach the energy-efficiency and carbon-neutral requirements of the European Commission. According to the EU's climate objectives and the *Energy Performance of Buildings Directive* reform proposal, all new constructions shall be zero-emissions buildings (ZEB) by 2030. The EU's building stock must be transformed into zero-energy buildings to achieve climate neutrality by 2050.

In particular, the deaths in nursing homes related to COVID-19 were the reason for choosing this research topic. The care homes in Spain, my country of origin, were severely stricken by the pandemic. Between March and June 2020, 20,000 deaths were associated with COVID-19 after a positive test. Around 10,500 more residents were deceased during that period without a diagnostic test. 31% of the COVID-19 deaths in Spain took place in nursing homes [1].

1.2 Goal

This master's thesis is based on the following hypothesis: to meet the decarbonisation goals of the EU and fulfil the needs of the future generation of older people living with dementia, an ambitious and holistic strategy to renovate the long-term care home stock in Norway is needed.

The main focus of the thesis is to calculate and evaluate the environmental, economic and social impacts of renovating nursing homes in Norway to achieve the zero emissions building (ZEB) ambition level while transforming care homes into dementia-friendly environments. Specifically, the goal is to minimise the embodied carbon emissions and reduce the operational energy use of a case study in Trondheim (Trondhjems Hospital) by proposing low-impact but meaningful renovation measures.

1.3 Research questions

The following research questions (RQ) will be answered in this master's thesis:

RQ1. What are the environmental (carbon emissions and operational energy use) and economic impacts (construction and energy costs) of renovating and transforming Norway's nursing homes into dementia-friendly environments with low-impact measures?

RQ2. What is the feasibility of renovating Norway's nursing home stock to reach zero-emissions/energy building (ZEB) ambition level?

RQ3. What are the needs of older people with dementia living in nursing homes, and how can a dementia-friendly environment contribute to their comprehensive well-being?

1.4 Research method

The research method implemented in this thesis involves a literature review, a case study analysis and elaborating a life cycle assessment (LCA), a life cycle cost assessment (LCCA) and an environmental quality assessment (EQA) to estimate the environmental, economic and social impacts, respectively. The methodology implemented in the thesis follows the same assumptions, calculation methods and scenarios that the FME-ZEN Research Centre Ydalir pilot project [2], [3], and has therefore been validated in a real case study. The tasks (T), represented in Figure 1, are:

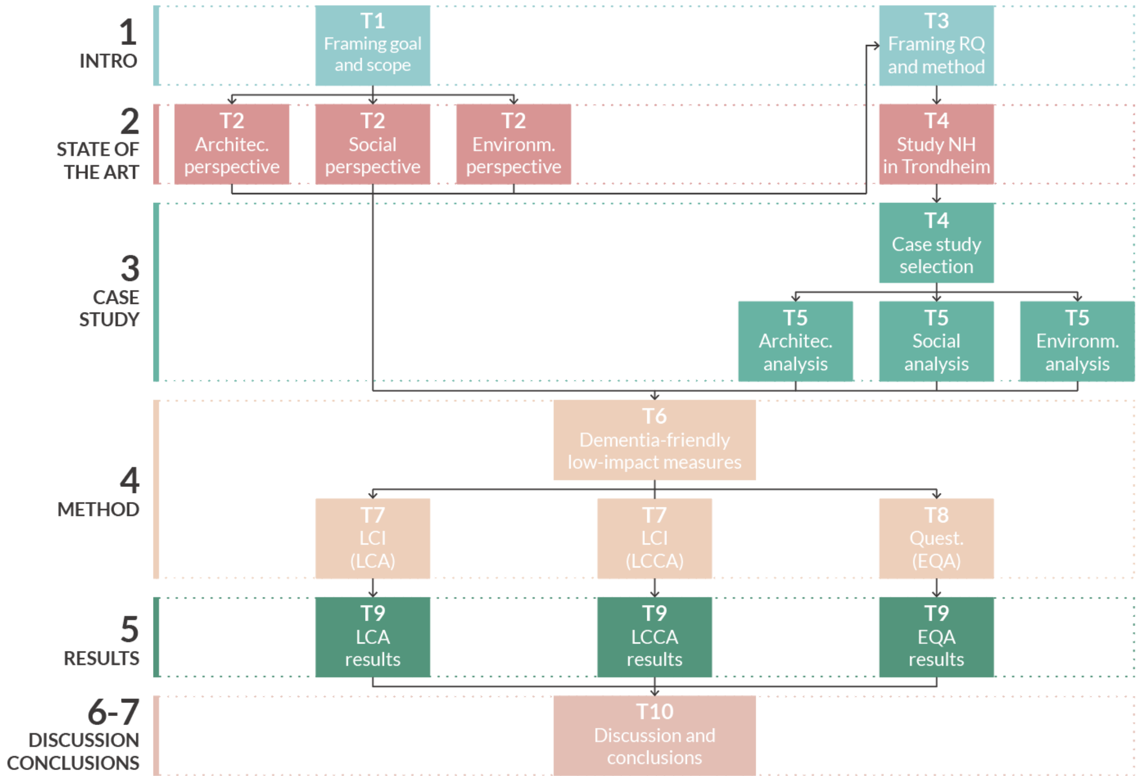


Figure 1. Research method flow chart

T1. Frame the research goal and scope of the thesis.

T2. Study the state of current research and practices about nursing homes in Norway from an architectural perspective (building, housing and healthcare typologies, users, construction date, programme, regulation), social perspective (demographic ageing, dementia and the built environment, design measures) and environmental perspective (climate neutrality goals, energy and carbon emissions standards and benchmarks).

T3. Establish the objectives of the master's thesis, research questions and research method.

T4. Study nursing homes in Trondheim to select a representative case study.

T5. Analyse the case study architecture, construction systems and energy performance.

T6. Establish a catalogue of low-impact and dementia-friendly renovation measures based on the literature review in T2.

T7. Set the life cycle inventory (LCI) of LCA and LCCA to evaluate the carbon emissions (embodied and operational energy) and cost of the renovation measures.

T8. Carry out the EQA questionnaire of the case study before and after the sustainable renovation.

T9. Analyse the LCA, LCCA and EQA results.

T10. Discuss the influence of the methodological assumptions and compare the results obtained in T9 with ZEB ambition levels and benchmark values. Estimate the financial restrictions and impacts of renovating the whole nursing home stock in Norway. Discuss the impacts of dementia-friendly measures.

1.5 Thesis outline

The thesis outline follows the same structure as the research method. The research project is organized into seven main sections: (1) introduction, (2) state of research and practice, (3) case study, (4) methodology, (5) results, (6) discussion, and (7) conclusion.

The state of research and practices is integrated by the literature review and background study of nursing homes in Norway, considering a social, architectural and environmental perspective. The case study section describes the history, architecture, programme, construction and energy performance of Trondhjems Hospital. The methodology chapter explains the scope, system boundaries, assumptions and scenarios to calculate the LCA, LCC, EQA and energy performance of the low-impact dementia-friendly renovation measures in Trondhjems Hospital. The results section explains the findings obtained in the LCA, LCCA, EQA and energy simulation, divided per scenario. The discussion chapter address the influence of the methodological assumptions, the ambition levels and the benchmark values reviewed in the second section. The section also analyses the feasibility of reaching ZEB in the Norwegian nursing home stock. Lastly, the conclusion summarises the master's thesis findings, limitations, future work and its influence on the field.

The master's thesis has five appendixes: the recommended functional areas for nursing homes in Trondheim (Appendix 1), the LCA inventory (Appendix 2), the Simien files and reports (Appendix 3), the Excel files used in the LCA, LCCA and EQA (Appendix 4), the LCCA inventory (Appendix 5), and the EAT-HC questionnaire used in the EQA (Appendix 6). Appendixes 3 and 4 can be found in the attached folder.

2 State of research and practices

2.1 Social perspective: dementia-friendy environments

2.1.1 Dementia in Norway

The rise in life expectancy has increased the proportion of older adults (65 years and over) in the European and Norwegian populations. Older people are progressively over-aged, dependent and feminised. According to Eurostat projections, the proportion of elderly people aged 80 years or over in Norway will increase from 4.4% in 2021 to 9.0% in 2050 [4]. In 2021, life expectancy at birth was 81.6 years for men and 84.7 for women, respectively 7.6 and 4.6 years more than three decades ago [5]. Although women live longer, they also live more years with illness: women have an unhealthy life expectancy (LE-HALE) of 13.6 years, three years more than men [6].

Several studies [7]–[11] show that the risk of cognitive and physical function diseases among the elderly might have been reduced in Europe and the United States, especially among older men. However, dementia, frailty or chronic diseases impacting the quality of life and mental health are still growing in Scandinavian countries [12], [13], along with the number of older people.

The proportion of residents with dementia living in nursing homes has also grown recently. The *Dementia Plan 2025* of the Norwegian Ministry of Health and Care Services [14] defines dementia as a general term that refers to several chronic diseases affecting the brain. The most common symptoms of dementia are progressive and frequent memory loss, confusion, personality change, apathy and withdrawal and loss of ability to perform everyday tasks [15]. Dementia can also lead to language impairment, problems with spatial navigation and orientation, loss of insight, agitation, aggression, anxiety, and depression.

A survey in Trøndelag [16] reveals that 14.6% of people aged 70 or older have dementia (Figure 2). The prevalence of dementia increases from 5.6% in the age group between 70 to 74 years to 48.1% among people older than 90. The most frequent types of dementia are Alzheimer's disease (57%) and vascular dementia (10%) [14]. The study estimated that 101,000 people had dementia in Norway in 2020. 84.3% of the residents living in nursing homes have dementia, while the rate of dementia among people living in their own homes is 10.8%. The incidence is 50% higher among women than men in the group of people aged 85 years or older [17]. In 2050, the number of people with dementia will increase to 236,789 and 380,134 in 2100 [9], [14].

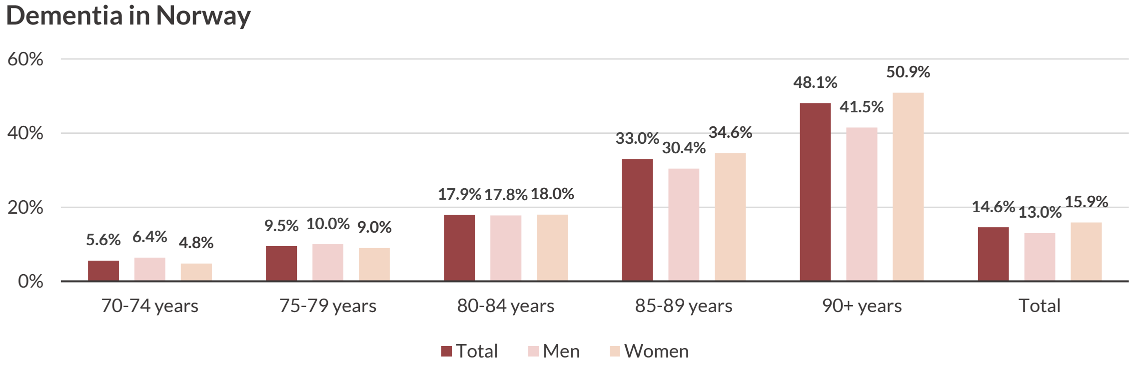


Figure 2. Proportion of people with dementia in Trøndelag [16]

2.1.2 Literature review: dementia and the built environment

The COVID-19 pandemic had dramatic consequences in nursing homes: 41% of all worldwide deaths related to COVID took place in long-term care homes [18]–[20]. In Norway, the pandemic was much more favourable. Only 1.3% of all deaths in nursing homes during 2020 were attributable to COVID-19 [21]. However, staff in Norwegian nursing homes are facing an increasing workload and mental stress [22].

To respond to future crises and improve the well-being of staff and residents, European countries are promoting a 'person-centred care model' [23]. Alzheimer's Association considers that "person-centred care is [focused] on elders' (residents' and clients') emotional needs and care preferences, consistent with their lifestyle. The emphasis is on relationships in the care (social model) rather than task-centred approaches that focus on the physical health of elders (Medical model)" [24, p. 1]. Common elements of a person-centred living facility are collaborative decision-making, close relationships between residents, families and staff, homelike atmosphere, resident-directed care and daily activities, staff empowerment and quality improvement processes [24].

A person-centred care model has to be supported by a quality-of-life-driven built environment [25], especially when residents have dementia. The 2018 Alzheimer's Association Dementia Care Practice Recommendations [26], based on person-centred care values, recognise the positive impact of supportive and therapeutic environments that (1) create a sense of community, (2) enhance comfort and dignity for everyone, (3) support courtesy, concern and safety, (4) provide opportunities for choice for all persons and (5) offer opportunities for meaningful engagement. In Norway, the Dementia Plan 2025 also addresses the urge to adapt available nursing homes to dementia-friendly environments [14].

Previous research on the effects of the built environment on people living with dementia has focused on identifying, modifying and reducing the difficulties experienced by the patients [15]. Several systematic reviews of environmental design for people with dementia have also been conducted [27]–[30]. The following literature review analyses the effects of a well-designed built environment on patients with dementia. The design measures are structured in ten categories, according to the Dementia Enabling Environment Principles proposed by Richard Fleming and Kirsty A. Bennet [15].

2.1.2.1 Unobtrusively reduce risks

People with dementia require an easy-to-move environment to continue their way of life. Architectural barriers (e.g., steps or level changes) must be minimised and marked. Safety measures have to be unobtrusive to lower frustration, anger, apathy and depression symptoms among the residents.

The risks of wandering away, getting lost or running over are the most common among people with dementia [31]. Several studies have found positive effects if a secure perimeter is provided, with preferable access to an outside area [32]–[35].

> *"Residents in facilities whose exits were well camouflaged and had silent electronic locks rather than alarms tended to be less depressed. A hypothesis to explain this correlation is that residents try to elope less in such settings and that caregivers […] afford residents greater independence of movement" [35, p. 708].*

Other researchers have suggested that a too-secured perimeter can have unwanted side effects on people with dementia, like risk-taking and passive self-harm [36], [37]. Securing doors, drawers, or cupboards does not provoke cognitive declines or behavioural disturbances [38].

There is also a debate in current literature about having segregated areas for patients that may harm themselves or others. Some authors recommend separated units with larger spaces (at least 30 m^2 per resident), a garden, a quiet area, a seclusion suite, activity rooms and a specific care model

[39]–[42]. Others stated that psychiatric units are enclosed due to cultural stigmas around patients, staff conveniences and hospital-wide resistance: several studies have found more disadvantages than benefits in having confined spaces [43], [44].

The built environment should also prevent falls among residents[45]–[47]. People with dementia are eight times more likely to experience a fall [48]. Restraints (e.g., lap belts and bed rails) were a common practice in nursing homes a few decades ago. However, the literature does not support the efficacy of this method in reducing falls [49], [50]. Physical restraints negatively affect patients with dementia, including lower cognitive performance, lower performance in daily activities and higher walking dependence. Long-term care homes should promote a restraint-free and multi-faceted approach to improve residents' quality of life and reduce falls [51], [52].

> *"The benefits of preventing falls by rearranging furniture, removing objects that may precipitate falls, maintaining step surfaces, removing loose carpets, providing grab bars, improving lighting, repositioning beds, adjusting bed and chair heights, repairing roller walkers and removing obstacles have been identified [by Kallin et al. [53]]" [15, p. 13].*

2.1.2.2 Provide a human scale

Over-scaled surroundings and multiple interactions can affect the feelings and behaviours of people with dementia, while a homelike scale can encourage the sense of well-being and enhance competencies. The experience of scale is influenced by the number of people, the overall size of the building and the size of individual components (e.g., doors, rooms and corridors).

The research literature has found that dementia-specific units need to have a small scale size to reduce agitation and confusion among residents [54]–[56] and to provide high-quality care [32], [57]. A domestic scale has been recommended to make the residents feel in a homelike atmosphere and improve patient monitoring. In contrast, a higher proportion of harmful behaviour has been found in nursing homes with more users and long corridors. Nevertheless, researchers have no consensus about the effect of scale on behavioural disturbance. Some reports support a reduction [58]–[60], others an increase [56], [61] and others no effect [62]–[65] on behavioural disturbance.

> *"Purpose-designed small units are very likely to be homelike, familiar and safe. While there is a range of evidence that supports the view that small numbers of people in dementia units are better than large numbers, it is not conclusive. The evidence also suggests that the combination of small unit size with the other attributes of specialised units is not demonstrably beneficial in the later stages of dementia" [15, p. 17].*

2.1.2.3 Allow people to see and be seen

People with dementia need to recognise where they are, where they come from and where they can go. Buildings can reduce confusion and promote confidence to explore among patients by providing good visual access to key places.

Direct visual access to relevant places (e.g., lounge and dining areas) and integrating reference points or unique-character zones promote the wayfinding of people with dementia [66]–[69]. The staff also benefits from good visual access, reducing the time spent locating and monitoring patients, supporting informal social interactions among caregivers and residents and increasing the user's feeling of being supported by the staff [45], [70].

2.1.2.4 Reduce unhelpful stimulation

Dementia diseases lower the ability to filter stimulus. The built environment should minimise unnecessary visual and auditory noise to reduce stress and agitation.

In addition to the risk of falling, people with dementia struggle with screening out overstimulation, becoming more confused, anxious and agitated [71], [72]. Common causes of visual and auditory overstimulation are entry doors visible to residents, clutter, public address systems, alarms, loud televisions, corridors and crowding [73]–[76].

Busy entry doors are the most significant source of overstimulation and may cause residents to leave. Several methods to avoid these problems are hiding the door or door handle, installing blinds in glazed doors [77], [78] or disguising the door with murals [79]. High noise levels in the living room and high temperatures in the resident's bedroom are associated with low levels of social interaction [80]. However, moderate sound levels improve patient engagement [81].

2.1.2.5 Optimise helpful stimulation

Visual, auditory and olfactory cues can increase orientation, minimising confusion and uncertainty. Text and images in signs, highlighting elements and distinctive finishes can be helpful, but they must be carefully designed not to become overstimulating.

Signs can help wayfinding [69], [82] and reduce behavioural symptoms [33] in people with dementia. Researchers have found that signs with words are most effective than pictograms. The signs should be large, have contrasting backgrounds and be placed low, preferably close or on the floor [83]–[85], due to people with dementia usually experiencing downcast gaze. However, direct visual access and pre-orientation training are more effective in improving wayfinding than signs [86].

Some signs can have a negative impact on people with dementia. Exit signs and door panic bars can trigger residents to leave the unit. Several studies have proved that installing mirrors, cloth panels, or black tape on exit doors reduces exit-seeking and wandering behaviours [77], [87], [88].

> *"The physical environment not only creates the wayfinding problems people have to solve but it can also provide information to solve these problems. […] Information should be presented by different means to allow for personal preferences and redundancy. […] Direct visual access to form and function is to be encouraged whenever possible. Attention has to be paid to avoid distracting residents by nonrelevant information displays. The environment has to speak a language that the user, the Alzheimer's patient, can understand. [69, p. 707]".*

Familiar objects can also promote orientation [89]. Displaying memorabilia and photographs of residents in their youth stimulates orientation in people with moderate dementia [90]–[92]. Labelling drawers and cupboard doors or installing clocks can increase wayfinding and the ability to perform daily activities [93], [94]. Another way to promote stimulation is by contrasting objects against their background. High contrast between toilet seats and floor, tablecloths and dishes, or residents' doors and walls can reduce agitation and orientation [95], [96]. On the other hand, people with dementia may perceive contrasting floorcoverings and geometric patterns as steps [97], [98].

The previous measures are only effective when an adequate illumination level is provided. Low light levels compromise wayfinding [68] and reduce patients' general well-being [80]. High light levels regulate circadian rhythms, improve function and sleep patterns [95], [99], [100] and reduce depression [101]. However, other studies have shown that high illumination may increase agitation and wandering behaviours [99], [100], [102]–[104].

2.1.2.6 Support movement and engagement

A defined path free of obstacles but with points of interest (e.g., plants, seating areas, fountains) creates opportunities for social interactions and increases residents' health and well-being.

Access to a natural environment or a secure garden can promote movement and engagement among people with dementia. Nature can improve their health and cognition and reduce sleep-related problems, agitation, fall-related morbidity, and the use of antipsychotics [105]–[110]. The benefits of multisensory gardens increase when the staff support residents' outdoor activities and social interactions [111]–[114].

Although the research literature demonstrates therapeutic gardens' positive effects, several studies have shown that nursing homes do not use outdoor spaces as much as they would if the garden is too complicated or over-dimensioned [112]. In this regard, Mitchell and Burton's findings show that the main requirements for an outdoor environment to be dementia-friendly are to be familiar, legible, distinctive, accessible, comfortable and safe [115].

2.1.2.7 Create a familiar place

Spaces with familiar and recognisable objects (furniture, fittings and colours) allow patients to maintain their competencies and way of life.

People with dementia show higher quality of life (less aggression, anxiety and depression) and better performance in daily activities when they can personalise the environment with their belongings [35], [45], [58], [116], [117]. A familiar environment can reduce agitation and disorientation and improve staff morale and residents' behaviour [117]–[120]. It is also essential to acknowledge social, gender, religious and racial diversity among the patients to achieve an intersectional homelike environment in the nursing home [121].

The use of current assistive and welfare technology is not recommended because it requires much support from the staff. It is better to install out-of-date items that people with dementia can operate thanks to their long-term memory [27], [122], [123].

2.1.2.8 Provide a variety of places to be alone or with others in the unit

The built environment should offer spaces to be alone or with others, indoors and outdoors, or with a different character to stimulate emotional responses.

Several studies [35], [69], [124]–[127] show that nursing homes with “more gradation between private, semi-private, and public spaces” and “well-defined spaces with different functions” improve the well-being and wayfinding and reduce anxiety and aggression of patients with dementia compared to those with “less privacy gradation” [15, p. 30]. Kumar and Ng [128] provide several design recommendations in dementia units, such as visually identifying the space’s function or using different colours, materials and lighting to define the space.

Current research on dementia-friendly environments deeply supports the benefits of single rooms for patients, as stated in Fleming and Bennett's literature review [15]:

> *“The advantages of single rooms have been summarised as including: the opportunity to choose between privacy and socialisation; the ability to personalise the space, providing familiarity and continuity with the past; support for a sense of security and individual identity, and allowing residents to control levels of stimulation [129]. Single rooms are important for most people with dementia in that they provide them with an opportunity to withdraw when they feel threatened [130], [131]. They have been associated with a reduction in the need for intervention, including medications, and improvements in sleeping [129]. Rather than increasing loneliness, when there are opportunities for the person with dementia to spend time elsewhere, single rooms contribute to privacy and choice [132]. Uncooperative behaviours have been found to be associated with shared rooms [36]” [15, p. 31].*

2.1.2.9 Provide a variety of places to be alone or with others in the community

Without frequent interaction with friends and family, people with dementia will lose their sense of identity. The care home should blend with the community, providing spaces for shared activities and events. Easy access and stimulating surroundings can increase the interaction between residents and visitors.

Welcoming and community-integrated dementia units encourage support from family and friends. When neighbours and visitors are involved in the activities happening in the nursing home, several studies have reported lower boredom and depression symptoms among the residents [133]–[136].

Architecture can enhance interaction between patients and the community by providing diverse spaces to have both private conversations and social activities. Visual and auditory stimulation is also recommended [137], [138].

2.1.2.10 Design in response to vision for a way of life

The built environment should respond to the facility's philosophy of care, which must be clearly stated to the residents and staff. The architecture should enhance the vision of the institution and the chosen residents' way of life.

Although the research in the last decades was centred on procuring homelike environments for people with dementia [139], current literature tendencies argue for a healthcare architecture that responds to a vision for a specific way of life. The building should cover the needs and demands of residents and caregivers, which can be a domestic environment but also a facility that offers hotellike services or a lifestyle environment focused on recreation and exercise.

> *"Health care providers are beginning to recognize the important role physical space plays in defining quality care experiences- not only for patients, but also for visitors, families, physicians, and staffers. One of the most notable trends is many hospitals' efforts to incorporate the concept of holistic care in facility design. […] The goal is to meet patients' biological, psychological, and social needs and help them attain higher levels of wellness. And these efforts are paying off-in increased patient, family, and physician satisfaction" [138, p. 5].*

The advantages of a homelike environment, where residents perform quotidian activities (e.g. cooking, doing laundry, gardening) as long as possible, have been deeply analysed and demonstrated in the available literature [116], [140]–[145]. Homelike units successfully improve the quality of life of people with dementia, reducing agitation, exit-seeking and wandering and increasing social interactions and eating behaviour [146]–[149].

2.1.3 Dementia-friendly design measures

The previous literature review has shown that a good environment can decrease confusion and agitation, improve orientation, and promote social interaction among patients and caregivers. However, a poorly designed environment can increase distress in people living with dementia and the feeling of helplessness in the staff, leading to burnout syndrome. Table 1 summarises a well-designed environment's effects on people with dementia [15].

Improvements	Reductions
Wayfinding	Agitation
Eating behaviour	Anxiety
Motor functions	Conflict
Activities of daily living	Confusion
Self-help skills	Depression
Mobility	Dyspraxia
Pleasure	Emotional disturbance
Use of toilet	Number of falls
Vitality	Restlessness
Interaction between staff and residents/patients	Stress associated with bathing
Ease of supervision	Time spent by staff monitoring residents
Independence in dressing	Number of attempts to leave
Likelihood of residents making friends with one another	Doses of antibiotics and psychotropic drugs
Quality of life	Wandering into other people's spaces

Table 1. Effects of dementia-friendly environments on people with dementia [15]

Alzheimer’s Western Australia has developed a website to provide “practical tips, guides and resources to help make the places where we live more dementia enabling” [150]. The guidelines are founded on the research literature about dementia and the built environment, specifically on the work of Richard Fleming and Kirsty A. Bennet [15], [27], [151], [152]. The design recommendations are tailored to the most common building typologies, including residential buildings (houses and apartments), care environments, gardens (in nursing homes and residential dwellings), public buildings and hospitals. Each measure is based on the Dementia Enabling Principles, previously employed to organise the literature review: (1) unobtrusively reduce risks, (2) provide a human scale, (3) allow people to see and be seen, (4) reduce unhelpful stimulation, (5) optimise helpful stimulation, (6) support movement and engagement, (7) create a familiar place, (8) provide a variety of places to be alone or with others in the unit, (9) provide a variety of places to be alone or with others in the community, and (10) design in response to a vision for a way of life.

Figure 3 visualizes the measures that apply to care environments. The floor plan represents a paradigmatic layout for a dementia-specific setting. The illustrations of each space demonstrate several design measures that can be implemented to improve the quality of life of people with dementia.

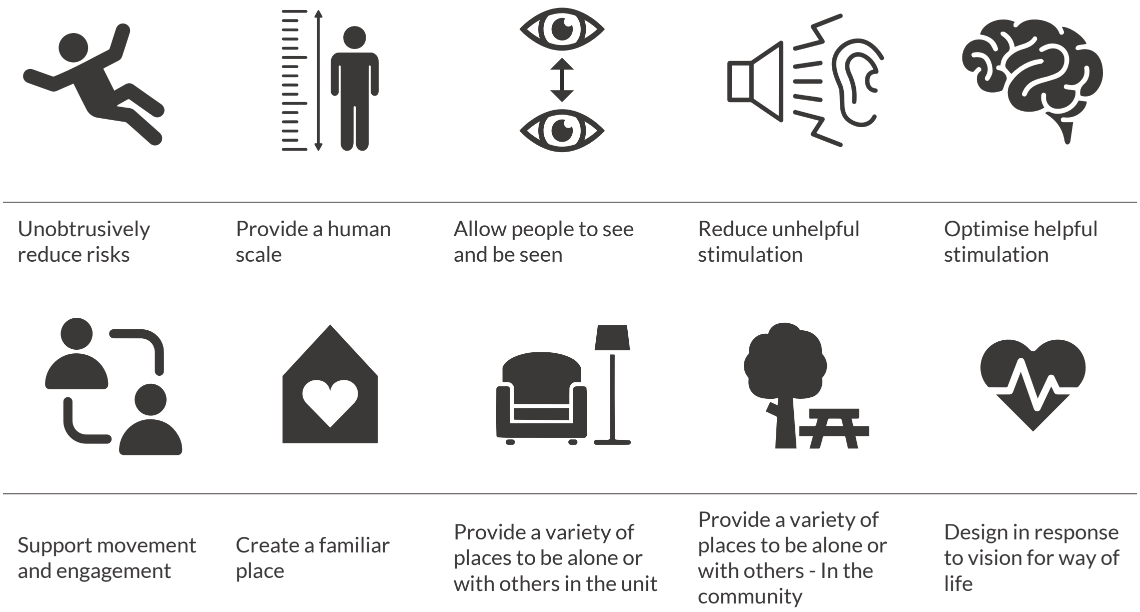


Figure 3. Dementia Enabling Environment Principles [15]

2.2 Architectural perspective: nursing homes

2.2.1 Norway

The exponential growth of the over-aged population and the people living with dementia represents a challenge for the Norwegian welfare system. In Norway, the municipalities are responsible for elderly care, operating nursing homes (*sykehjem*), and providing healthcare services at home (*helsetjenester i hjemmet*) or in adapted dwellings for older people (*omsorgsbolig*) [153]. This master's thesis focuses explicitly on nursing homes, considering that people with dementia are the primary residents of these facilities (84.3%) and rarely use home-based services (10.8%) [14].

According to Statistics Norway [154], 923 long-term care homes with 39,302 beds were available in 2022, 31,607 for long-term stays and 9,581 for short-term stays. 99% of the beds are provided in single rooms, while 92.4% of the bedrooms are user-adapted and have a private bathroom. Only 6.3% of the nursing homes were run by private operators, 4.6% non-profit and 1.7% commercial. However, most private operators managed the facilities on contract for municipalities [153]. In order to prioritise 'ageing in place' and home-based services, Figure 4 shows that the Norwegian care system has progressively reduced the number of institutions and beds and increased the number of municipality-owned nursing homes since 2015. The proportion of public beds is two points lower than the share of public nursing homes because private institutions tend to have large-scale facilities with more places.

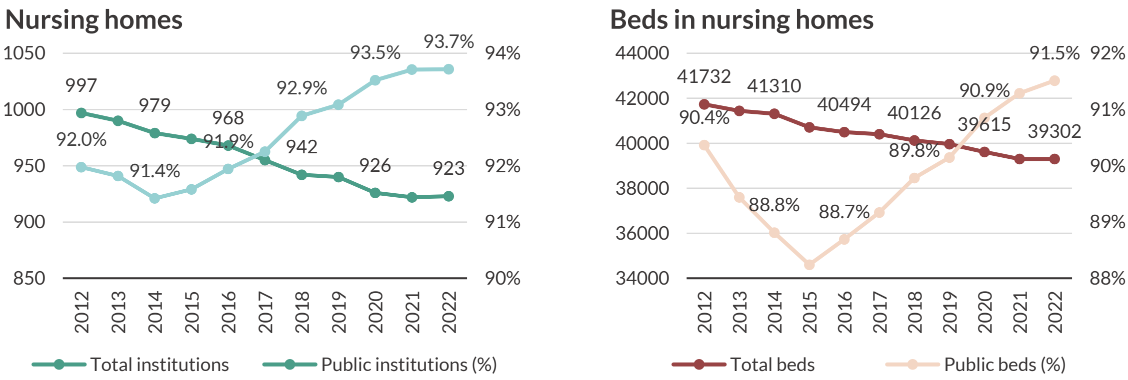


Figure 4. Nursing homes and beds (total and public) in Norway between 2012-2022 [154].

Regarding users, in 2021, there were 41,188 residents living in care institutions, 42,597 living in dwellings and 203,169 users of home-based services. Figure 5 shows the proportion of healthcare users by age. People under 67 years mainly use adapted dwellings and home-based services, while nursing homes are the primary care service for people over 67 years. 36.4% of long-term care home residents are 80 to 89 years, and 27.9% are 90 or over. From a gender perspective, women are the majority in the care system as users and caregivers. More than 80% of the healthcare personnel [155] and at least 60% of the nursing home residents [156] are women.

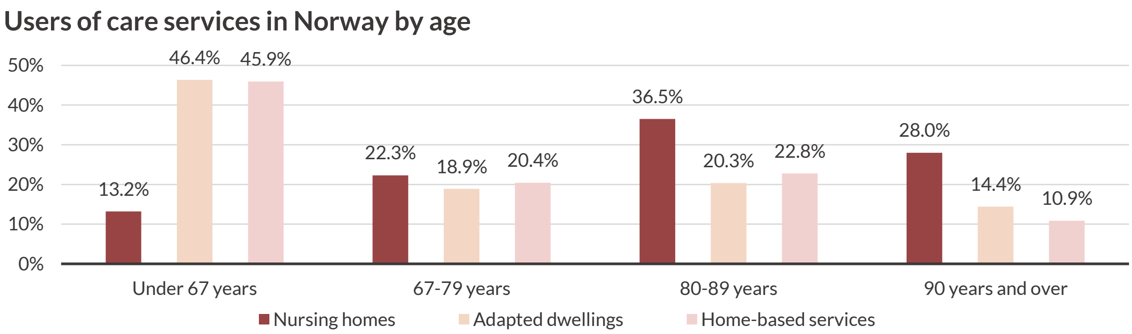


Figure 5. Users of care services in Norway by age [154]

Some long-term care institutions in Norway offer places in dementia-specific units. Figure 6 graphically represents the ratio of beds (total and dementia-specific places) per older people (65 years or over and 80 years or over) by municipality (*kommune*). The ratio of beds provides a better perspective of the care system because it also takes into account the share of older people in Norway. Considering the proportion of people over 65 years old in each municipality, there are not enough beds in Norwegian nursing homes. The average ratio of beds is 4.4% (total places) and 0.9% (dementia-specific places), which is below the 5% ratio recommended by the World Health Organisation (WHO) [157]. However, 64.5% of nursing home residents are 80 or older, and functional incapacity related to dementia usually starts showing after 80-85 years of age. If only the share of the population of 80 years and over is studied, the average ratio of beds is 17.3% (total places) and 2.8% (dementia-specific places).

Therefore, there is an adequate number of available places in nursing homes in Norway but a considerable lack of beds for patients with dementia. This situation can be improved by transforming nursing homes and care units into dementia-friendly environments instead of building new institutions. As explained in the social perspective section, people with late-stage dementia require round-the-clock assistance and daily personal care in a safe, adapted setting that reduces disorientation and wandering symptoms. While older people without cognitive impairments can 'age in place' with minor architectonical elderly-friendly adaptations and home-based care services, people with dementia benefit from tailor-made communities in the existing institutions [158].

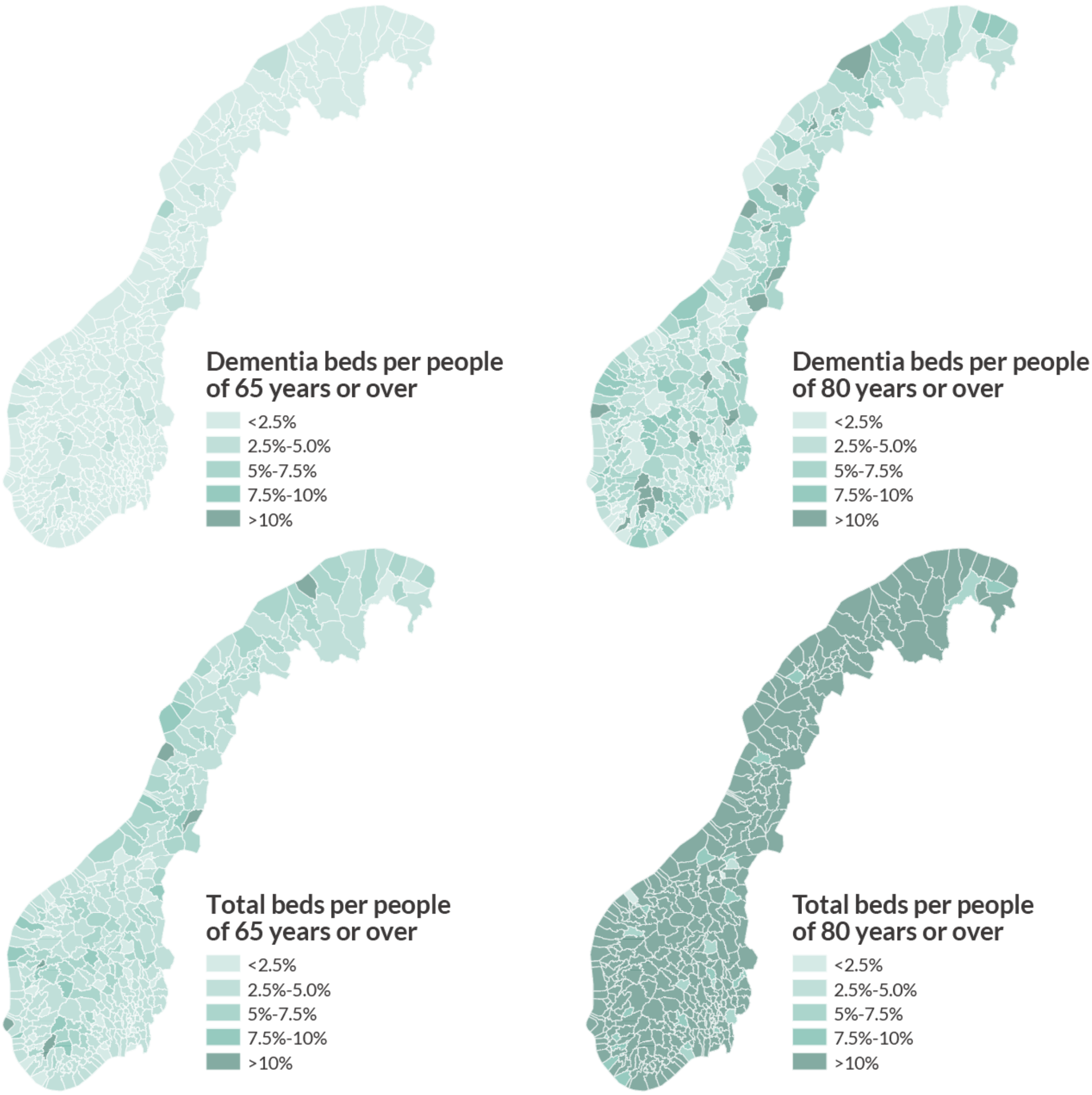


Figure 6. Ratio of nursing home beds per older people by municipality in Norway [154]

Due to nursing homes being operated by municipalities, no national guidelines or regulations specify direct requirements to design health and welfare centres. However, there are several plans and reports from the Norwegian Ministry of Health and Care Services setting design-related recommendations: the *Dementia Plan 2025* [14], *NOU 2018:16 First things first: Prioritisation principles for municipal health and care services and publicly funded dental health services* [159], *Meld. St. 15 (2017-2018) A full life – all your life: A Quality Reform for Older Persons* [160] and *Meld. St. 34 (2015–2016) Principles for priority setting in health care* [161], among others [162].

2.2.2 Trondheim

2.2.2.1 Architecture

As of January 2016, Trondheim municipality had 23 health and welfare centres (*helse- og velferdssenter*) (Figure 7) with 1,060 nursing home places. There were also 171 long-term beds available in four health centres (*helsehus*) and 370 places in elderly-adapted apartments (*omsorgsbolig*) with the possibility of receiving round-the-clock care assistance [162]. According to Statistics Norway [154], the number of places has increased in 2022, with 1,503 beds available in nursing homes (1,369 municipal beds and 134 private beds), 563 in elderly-adapted apartments and 74 dementia-specific places in institutions.

Considering that in 2022 there were 32,585 people 65 years old and over (14,919 men and 17,666 women) and 7,597 people 80 years old and over (3,028 men and 4,569 women) [163], the ratio of beds in health and welfare centres per older people is 6.3% and 27.2%, respectively. Compared to the WHO's minimum bed ratio of 5% [157], the healthcare system in Trondheim is vastly over the recommended ratio. However, there are not sufficient places adapted for patients with dementia. The conclusion is the same as in the Norwegian context: instead of building new institutions, nursing homes in Trondheim must be transformed into dementia-friendly environments.

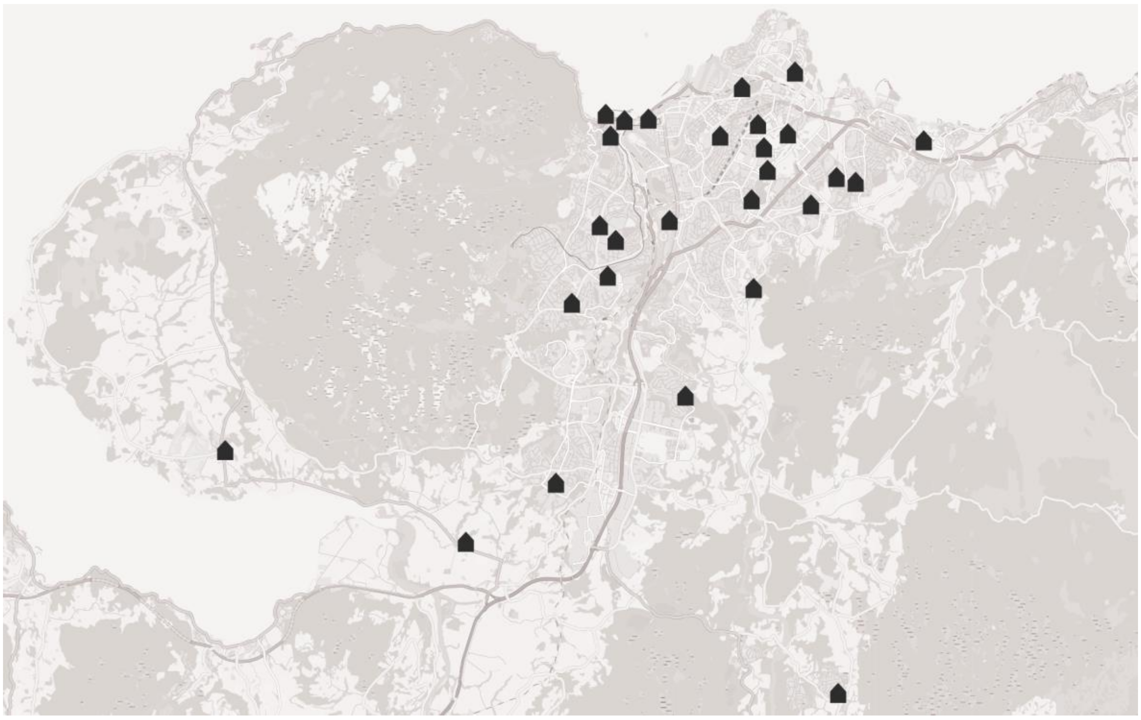


Figure 7. Location of health and welfare centres operated by Trondheim Komunne

Health and welfare centres in Trondheim consist of a nursing home (*sykehjem*), an activity and cultural centre (*aktivitets- og kultursenter*) and elderly-adapted apartments (*omsorgsbolig*). The nursing homes are usually distributed in wards with housing units formed by 10-15 residents. The culture and activity centre hosts the district café, activities for seniors and beauty and self-care services such as hairdressers and pedicurists. The district café is available for all citizens. The elderly-adapted apartments can be individual or collective dwellings with shared common areas. All health and welfare centres must have a carefully-designed outdoor area to promote physical activity and social engagement among residents, staff and visitors. The outdoor area should be accessible, well-oriented and diverse, including public and private gardens on the ground level, balconies, and rooftop terraces [162].

Care homes in Trondheim are designed to encourage social networks within the community in order to prevent residents' loneliness. The centres usually share equipment and outdoor spaces with other public buildings like schools and kindergartens. Furthermore, many of the larger health and welfare centres also offer meeting rooms and common spaces that can be rented to voluntary groups and organisations [162]. The municipality is also implementing programs and action plans to introduce welfare technology in nursing homes and elderly-adapted apartments [164].

Table 2 displays the building form, name, location, construction date and the number of users of Trondheim's 23 health and welfare centres (HVS). The users are divided per nursing home (*sykehjem*, SH) and elderly-adapted apartments (*omsorgsbolig*, O). The number of users of each centre was obtained from the Trondheim Kommune website [165]. 16 out of 23 care homes offer both housing typologies, while the rest seven only have nursing home places available. As can be seen in Table 2, most nursing homes were built between 2000 and 2010. The number and distribution of residential units determine the scale of the complex, going from small-scale health and welfare centres with two units connected by the common area (Kystad, Bromstad) to large-scale facilities with five residential units and an activity and cultural centre (Tempe, Byneset).

The architectural form follows a hybrid hospital-like building typology, combining a pavilion layout with one or several types of ward layouts. The pavilion layout is formed by a series of wards connected by a corridor. In contrast, the ward layout is determined by the circulation arrangement, which can be linear, racetrack/deep or a courtyard [166]. In the linear ward layout, the rooms are organised in a straight line around a single or double-loaded corridor (Charlottenlund, Persaunet, Ilsvika). Combined with the pavilion layout, the building presents an F (Brundalen, Kattem, Moholt) or H-shaped form (Dragvoll, Ladesletta). In the racetrack/deep ward, the layout has a continuous circulation containing resident rooms along the external section, whereas the inner section comprises service areas that do not require daylight (Munkvoll, Trondhjems Hospital, Hjorten). Lastly, in the courtyard ward layout, the rooms are arranged around an open (Baklandet, Nypantunet, Kystad, Tiller, Laugsand, Havstein) or an enclosed courtyard (Klæbu, Risvollan, Ilevollen, Trondhjems Hospital, Zion).

2.2.2.2 Regulation and guidelines

The city council is committed to supporting active ageing and promoting elderly-friendly policies. The Elderly Plan 2016-2026 (*Eldreplan*) collects the public strategies directed at older people, with the purpose of transforming Trondheim into a good city to grow old in [167]. Since 2015, Trondheim has been part of The WHO Global Network for Age-friendly Cities and Communities (GNAFCC). The association is formed by 1445 cities and communities in 51 countries [168]. Twenty-one nursing homes in Trondheim have *livsgledehjem* certification (joy-of-life nursing home). Risvollan and Klaebu are not part of the national certification system, but it might be due to being recently built (2019-2021) and not having gone through the evaluation process yet. To become a joy-of-life centre, the nursing home must meet nine criteria: (1) employees must know what the joy-of-life certificate is and work according to its standards, (2) cooperation with schools, kindergartens, volunteers and organizations, (3) residents enjoy outdoor spaces at least once a week, (4) interactions with animals, (5) residents can maintain their hobbies and interests, (6) residents' musical, cultural and spiritual needs are met, (7) pleasant and calm atmosphere during meals, (8) families are informed and take part in meaningful activities, (9) the changing of seasons plays a noticeable part in daily life [169].

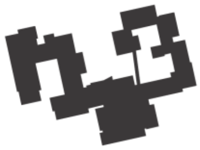
			
Bakklandet	**Brundalen**	**Byneset og Nypantunet**	**Dragvoll og Charlottenlund**
Rosenborg, 1955 SH: 37 / O: 7	Brundalen, 1982 SH: 80	Spongdal, 2002 SH: 64 / O: 36	Dragvoll, 2011-12 SH: 128
			
Havstein	**Havsteinekra**	**Hjorten**	**Illevollen og Ilsvika**
Havstein, 1990 SH: 29 / O: 30	Havstein, 2006 SH: 68	Ila, 2004 SH: 38	Ila, 1990-2001 SH: 66 / O: 28
			
Kattem	**Klæbu**	**Kystad**	**Ladesletta**
Kattem, 2008 SH: 48	Klæbu, 2021 SH: 60	Munkvoll, 2002 SH: 24 / O: 22	Lade, 2014 SH: 76 / O: 37
			
Laugsand	**Moholt og Bromstad**	**Munkvoll**	**Persaunet**
Rosendal, 2003 S: 24 / O: 25	Moholt, 1993-99 S: 42	Munkvoll, 2003 S: 24 / O: 54	Persaunet, 2016 S: 96 / O: 50
			
Ranheim	**Risvollan**	**Tempe**	**Tiller**
Ranheim, 1999 S: 24 / O: 16	Risvollan, 2019 S: 72 / O: 50	Tempe, 2003 S: 24 / O: 61	Tiller, 2004 S: 24 / O: 30
			
Trondhjems Hospital	**Valentinlyst**	**Zion**	
Midtbyen, 1844-1977 S: 50 / O: 38	Valentinlyst, 2003 S: 36 / O: 19	Steinan, n.d. S: 23 / O: 36	

Table 2. Description of health and welfare centres in Trondheim

Concerning municipal building regulations for nursing homes, Trondheim Kommune has released a Functional and area program (*Funksjons- og arealprogram*) [162] and Project instructions (*Prosjektanvisningen*) [170] for health and welfare centres. The municipality has also developed the *Project planning tool for universal design in public buildings* [171] based on TEK17 technical requirements. Both the Project instructions and the Project planning tool for universal design will be taken into account for the case study's sustainable renovation.

The Functional and area program is a catalogue of architectural recommendations for health and welfare centres in Trondheim. The program establishes seven principles for dementia-friendly environments, based on the report from Oslo municipality's Resource Centre for Dementia and Geriatrics [172]: (1) safety, (2) atmosphere, (3) clear physical surroundings, (4) marking and signage, (5) audition and noise, (6) vision and lighting and (7) colours and contrasts. These principles are aligned with the Dementia Enabling Environment Principles reviewed in the social perspective section.

Figure 8 summarises the area distribution per functional zones required by the regulation. Appendix 1 gathers the functional program and number of employees required by the regulation, considering a nursing home for 72 residents and elderly apartments for 50 people.

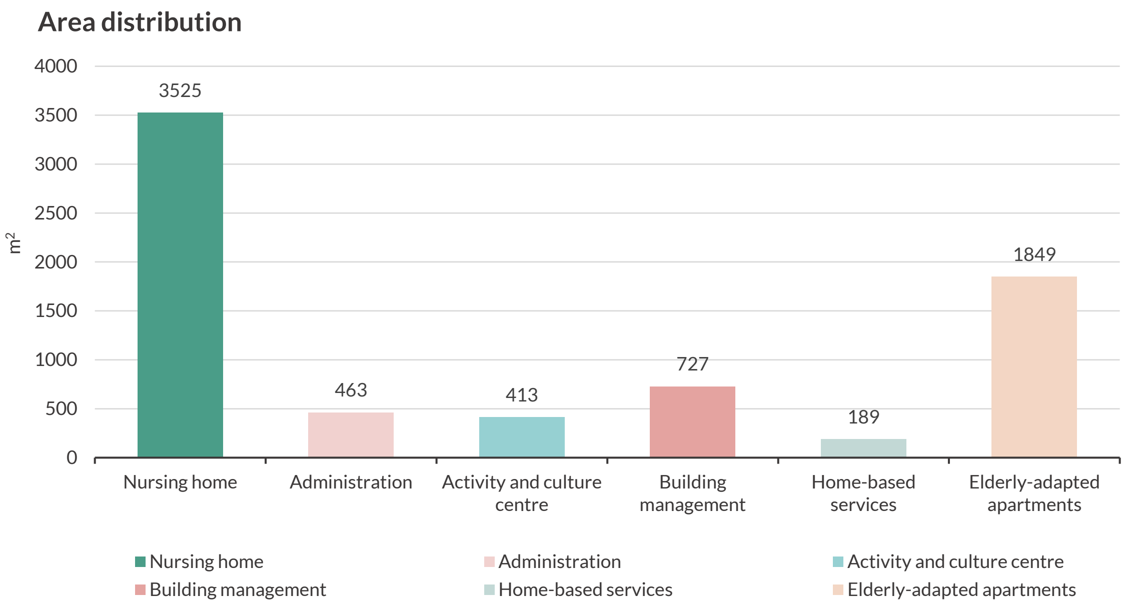


Figure 8. Area distribution of nursing homes in Trondheim [162]

2.3 Environmental perspective: building stock decarbonisation

2.3.1 Climate neutrality in the European Union

In the current context of climate change and global warming, the European Green Deal is a strategic plan to transform the EU into the first climate-neutral continent and a modern, resource-efficient and competitive economy. The Green Deal is built around three pillars: no net emissions of greenhouse (GHG) gases by 2050, economic growth decoupled from resource use, and no person and no place left behind [173]. To achieve the complete decarbonisation of the economy by 2050, all EU Member States committed to reducing emissions by at least 55% by 2030, compared to 1990 levels (Figure 9). The European Climate Law is the legally binding document that sets the previous targets. The law establishes the path to reach climate neutrality by 2050 and limits the temperature increase to 1.5°C above pre-industrial levels, as approved in the Paris Agreement [174].

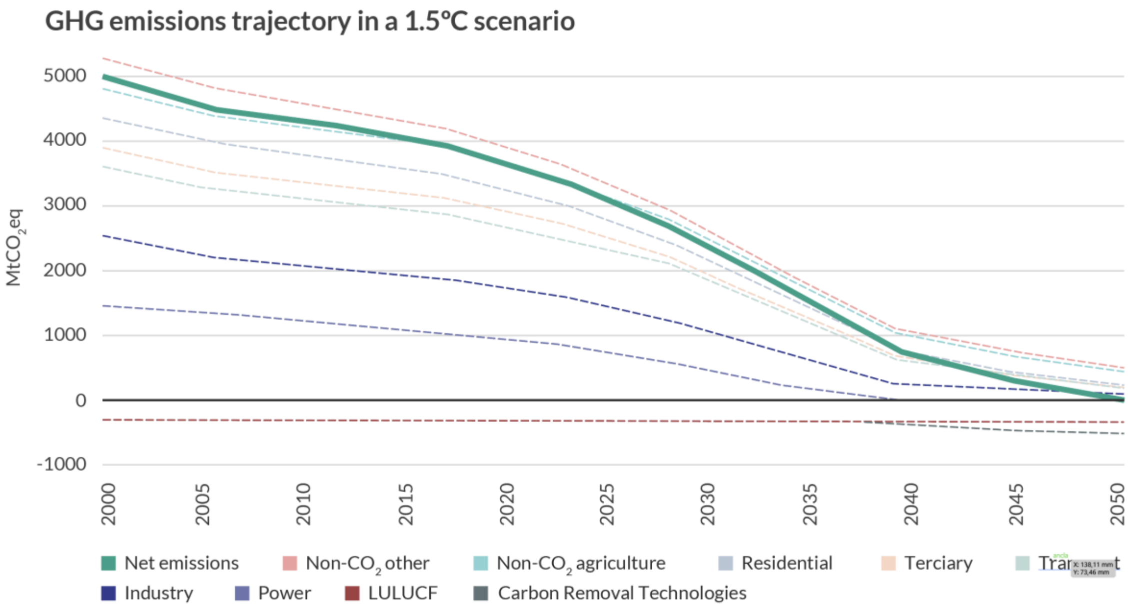


Figure 9. GHG emissions trajectory to climate-neutrality objective [174]

Regarding the construction sector, the Energy Performance of Buildings Directive 2010/31/EU is the key legislative instrument to decarbonise the building stock, which accounts for 1/3 of waste generation, approximately 36% of all CO_2 emissions and 40% of total energy consumption from the EU [175]. In addition, 75% of the EU buildings are still energy-inefficient [176]. The Directive requires that all new buildings are nearly zero-energy buildings (NZEB) by 31 December 2020. After 31 December 2018, new buildings occupied and owned by public authorities have to be nearly zero-energy buildings. NZEB is defined as "a building that has a very high energy performance [...]. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby" [177].

In 2021, the European Commission proposed to revise the current directive, moving from nearly zero-energy building (NZEB) to zero-emission building (ZEB) by 2030. The Commission also intended that all public buildings must be zero-emissions by 2027. The updated version has not yet been published but several key changes have been revealed in the latest draft: introduction of energy performance standards and building renovation passports, mandatory long-term renovation strategies and plans for national governments, and changes in the energy performance certificates (EPCs) [175], [176].

2.3.2 Energy efficiency regulation in Norway

Although Norway is not part of the EU, the government has set a long-term low-emissions strategy to reach a net-zero emissions scenario by 2050. In agreement with the European Commission's decarbonisation goals, Norway communicated a nationally determined contribution in 2020 to reduce emissions by 55% by 2030, compared to 1990 [178].

The Norwegian building stock and energy system is a particular case among European countries. Direct electricity accounts for around 85% of the total energy share and is used as the main energy carrier to heat the building stock, while 95% of the domestic electricity is generated by hydropower. Fuel oil was prohibited by law in 2020 to reduce carbon emissions. Therefore, the GHG emissions from the building stock in Norway are produced by indirect emissions from electricity and district heating [179].

ZEB buildings and technologies are also a widespread tendency in the Norwegian construction sector. TEK17 is the current building code for newly built, which is already considered a low-energy and high-efficiency energy standard [179]. From 2025, new constructions must satisfy the Norwegian Passive House standard. The energy efficiency requirements of TEK17 and Passive House regulations are described in the following sections, highlighting the parameters that affect nursing homes in Norway.

2.3.2.1 TEK17 building code

TEK17 Byggteknisk forskrift [180] is the building code and energy standard that regulates the architectural and technical requirements for new buildings in Norway.

Chapter 14 defines the specific energy efficiency requisites per building category. According to Section 14-2 (Table 3), nursing homes must have a maximum energy demand of 195 kWh/m^2_{HFA}/year, 230 kWh/m^2_{HFA}/year in the areas where heat recovery of ventilation air entails a risk of pollution spread or infection. All buildings must also satisfy the minimum U-values in Section 14-3, which are 0.22 W/m^2·K for exterior walls, 0.18 W/m^2·K for roofs, 0.18 W/m^2·K for ground floors and 1.2 W/m^2·K for windows and doors. The maximum leakage at 50 Pa is 1.5 h^{-1}.

Building category	Total net energy demand (kWh/m_{2HFA}/year)
Detached houses and leisure homes with > 150 m^2_{HFA}	100 +1600/ m^2_{HFA}
Residential block	95
Kindergarten	135
Office	115
School	110
University	125
Hospital	225 (265)
Nursing home	195 (230)
Hotel	170
Sports	145
Commercial	180
Cultural	130
Light industry/workshop	140 (160)

Table 3. Requirements for energy efficiency in TEK17 [180]

2.3.2.2 Passive House standard

The Passive House standard is regulated in *NS 3700:2013 Criteria for passive houses and low energy buildings – Residential buildings* [181] and *NS 3701:2012 Criteria for passive houses and low energy buildings – Non-residential buildings* [182]. Nursing homes are considered non-residential buildings, which are regulated by NS 3701:2012.

Heat loss transmission and infiltration heat loss requirement for nursing homes over 1,000 m^2_{HFA} is 0.40 W/m^2·K according to the Passive House (PH) standard and 0.50 W/m^2·K according to the Low-energy buildings (LEB) standard. The net energy demand for heating in nursing homes is 20 kWh/m^2_{HFA}/year in PH standard and 30 kWh/m^2_{HFA}/year in LEB standard. The cooling demand coefficient is 1.6 (PH) and 2.3 (LEB), the net energy demand for lighting is 29.1 kWh/m$^2_{HFA}$/year (LENI), and the average power demand during the operating period is 5.0 W/m^2 (Table 4).

Energy requirements per building category

		Kindergarten	Office	School	University	Hospital	Nursing home	Hotel	Sports	Commercial	Cultural	Light industry/workshop
Heat loss transmission and infiltration heat loss requirement (W/m²·K)	*PH*	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.45	0.40	0.40	0.40
	LEB	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.60	0.50	0.50	0.55
Net energy demand for heating (kWh/m$^2_{HFA}$/year)	*PH*	25	20	20	20	20	20	25	20	25	25	25
	LEB	40	35	30	35	35	30	40	35	40	40	40
Cooling demand coefficient	*PH*	0.75	1.4	0.75	1.5	2.9	1.6	1.5	0.9	3.3	1.2	1.1
	LEB	0.75	2.1	0.75	3.0	3.6	2.3	2.2	1.6	4.8	1.9	1.8
Net energy demand for lighting (LENI, kWh/m$^2_{HFA}$/year)		13.0	12.5	9.9	14.0	29.1	29.1	17.5	14.5	28.1	17.2	10.5
Net energy demand for lighting (Average power demand during operating period, W/m²)		5.0	4.0	4.5	4.5	5.0	5.0	3.0	5.5	7.5	6.0	4.5
Average air volume during operating hours (m³/(m²·h))		6.0	6.0	8.0	7.0	9.0	7.0	5.0	6.0	11.0	6.0	6.0
Average air volume outside of operating hours (m³/(m²·h))		1.0	1.0	1.0	1.0	3.0	3.0	1.0	1.0	1.5	0.6	1.0
Heat contribution from equipment (W/m²)		2.0	6.0	4.0	5.0	8.0	4.0	1.0	1.0	1.0	1.0	10.0
Heat contribution from people (W/m²)		6.0	4.0	12.0	6.0	2.0	3.0	2.0	10.0	10.0	3.2	2.0
Annual average heat allowance (W/m²)		3.9	5.0	5.0	5.5	10.7	9.0	4.7	4.9	7.9	3.3	4.4

Table 4. Requirements for energy efficiency in Passive House [182]

The minimum requirements for building parts and leakage values affect all building categories (Table 5). The U-value for windows and doors is 0.80 W/m^2·K (PH) and 1.20 W/m^2·K (LEB), the normalized cold bridge value is 0.03 W/m^2·K (PH) and 0.05 W/m^2·K (LEB), the annual average temperature efficiency for heat recovery is 80% (PH) and 70% (LEB), the SFP factor for ventilation system is 1.5 kW/(m^3/s) (PH) and 2.0 kW/(m^3/s) (LEB), and the leakage value at 50 Pa is 0.60 h^{-1} (PH) and 1.5 h^{-1} (LEB).

Minimum requirements for building parts, components, systems and leakage

Parameter	PH	LEB
U-value windows and doors (W/m²·K)	0.80	1.2
Normalized cold bridge value (W/m²·K)	0.03	0.05
Annual average temperature efficiency for heat recovery	80%	70%
SFP factor ventilation system (kW/(m³/s))	1.5	2.0
Leakage value at 50 Pa (h^{-1})	0.60	1.5

Table 5. Requirements for building systems in Passive House standard [182]

The standard also recommends a range of U-values to comply with Passive House and Low-energy buildings' energy-efficiency requirements: 0.10-0.12 W/m^2·K (PH) and 0.15-0.16 W/m^2·K (LEB) for external walls, 0.08-0.09 W/m^2·K (PH) and 0.10-0.12 W/m^2·K (LEB) for roofs, and 0.08 W/m^2·K (PH) and 0.10-0.12 W/m^2·K (LEB) for ground floors.

2.3.3 Benchmarks and ambition levels in Norway

In order to reach European climate neutrality and decarbonisation goals, several Norwegian research institutions have developed benchmarks and ambition levels that can be used to assess the environmental impact and the energy efficiency of new buildings and renovation projects. The GHG emissions from renovating the case study are compared against ZEB ambition level and the benchmark values defined by Enova and Asplan Viak.

2.3.3.1 ZEB ambition level

In Norway, the Research Centre on Zero Emission Buildings (ZEB) [183] was the institution responsible for the research, innovation and implementation of energy-efficient zero-emissions buildings from 2009 to 2017. The Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME-ZEN) [184] is the successor of the ZEB Research Centre, broadening the research scope to sustainable neighbourhoods with zero GHG emissions. The centre is hosted and managed by the Norwegian University of Science and Technology (NTNU) and SINTEF.

According to the ZEB Research Centre, "a zero-emission building (ZEB) produces enough renewable energy to compensate for the building's greenhouse gas emissions over its life span" [185] (Figure 10). In contrast with the 'net zero energy building' definition (net ZEB), the net zero balance is measured in GHG emissions during the building's lifetime instead of in energy demand versus energy supply [186].

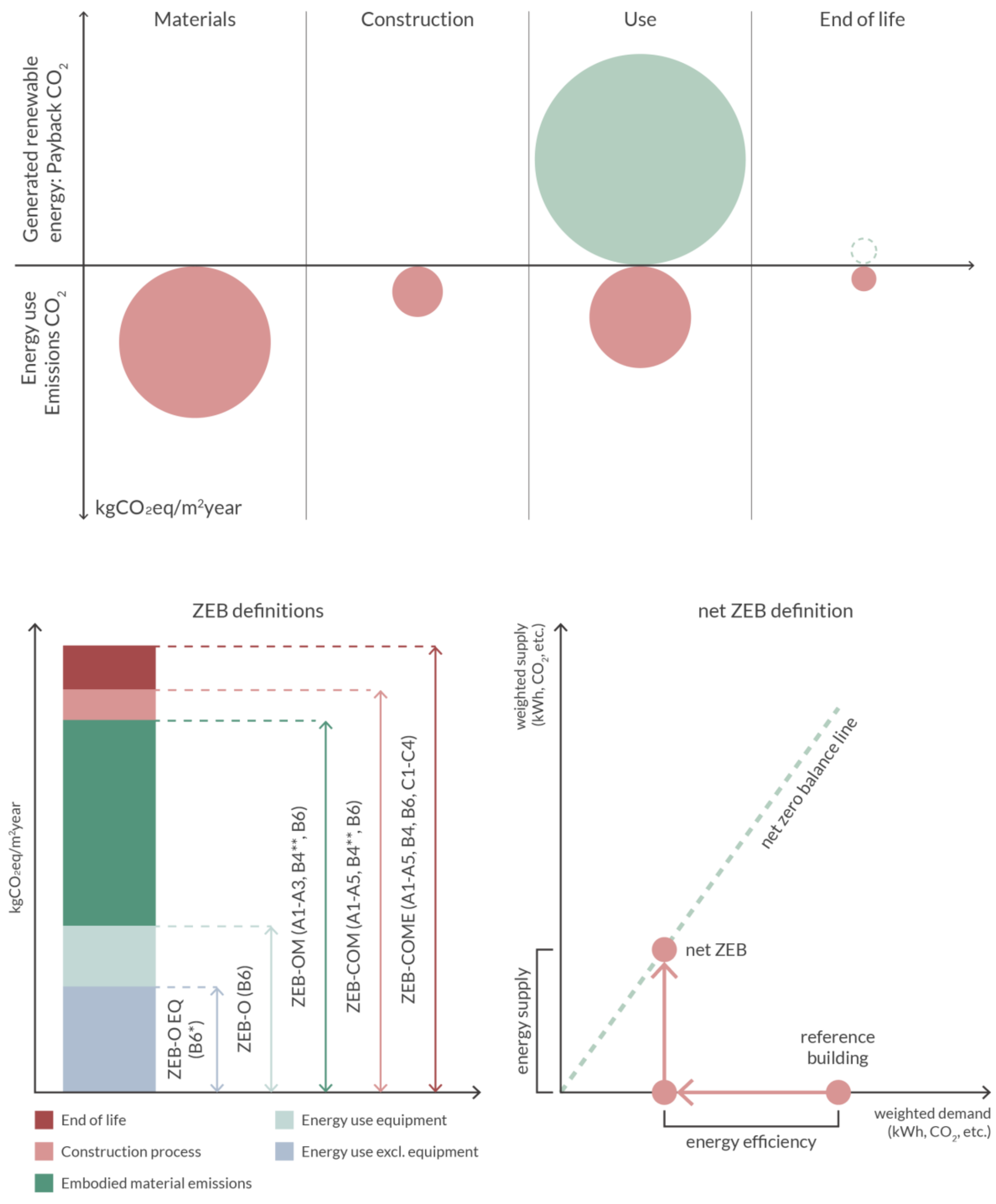


Figure 10. Net ZEB and ZEB definitions [186].

The life cycle system boundaries are defined by the standard *NS-EN 15978:2011 Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method* [187]. ZEB is divided into six ambition levels according to the life cycle stages included in the calculation (Table 6):

ZEB-O÷EQ. The building's renewable production compensates for GHG emissions from the operation of the building, excluding the energy use of equipment (B6*).

ZEB-O. The building's renewable production compensates for GHG emissions from the operation of the building (B6).

ZEB-OM. The building's renewable production compensates for GHG emissions from operation and production of building materials (A1-3, B4**, B6).

ZEB-COM. The building's renewable production compensates for GHG emissions from construction, operation, and production of building materials (A1-5, B4***, B6).

ZEB-COME. The building's renewable production compensates for GHG emissions from construction, operation, production, and demolition of building materials (A1-5, B4, B6, C1-4).

ZEB-COMPLETE. The building's renewable production compensates for GHG emissions from the entire life cycle of the building (A-D).

LCA System boundaries (NS-EN 15978:2011)	A1-3 Product stage			A4 Construction stage		B1-7 Use stage							C1-4 End-of-lie				D Benefits and loads
Emission source	A1: Raw material supply	A2: Transport to manufacturer	A3: Manufacturing	A4: Transport to building site	A5: Installation into building	B1: Use	B2: Maintenance (incl. transport)	B3: Repair (incl. transport)	B4: Replacement (incl. transport)	B5: Refurbishment (incl. transport)	B6 Operational energy use	B7: Operational water use	C1: Deconstruction / demolition	C2: Transport to end-of-life	C3: Waste processing	C4: Disposal	D: Reuse, recovery, recycling
ZEB-O÷EQ											■ *						■
ZEB-O											■						■
ZEB-OM	■	■	■						■ **		■						■
ZEB-COM	■	■	■	■	■ ****				■ ***		■						■
ZEB-COME	■	■	■	■	■				■		■		■	■	■	■	■
ZEB-COMPLETE	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 6. LCA System boundaries included in ZEB ambition level [186]

*Does not include operational energy of electrical equipment.
** Does not include transport to building site (A4), installation into the building (A5) or end-of-life treatment of the replaced materials.
*** Does not include end-of-life treatment of the replaced materials.
****At a ZEB-COM level, waste generated from the installation (A5) does not include end-of-life treatment but emissions from A1-5.
Biogenic carbon should only be included at a ZEB-COME or ZEB-COMPLETE level. Module D includes on-site energy production, required by the building during operation, and energy exported to the grid.

The functional unit of ZEB ambition level is kilograms of CO_2-equivalent per square meter of heated floor area per year($kgCO_2eq/m^2_{HFA}/year$) over a lifetime of 60 years. Regarding embodied emissions from materials and building parts included in the 'M' ambition level, ZEB follows the standard *NS 3451:2022 Table of building elements and table of codes for systems in buildings with associated outdoor areas* [188]. The list of materials and components included in ZEB ambition level is described in Table 7.

LCA Building parts (NS 3451:2022)	
Building part	**Building component**
2 Building	21 Ground and foundations
	22 Load-bearing systems
	23 External walls
	24 Internal walls
	25 Slabs
	26 Roof
	27 Fixed inventory
	28 Stairs, balconies, etc.
	29 Other building parts
3 Heating, ventilation and air conditioning	31 Sanitary
	32 Heating
	36 Air treatment
4 Power	44 Light
	45 Electrical heating
	49 Other technical power installations
6 Other installations	61 Prefabricated rooms
	62 Passenger and goods transport
7 Outdoors	72 Outdoor constructions
	73 Outdoor piping systems
	74 Outdoor electrical power
	76 Roads and sites
	77 Parks and gardens

Table 7. LCA building parts included in ZEB ambition level [186]

Energy performance is calculated using dynamic simulation tools validated by *NS-EN ISO 52017-1:2017 Energy performance of buildings - Sensible and latent heat loads and internal temperatures - Part 1: Generic calculation procedures* [189] and documented according to *SN-NSPEK 3031:2021 Energy performance of buildings – Calculation of energy needs and energy supply* [190]. The building should at least satisfy the Passive House energy standard, defined in *NS 3701:2012 Criteria for passive houses and low energy buildings – Non-residential buildings* [182].

The GHG emissions from operational energy are calculated considering the delivered energy and CO_2 equivalent (CO_2eq) conversion factors for the different energy carriers. The CO_2 factors employed at the ZEB Research Centre are shown in Table 8. Norway is considered a part of the EU power system, and therefore the energy mix is calculated taking into account the carbon emissions from the European consumption mix (309 gCO_2eq/kWh in 2020 and expected to decrease to 13 gCO_2eq/kWh in 2050) and the Norwegian mix (18 gCO_2eq/kWh) [186].

Energy carrier	gCO2eq/kWh
Electricity from the grid	130
Oil (fossil)	285
Gas (fossil)	210
Wood chips	4-15
Pellets/briquettes	7-30
Biogas from manure	25-30
Bio-diesel and bio-oil	50
Bio-ethanol	85
Waste incineration (heat only)	185-211

Table 8. CO_2 energy conversion factors employed at the ZEB Research Centre [186]

The environmental impact of renovating the master's thesis case study is compared against ZEB ambition levels, assessing if the building's renewable production compensates for its embodied emissions during the life cycle.

Regarding GHG emissions benchmarks, ZEN Report No.24 [191] gathered lifecycle-based global warming potential (GWP) calculations from over 130 Norwegian buildings from 2009 and 2020, focusing on the production (A1-A3), replacement and use phase (B4). The average benchmark values obtained were 6.6 kgCO_2eq/m^2_{GFA}/year (all buildings), 7.2 kgCO_2eq/m^2_{GFA}/year (residential), 5.7 kgCO_2eq/m^2_{GFA}/year (office), 6.1 kgCO_2eq/m^2_{GFA}/year (school), 7.0 kgCO_2eq/m^2_{GFA}/year (kindergarten) and 2.6 kgCO_2eq/m^2_{GFA}/year (renovated building).

2.3.3.2 Enova benchmarks

Enova SF [192] is a Norwegian government company working for Norway's transition to a low-emission society, exploring clean energy sources to reduce energy consumption and promoting energy-efficient practices. In the report *Studying the potential and barriers to the use of climate-friendly materials* (*Studie potensial og barrierer for bruk av klimavennlige materialer*) [193], developed by Asplan Viak for Enova, the authors defined reference levels for GHG emissions from materials for different building categories . The benchmarks are based on calculation models from studies developed by the Directorate for Building Quality (*Direktoratet for byggkvalitet*, DiBK) and the Oslo Municipality Climate Agency [194]. In particular, the reference levels are built on the current DiBK investigation around the nearly zero-energy buildings (nZEB) definition and requirements for the future TEK building code.

The scope of the reference values considers materials production (A1-3), transport of materials to the construction site (A4) and replacements during the lifecycle of the building (B4-5). The functional unit is kilograms of CO_2 equivalent per square meter of gross floor area (GFA) per year ($kgCO_2eq/m^2_{GFA}/year$) during a lifetime of 60 years. The building categories are office buildings, schools, residential blocks, commercial buildings, nursing homes, detached houses and basements (heated and non-heated). The benchmarks also cover the following building parts categories: 22 Load-bearing systems, 23 External walls, 24 Interior walls, 25 Slabs, 26 Roofs and 28 Stairs and balconies. The benchmarks consider four GHG emissions scenarios for each building category: a reference scenario for new buildings, a scenario for new low-energy buildings, a scenario for renovated low-energy buildings, and a scenario for reused low-energy buildings (Figure 11):

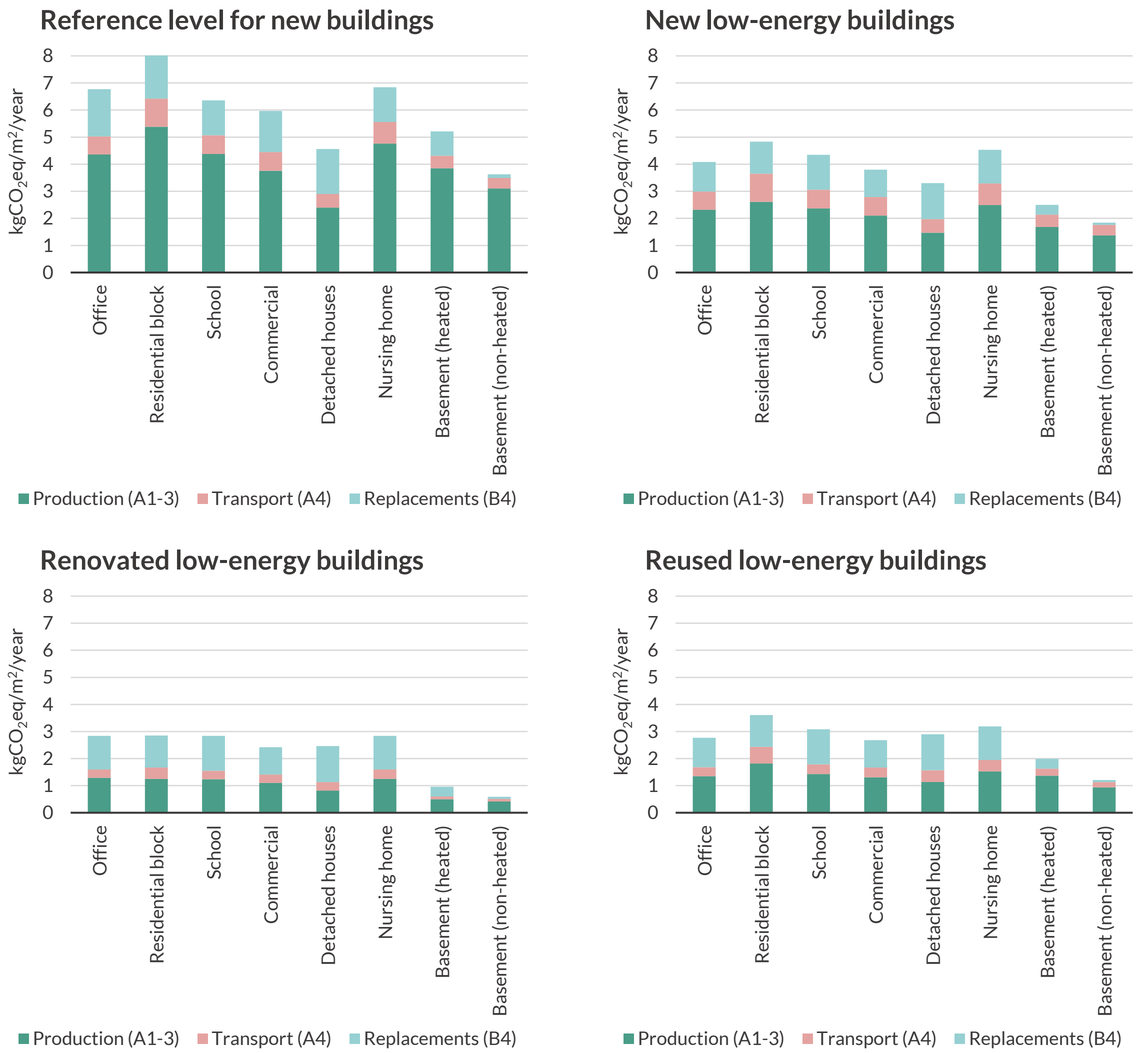


Figure 11. Enova GHG emissions benchmark levels [193]

Table 9 shows the GHG emissions values per life cycle module, building component and building type for nursing homes in Norway. Renovated low-energy buildings and reused low-energy buildings reference values are not divided by building components. The sustainable renovation implemented in the master's thesis case study is compared against renovated low-energy buildings benchmark: 1.25 $kgCO_2eq/m^2_{HFA}$/year for production (A1-A4), 0.35 $kgCO_2eq/m^2_{HFA}$/year for transportation (A4), and 1.24 $kgCO_2eq/m^2_{HFA}$/year for replacements (B4).

Building component	Reference level			New low-energy buildings			Renovated low-energy buildings			Reused low-energy buildings		
	A1-3	*A4*	*B4*	*A1-3*	*A4*	*B4*	*A1-3*	*A4*	*B4*	*A1-3*	*A4*	*B4*
22 Load-bearing systems	0.96	0.13	0.00	0.42	0.16	0.00	-	-	-	-	-	-
23 External walls	0.77	0.24	0.17	0.46	0.13	0.16	-	-	-	-	-	-
24 Interior walls	0.57	0.09	0.39	0.29	0.10	0.38	-	-	-	-	-	-
25 Slabs	1.2	0.20	0.43	0.74	0.26	0.42	-	-	-	-	-	-
26 Roof	0.91	0.13	0.28	0.57	0.15	0.27	-	-	-	-	-	-
28 Stairs and balconies	0.02	0.00	0.00	0.01	0.00	0.00	-	-	-	-	-	-
SUM	**4.76**	**0.80**	**1.28**	**2.49**	**0.80**	**1.24**	**1.25**	**0.35**	**1.24**	**1.53**	**0.42**	**1.24**

Table 9. Enova's GHG emissions benchmarks for Norwegian nursing homes [193]

2.3.3.3 Norwegian price book benchmarks

The Norwegian Price Book (*Norsk Prisbok)* [195] is a reference book for the construction industry in Norway. The encyclopedia provides an updated price and carbon footprint database of construction products to elaborate life cycle (LCA) and life cycle cost assessments (LCCA).

The catalogue is organised into elements and building types. In the building category "7.2.1 Nursing home", there are benchmark values for newly built nursing homes according to TEK (7211) and the Passive House standard (7212), as shown in Table 10. Although the case study is a renovation project and not a new building, both price reference levels can be compared against the calculated cost of the sustainable renovation.

Building type	Building parts	Price (NOK/m^2)	Total emissions ($kgCO^2eq/m^2$)	Emissions per year ($kgCO^2eq/m^2$/year)
Nursing home TEK (7211)	21 Ground and foundations	1011	25.29	0.42
	22 Load-bearing systems	1623	50.71	0.85
	23 External walls	3276	53.59	0.89
	24 Interior walls	2777	37.53	0.63
	25 Slabs	3083	142.26	2.37
	26 Roof	1291	106.37	1.77
	27 Fixed inventory	1215	11.15	0.19
	28 Stairs, balconies, etc.	525	12.06	0.20
	SUM	14,801	438,96	7,32
Nursing home Passive House (7212)	21 Ground and foundations	1011	25.29	0.42
	22 Load-bearing systems	1623	50.71	0.85
	23 External walls	3405	56.03	0.93
	24 Interior walls	2834	38.12	0.64
	25 Slabs	3158	145.36	2.42
	26 Roof	1352	111.72	1.86
	27 Fixed inventory	1215	11.15	0.19
	28 Stairs, balconies, etc.	525	12.06	0.20
	SUM	15,123	450,44	7,51

Table 10. Norwegian Price Book reference values for nursing homes [195]

3 Case study: Trondhjems Hospital

3.1 History and architecture

Trondhjems Hospital is the representative case study of Norwegian nursing homes selected to carry out the life cycle (LCA) and life cycle cost assessment (LCCA). The main reason to conduct a detailed analysis of this institution is based on the wide variety of construction systems, building elements, construction periods and elderly housing typologies represented in the nursing home. This situation is optimal for creating a broad catalogue of architectural, energy-efficient and dementia-friendly sustainable renovation measures.

Trondhjems Hospital (Figure 12) is a unique non-profit welfare institution, the oldest of its kind in the Nordic countries. It has been in continuous operation since 1277, when it was founded by King Magnus Lagabøter in the area later called Hospitalsløkkan, outside of Trondheim's medieval town. During the first centuries of operation, the centre was a charity foundation for disabled and poor, sick people and an isolated residence for lepers. In 1864, the hospital was transformed into a nursing home for older people. After 1945, the public sector became an important contributor to the hospital's operation. Nowadays, Trondhjems Hospital is a care home run by the municipality (*Trondheim komunne*) and the private foundation (*Stiftelsen Trondhjems Hospital*) in a cooperation agreement that finances care services for the residents. There are approximately 220 employees and around 150 residents in the nursing home [196], [197].

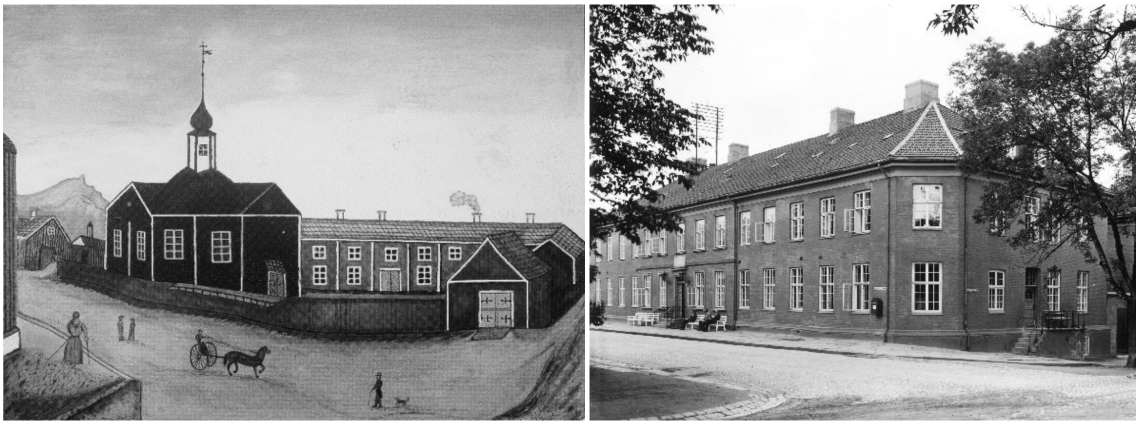


Figure 12. Trondhjems Hospital circa 1800 (left) and 1958 (right) [196], [197]

The nursing home is located in Hospitalsløkkan 2-4, west of the city centre of Trondheim. Hospitalsgata street and Hospitalskirka park surround the block to the south, Hospitalsgata street to the east, Sandgata street and the canal to the north, and Batteriveita to the west. The institution is easy-to-access by public transportation and private vehicle, thanks to Hospitalskirka bus and tram stops and Sandgata parking. The institution also operates four elderly-adapted apartment complexes and 12 rental properties in the area of Hospitalsløkkan [198].

Trondhjems Hospital complex has a footprint of around 4,865 m^2. Although the institution dates back to the 13^{th} century, the oldest buildings of Trondhjems Hospital were built in the 19^{th} century. The city fire on 24^{th} January 1842 destroyed the nursing home, and only the wooden church (*hospitalskirka*) built in 1705 was saved from the flames.

Figure 13 shows the site plan of Trondhjems Hospital. The four wings (main building, north, east and west wings) framing the eastern courtyard were constructed between 1845 and 1896 and listed in 1927 due to their cultural and historical interest [199]. The buildings to the west are a modern extension of the nursing home built in 1977 by Arkiplan AS, and therefore they are not protected by the Directorate for Cultural Heritage Management (Dire*ktoratet for kulturminneforvalting*).

Figure 13. Site plan of Trondhjems Hospital

The **main building** (*hovedbygningen*, cultural ID 87604-1) was projected by the architects Theodor Broch and Fredrik Stockfleth in 1843 after the city fire (Figure 14). It was erected in 1845, a few meters north of the original location, to protect the church in the case of another fire. *Hovedbygningen* is a two-story-high building in the Imperial style with a gross floor area of 1669 m^2, including the basement and the attic. The symmetrical main façade along Hospitalskirka Park is 42 meters long and built in red painted brick. The slabs and roof structure are made of wood. There is one main entrance towards the park, a secondary to the east in Hospitalsgata, and several doors facing the courtyard to access the first floor and the basement. The building is organised by a central corridor on both floors. The stair is located in front of the main entrance. The traditional wooden windows (*krysspostvindu*) were installed during a major renovation between 1900 and 1901. The stair hall window facing the courtyard was enlarged between 1901 and 1934 [197], [199], [200].

Figure 14. Main building (*hovedbygningen*) in Trondhjems Hospital

The **east wing** (*østfløy*, cultural ID 87604-2) was built in the same period as the *hovedbygningen*. Originally consisted of one floor, but it was extended between 1873-75 and finalized in 1896 (Figure 15). The building follows the Imperial style, mimicking the external appearance of the main building. It has two floors, a basement and an attic, with a gross floor area of 526 m^2. The east wing entrance door is in the courtyard and oriented to the south. The stairs are located on a west annexe, providing a T-shape form to the building. The internal layout was redistributed and renovated in 1992 to host apartments for people with dementia [197], [199], [200].

Figure 15. East wing (*østfløy*) in Trondhjems Hospital

The **north wing** (*nordfløy*, cultural ID 87604-3) was built with the east wing in 1845. It has a non-painted brick façade and a wall base plinth made of cement render (Figure 16). The building was renovated in the 1930s and 1992. In the decade 1930, the traditional wooden windows were exchanged. Until 1992, the north wing was two-stories-heigh, several meters lower than the east wing. The major renovation added a new floor on top of the existing levels, an exterior gate and a glass veranda in front of the south façade to the courtyard. The extension permitted to use the veranda as a corridor and increased the size of the rooms in the north wing. The current gross floor area, including the basement and three floors, is 1955 m^2 [197], [199], [200].

Figure 16. North wing (*nordfløy*) in Trondhjems Hospital

The **west wing** (*vestfløy*, cultural ID 87604-5) was built along with the east and north wing in 1845 but was rebuilt and completed in 1945 (Figure 17). It also underwent two minor renovations in 1992 and 2000. The last refurbishment incremented the number of residents' bedrooms and added two new glazed balconies to the western courtyard. The west wing has three floors and the same exposed brick façade as the north wing. As the east wing, it has a stairwell annexe to the west courtyard. There is a passageway connecting the two courtyards. The total gross floor area is 554 m^2 [197], [199], [200].

Figure 17. West wing (*vestfløy*) in Trondhjems Hospital

The **nursing home extension** (*sykehjem*) was built in 1977. It is located on the west side of the complex, connected to the old nursing home by a one-story-high wing that works as the public entrance of the institution and hosts a roof terrace and solarium. Another annexe connects the new nursing home building with the north wing. It has one floor and is used for storage and maintenance.

The *sykehjem* (Figure 18) is a five-story-high building with an exposed brick façade and concrete structure. The total gross floor area, including the basement, is 5110 m^2. Compared with the listed wings, which have gable or hip roofs made of ceramic tiles, the modern extension combines a mansard and a flat roof. The internal layout was renovated in 2002 to transform the previous double rooms into individual rooms. One-third of the previous windows were walled in to have space for the new partitions. Two new glazed balconies were added to the existing north veranda [197], [199], [200].

Figure 18. The nursing home extension in Trondhjems Hospital

3.2 Programme

Figure 19 shows the site visit pictures and Figure 20 the architectural drawings of Trondhjems Hospital. Due to the 3.8 meters difference between Hospitalsgata and Sandgata street level, the ground floors of each wing are not on the same level. Moreover, the different construction periods and partial renovations have led to a complex vertical and horizontal circulation. The architectural barriers have been fixed by installing ramps and elevators. However, the corridors on the east, north and west wings are not dimensioned for wheelchair users. For this reason, only the *sykehjem* rooms and the apartments in the main building can be used by residents with physical disabilities.

The main building hosts staff offices, common living areas, health services on the ground floor, and nine elderly-adapted apartments on the first floor. The attic is used for storage and technical equipment. The main building is connected to the *sykehjem* by the public entrance, which includes a reception and a common area for visitors and patients.

The modern nursing home hosts individual bedrooms for 50 residents needing round-the-clock care services. From the first to the fourth floor, the internal layout is organised by a central corridor that gives access to the external room perimeter and the service core. The residents' rooms are on the external west and east side, the balconies, living room, dining room and communal kitchen are on the north side, and the staff offices are on the south. The service core hosts the main stairs, elevators, laundry rooms and other technical and maintenance rooms. The basement has storage and technical spaces, while the ground floor host the central kitchen, storage rooms, staff's changing rooms and spaces for celebrations and events.

The west wing is mainly used as a storage and technical space on the ground floor. The first and second floors of the west wing and all the floors of the north wing are dedicated to an enclosed unit for 23 patients with severe dementia but no physical disabilities. The rooms are distributed along the west and north façade and connected through a corridor along the east and south façades. The service area is in the west wing, close to the main building. The living room is in the northwest corner, and the dining room and communal kitchen are in the centre of the north wing. Vertical communications are situated at the ends of the L-shaped wings. Lastly, the east wing offers four short-term apartments for patients with dementia and no physical disabilities younger than 65 years old. The communal living room is located below the staircase.

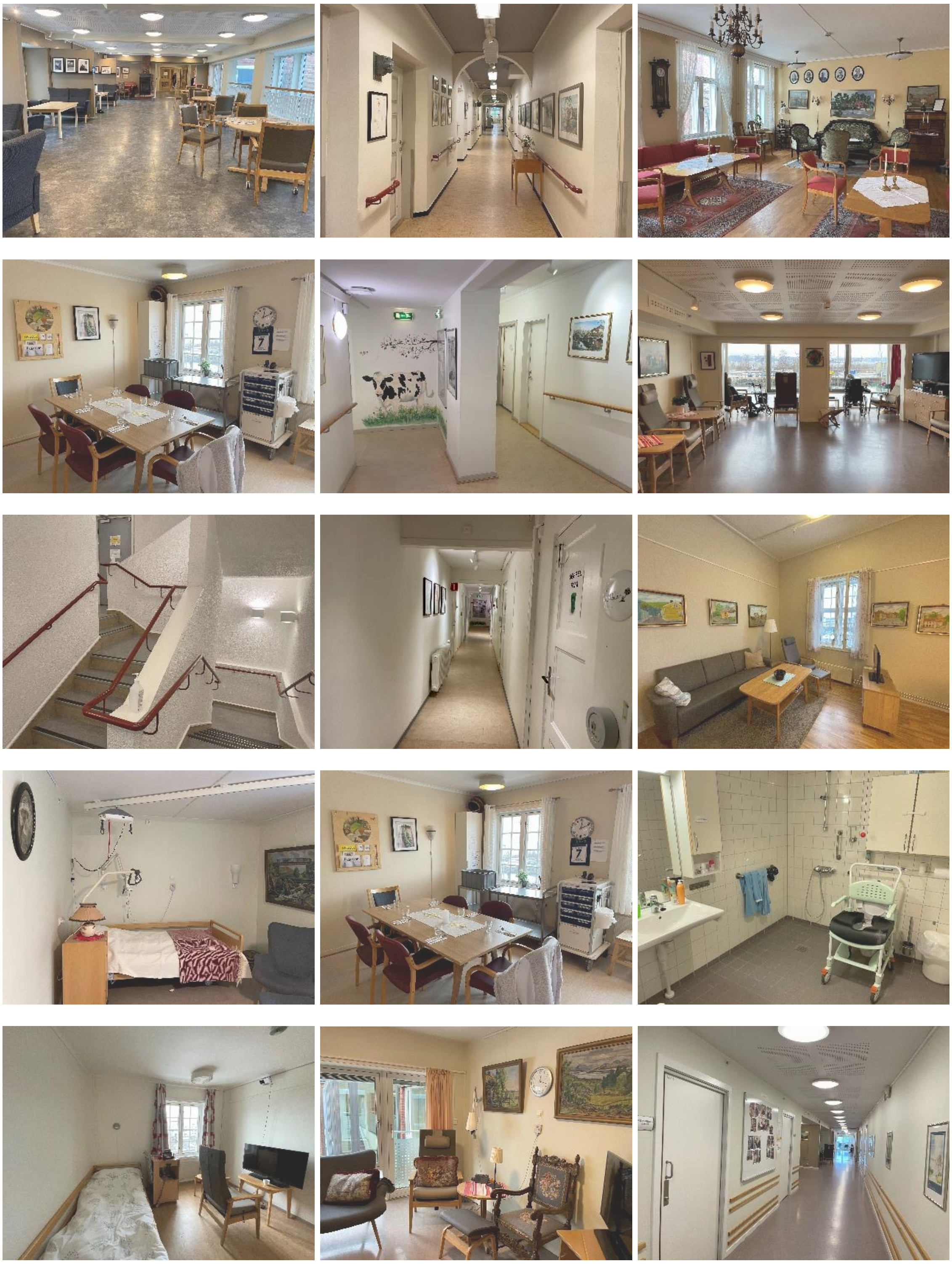


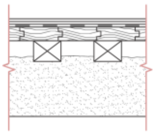
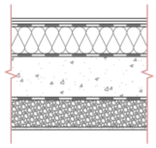
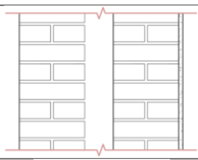
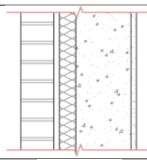
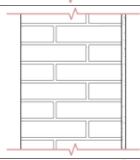
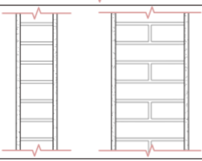
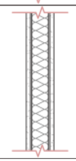
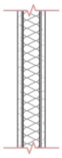
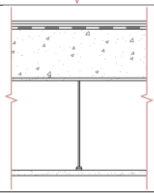
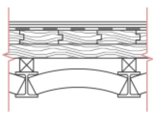
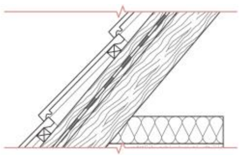
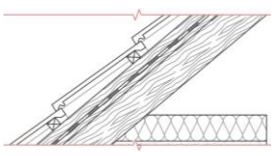
Figure 19. Pictures of Trondhjems Hospital during the site visit

Figure 20. Floorplan and section of Trondhjems Hospital

3.3 Construction

Trondhjems Hospital presents a wide range of construction systems and elements due to different construction periods, styles and renovations. Table 11 represents the main building components in the existing nursing home. Each building component has a code and a name stating the location and building category. These components are later used in the sustainable renovation of Trondhjems Hospital.

The construction details were drawn up from architectural drawings provided by Trondheim Municipal Archives (*Trondheim byarkiv*) [201] and cross-checked with the following SINTEF *Byggforskserien* articles about historical construction techniques: *721.111 Old building foundations and foundation walls. Methods and materials* [202], *723.308 Old external walls of brick and concrete. Methods and materials* [203], *722.310 Wooden slabs in old residential buildings. Methods and materials* [204], *722.311 Ground floor and slabs made of steel and concrete in older residential buildings. Methods and materials* [205], and *733.161 Old windows. Window shapes and materials* [206]. *Byggforskserien* [207] is a catalogue of building solutions in accordance with Norwegian building technical regulations (*teknisk forskrift*, TEK).

Main building		Nursing home extension (*sykehjem*)	
MB_GF_400 Main building_ Ground floor 400 mm Linoleum 20 mm Intermediate layer PVC Wood board 50 mm Wood beams 75x150 c/500 mm Clay and sand filling 200 mm		***SH_GF_370 Sykehjem_ Ground floor 370 mm*** Linoleum 20 mm Intermediate layer PVC Reinforced concrete 150 mm Intermediate layer PVC XPS insulation 100 mm Draining layer gravel 100 mm Fiber cloth	
MB_EW_600 Main building_ External wall 600 mm Trondhjemshulmur 560 mm Plaster and paint 30 mm		***SH_EW_400-500 Sykehjem_ External/bas. wall 400-500 mm*** Brick cladding 1/2 120 mm Mineral wool insulation 60 mm Concrete wall 200-300 mm Plaster and paint 20 mm	
MB_IW_400 Main building_ Internal wall 400 mm Brick wall 1 1/2 360 mm Plaster and paint 40 mm		***SH_IW_200-300 Sykehjem_ Internal wall 200-300 mm*** Concrete wall 180-280 mm Plaster and paint 20 mm	
MB_IW_150-300 Main building_ Internal wall 150-300 mm Brick wall 120-235 mm Plaster and paint 30 mm		***SH_IW_100 Sykehjem_ Internal wall 100 mm*** Gypsum board and paint 30 mm Steel frame with mineral wool insulation 70 mm	
MB_IW_150 Main building_ Internal wall 100 mm Gypsum board and paint 30 mm Steel frame + mineral wool insulation 70 mm		***SH_S_220 Sykehjem_ Slab 220 mm*** Linoleum 20 mm Intermediate layer PVC Soundproof foam PVC Reinforced concrete 180 mm Plaster and paint 20 mm	
MB_S_390-400 Main building _Slab 390-400 mm Linoleum 20 mm Intermediate layer PVC Wood board 50 mm Double wood beams 50 c/ 200 mm Brick vault with steel beams c/ 1.5 m		***SH_R_350 Sykehjem_Roof 350 mm*** Clay roof tiles Wood battens 70 mm Wind barrier Wood board 20 mm Wood beam 120 mm Mineral wool insulation 150 mm Gypsum board and paint 15 mm	
MB_R_300 Main building_ Roof 300 mm Clay roof tiles Wood battens 70 mm Wind barrier Wood board 20 mm Wood beam 120 mm Mineral wool insulation 100 mm Gypsum board and paint 15 mm			

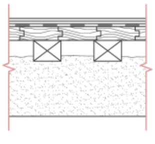
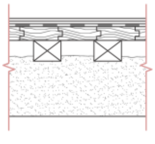
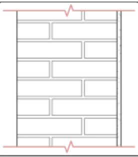
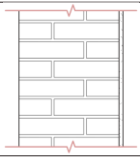
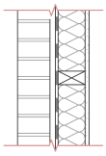
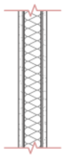
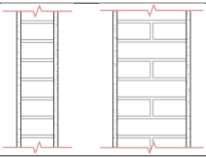
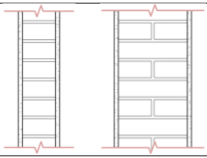
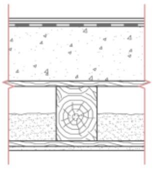
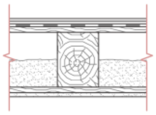
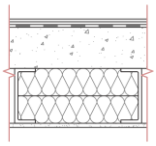
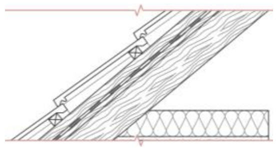
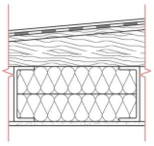
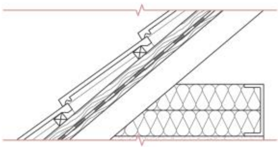
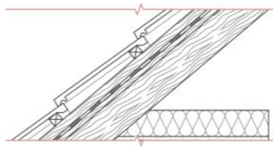
West + north wing		East wing	
WNW_GF_400 West north wing_ Ground floor 400 mm Linoleum 20 mm Intermediate layer PVC Wood board 50 mm Wood beams 75x150 mm Clay and sand filling 200 mm		***EW_GF_400 East wing_ Ground floor 400 mm*** Linoleum 20 mm Intermediate layer PVC Wood board 50 mm Wood beams 75x150 mm Clay and sand filling 200 mm	
WNW_EW_400-500 West north wing_External wall 400-500 mm Brick wall 360-485 mm Plaster and paint 15 mm		***EW_EW_400-500 East wing_ External wall 400-500 mm*** Brick wall 360-485 mm Plaster and paint 15 mm	
WNW_EW_250-300 West north wing_External wall 250-300 mm Brick cladding 1/2 120 mm Wind barrier Half-timber struct. 100-150 mm Mineral wool insul. 100-150 mm Gypsum board and paint 15 mm		***EW_IW_100 East wing_ Internal wall 100 mm*** Gypsum board+paint 30 mm Steel frame with mineral wool insulation 70 mm	
WNW_IW_150-300 West north wing_Internal wall 150-300 mm Brick wall 120-235 mm Plaster and paint 30 mm		***EW_IW_150-300 East wing_ Internal wall 150-300 mm*** Brick wall 120-235 mm Plaster and paint 30 mm	
WNW_S_500 West north wing_ Slab 500 mm Linoleum 20 mm Intermediate layer PVC Light clinker slab 200 mm Wood board 20 mm Wood beams 200x250 Clay filling 200 mm Wood board 20 mm Gypsum board and paint 15 mm		***EW_S_300 East wing_ Slab 300 mm*** Linoleum 20 mm Intermediate layer PVC Wood board 20 mm Wood beams 200x250 mm Clay filling 200 mm Wood board 20 mm Gypsum board+paint 15 mm	
WNW_S_390 West north wing_ Slab 390 mm Linoleum 20 mm Intermediate layer PVC Light clinker slab 200 mm U200 Steel beam Mineral wool insulation 200 mm Gypsum board and paint 15 mm		***EW_R_300 East wing_ Roof 300 mm*** Clay roof tiles Wood battens 70 mm Wind barrier Wood board 20 mm Wood beam 120 mm Mineral wool insul. 100 mm Gypsum board+paint 15 mm	
WNW_R_330 West north wing_Roof 330 mm Veranda Copper roofing panels 10 mm Wind barrier Wood board 20 mm Wood beams 50x100 mm U200 Steel beam Mineral wool insulation 200 mm Gypsum board and paint 15 mm			
WNW_R_400 West north wing_ Roof 400 mm Clay roof tiles Wood battens 70 mm Wind barrier Wood board 20 mm Steel truss 100 mm U200 Steel beam Mineral wool insulation 200 mm Gypsum board and paint 15 mm			
WNW_R_300 West north wing_ Roof 300 mm Clay roof tiles Wood battens 70 mm Wind barrier Wood board 20 mm Wood beam 120 mm Mineral wool insulation 100 mm Gypsum board and paint 15 mm			

Table 11. Building components of Trondhjems Hospital

4 Methodology

4.1 Life cycle assessment

Life cycle assessment (LCA) is a method to evaluate and improve the environmental impact of a building throughout its life cycle modules: product and construction stage (A), use stage (B), end-of-life stage (C), and benefits and loads beyond the system boundary (D). LCA studies are usually focused on assessing the carbon emissions of a building from cradle-to-grave. The GWP is determined by the embodied carbon (produced by materials and energy during the construction and maintenance phases) and the operating carbon (attributed to the use phase) [208].

In Norway, the LCA methodology framework is defined by the European standards *NS-EN 15978:2011 Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method* [187] and *NS-EN 15804:2012+A2:2019+AC:2021 Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction product* [209]. The national standard *NS 3720:2018 Method for greenhouse gas calculations for buildings* [210] provides further guidance and a calculation method to evaluate the GHG emissions of a building [211].

The LCA of Trondhjems Hospital analyses the GWP of seven scenarios (Table 12). The environmental impact of the building encompasses the embodied emissions from the construction products and the operational energy emissions from the energy use. The baseline scenario establishes the energy performance o the existing buildings. Scenarios 1, 2, 3, and 4 evaluate the embodied emissions of several renovation measures: Scenarios 1 and 2 improve the building envelope (externally or internally) according to Norwegian energy standards; Scenario 3 considers the emissions of changing the windows; and Scenario 4 consists of low-impact interior measures to transform the nursing home into a dementia-friendly environment. Scenario 5 assesses the operational energy emissions from adapting the nursing home to Norwegian energy standards. The last scenario (SS) is the summary of the previous scenarios, considering the effect of the architectural (S1, S2, and S3) and interior renovation measures (S4) on the energy performance of the building (S5).

Scenario	BS Baseline scenario	S1 External insulation	S2 Internal insulation	S3 Changing windows	S4 Dementia-friendly environment	S5 Energy performance
Unit	Sykehjem Dementia wings	Sykehjem	Dementia wings	Sykehjem Dementia wings	Sykehjem Dementia wings	Sykehjem Dementia wings
Material GWP		X	X	X	X	
Energy GWP	X					X

	Scenario	**Unit**	**Material** GWP	**Energy GWP**
SS	Sustainable renovation (S1/S2+S3+S4+S5)	Sykehjem Dementia wings	X	X

Table 12. LCA scenarios by unit and type of emissions assessed

4.1.1 Goal and scope

The goal of the LCA is to compare and evaluate the environmental impact of design options and building solutions commonly used in the Norwegian construction industry, with the purpose of creating a catalogue of low-impact dementia-friendly measures that can be implemented in nursing home renovations.

The service life is 60 years, and the functional units are kilograms CO_2-equivalent per year per square meter of gross floor area ($kgCO_2eq/year/m^2_{GFA}$) and kilograms CO_2-equivalent per year per person ($kgCO_2eq/year/person$). The dementia wings have a gross floor area of 1654.6 m^2 and 23 residents. The *sykehjem* has a gross floor area of 6361.9 m^2 and 50 residents. The calculations do not include the main building (*hovedbygningen*) because the residents living in the elderly-adapted apartments do not receive round-the-clock care services. The sustainable renovation proposal, explained in the following sections, focuses on improving the environmental quality of the residential units with patients with dementia, which are the nursing home extension (*sykehjem*) and the west, east, and north wings (dementia wings).

For all seven scenarios, GHG emissions calculations are performed according to NS 3720:2018 and FutureBuilt ZERO (FBZ) methods in Reduzer software [212]. NS3720 is the standardized method in Norway to calculate GHG emissions of a building's entire life cycle (cradle-to-grave). Compared with the European standard EN 15978:2011, NS 3720 expands the system boundary by including transport in the operational phase. FBZ is based on NS 3720 standard but incorporates additional dynamic LCA considerations like time-weighting, future technology improvements and modelling of biogenic carbon [213].

Building elements are structured according to the Norwegian standard *NS 3451:2022 Table of building elements and table of codes for systems in buildings with associated outdoor areas* [188], including 21 Ground and foundations, 22 Load-bearing systems, 23 External walls, 24 Internal walls, 25 Slabs, 26 Roof, 27 Fixed inventory, 28 Stairs and balconies, 29 Other building parts and 47 Local electricity production. The main criterium of FBZ does not consider the emissions from building elements in the 21 Ground and foundations category. However, in this analysis, all building elements were included in the system boundary.

The material inventory is gathered from a Building Information Modeling (BIM) model in Autodesk Revit [214]. The 3D model was drawn up from site visit pictures and architectural drawings provided by Trondheim Municipal Archives (*Trondheim byarkiv*) [201]. GWP of materials are collected from Environmental Product Declarations (EPDs) and reference emissions factors provided by Enova and Asplan Viak [193]. Table 13 and Table 14 summarise the calculation schemes implemented in the LCA based on NS3720 and FBZ methods and system boundaries. In Table 14, the system boundaries are named depending on the calculation method implemented.

	NS3720	**FBZ**
Functional units	$kgCO_2e/year\ /m^2_{GFA}$ $kgCO_2e/year/person$	$kgCO_2e/year\ /m^2_{GFA}$ $kgCO_2e/year/person$
Building elements	All	All
Service life	60 years	60 years
Time horizon	100 years	100 years
Future technological developments	0%	1%
Biogenic carbon	Instantaneous combustion	After harvest
Cement carbonation	Fixed amount over period	Fixed amount over period
Waste incineration	Construction phase: 100% Use phase: 100% End-of-life phase: 100% Carbon content wood: 50% Carbon content fossil: 80% Allocation to energy sector: 0%	Construction phase: 97% Use phase: 57% End-of-life phase: 20% Carbon content wood: 50% Carbon content fossil: 80% Allocation to energy sector: 50%
Circularity	Discount reused material: 80% Compensation from reusability: 0%	Discount reused material: 80% Compensation from reusability: 10%

Table 13. Comparison between NS3720 and FBZ calculation methods [212]

LCA System boundaries (NS-EN 15978:2011)																		
		A1-3 Product			A4 Constr.		B1-7 Use							C1-4 End-of-lie				D Benefits and loads
Emission source		*A1: Raw material supply*	*A2: Transport to manufacturer*	*A3: Manufacturing*	*A4: Transport to building site*	*A5: Installation into building*	*B1: Use*	*B2: Maintenance (incl. transport)*	*B3: Repair (incl. transport)*	*B4: Replacement (incl. transport)*	*B5: Refurbishment (incl. transport)*	*B6 Operational energy use*	*B7: Operational water use*	*C1: Deconstruction / demolition*	*C2: Transport to end-of-life*	*C3: Waste processing*	*C4: Disposal*	*D: Reuse, recovery, recycling*
Energy	*Energy use delivered*					X						X		NS				
	Energy use exported																	FB
Products used	*Production*	X	X	X						X								
	Transport				X					X								
	Biogenic uptake						X											
	Carbonation uptake						X											
	Reusability compensation																	X
Wastage products used	*Production*					X				X								
	Transport					X				X								
	Incineration					X				X								
Waste from replacements and end-of-life	*Transport*									NS					NS			
	Incineration									X						X		

Table 14. LCA System boundaries in NS3720 and FBZ calculation methods [187]

Energy calculations are performed according to *SN-NSPEK 3031:2021 Energy performance of buildings – Calculation of energy needs and energy supply* [190] in Simien software [215]. Simien is a Norwegian-developed energy calculation software validated by *NS-EN ISO 15265:2004 Ergonomics of the thermal environment - Risk assessment strategy for the prevention of stress or discomfort in thermal working conditions* [216]. The software performs dynamic simulations of energy needs and indoor climate. It also dimensions heating, ventilation, and cooling systems (HVAC) and evaluates the building against TEK17 and Passive House requirements [217].

All scenarios are divided into two scenario variations (TEK and Passive house) considering the requisites of the energy standards available in Norway: *TEK17 Building technical regulations* [180] and *NS 3701:2012 Criteria for passive houses and low energy buildings – Non-residential buildings* [182].

The delivered energy results, expressed in kWh/m^2/year, are used to calculate the operational energy GHG emissions in life cycle module B6 Operational energy use. The GHG emissions of the exported PV energy are accounted for in module D Benefits and loads beyond the system boundary.

GHG emissions factor for direct electricity and electricity to the heat pump system is 136 gCO_2eq/kWh, considering the exchange with the European consumption mix (EU28+NO) [210]. Direct emissions from PV panels are set to zero. Indirect emissions are accounted for in the building material inventory under 47 Local electricity production. For the solar power export, the emission factor for electricity (136 gCO_2eq/kWh) is used for compensation.

4.1.2 Life cycle inventory

Life cycle inventory (LCI) is the data-collection step of an LCA that involves setting an inventory of input and output flows, such as construction products and energy [218]. The LCI of Trondhjems Hospital is structured into seven scenarios. The seveth scenario (Sustainable renovation) is the sum of all scenarios, S1, S3, S4 and S5 in the case of the *sykehjem*, and S2, S3, S4 and S5 in the case of the dementia wings (Figure 21).

Figure 21. Location of the LCA scenarios in Trondhjems Hospital

Table 15 defines the general minimum requirements of each energy standard and the specific input values used in the energy simulations and GHG emissions calculations for the dementia wings (DW) and the *sykehjem* unit (SH). The correlation between U-values and insulation thicknesses has been assumed considering the existing insulation and construction elements in the building, as well as the reference values provided by SINTEF Byggforskserien in articles *723.314 Post-insulation of brick walls* [219], *722.506 Post-insulation of slabs above the basement* [220], and *725.403 Post-insulation of wooden roofs* [221]. The U-value of the external walls in PH scenario (0.09 W/m_2K) is the closest to the criteria (0.10-0.12 W/m_2K) that satisfies all PH requirements in Simien.

		PH		**TEK**	
		Required	***Value***	***Required***	***Value***
U-value external walls		0.10-0.12 W/m^{2}K	0.09 W/m^{2}K 350 mm insulation	≤ 0.22 W/m^{2}K	0.22 W/m^{2}K 150 mm insulation
U-value roof		0.09-0.08 W/m^{2}K	0.09 W/m^{2}K 450 mm insulation	≤ 0.18 W/m^{2}K	0.18 W/m^{2}K 250 mm insulation
U-value ground floor		0.08 W/m^{2}K	0.08 W/m^{2}K 450 mm insulation	≤ 0.18 W/m^{2}K	0.18 W/m^{2}K 250 mm insulation
U-value windows and doors	***SH***	≤ 0.8 W/m^{2}K	0.8 W/m^{2}K	≤ 1.2 W/m^{2}K	1.2 W/m^{2}K
	DW		0.7 W/m^{2}K		1.2 W/m^{2}K
Normalised thermal bridge	***SH***	≤ 0.03 W/m^{2}K	0.03 W/m^{2}K	≤ 0.09 W/m^{2}K	0.09 W/m^{2}K
	DW		0.02 W/m^{2}K		0.09 W/m^{2}K
Air leakage	***SH***	≤ 0.6 h^{-1}	0.6 h^{-1}	≤ 1.5 h^{-1}	1.5 h^{-1}
	DW		0.5 h^{-1}		1.5 h^{-1}
Specific fan power (SFP) ventilation system	***SH*** ***DW***	≤ 1.5 kW/(m^3/s)	1.5 kW/(m^3/s)	≤ 1.5 kW/(m^3/s)	1.5 kW/(m^3/s)
Heat recovery temperature efficiency	***SH*** ***DW***	≥ 80%	80%	≥ 80%	80%

Table 15. Energy simulations requirements and input values according to PH and TEK standards

The complete LCI of each scenario is described in Appendix 2. The appendix contains information about the quantities, EPDs, transportation distance, service life, wastage and CO_2 factor of the components and products inputted in Reduzer. Appendix 3 gathers the TEK17 and Passive House reports obtained from energy simulations in Simien. The calculations are described in Appendix 4.

4.1.2.1 Baseline scenario

Due to the lack of information about the current energy use and delivered energy in Trondhjems Hospital, an energy simulation was carried out in Simien to establish a reference energy performance that can be compared with the renovation measures.

Table 16 defines the input values assumed in the baseline scenario energy simulations for the dementia wings (DW) and the *sykehjem* unit (SH). As in the case of the existing building components, the U-values were assumed from former Norwegian building codes and reference values provided by SINTEF Byggforskserien in articles *723.314 Post-insulation of brick walls* [219], *722.506 Post-insulation of slabs above the basement* [220], and *725.403 Post-insulation of wooden roofs* [221]. The U-values of the *sykehjem* correspond to TEK 1969 [222] requirements for Zone III (Sør-Trøndelag region). The U-values of the dementia wings correspond to TEK 1987 [223] requirements for an interior temperature above 18°C.

	Sykehjem	***Dementia wings***
U-value external walls	0.81 W/m^{2}K	0.3 W/m^{2}K
U-value roof	0.46 W/m^{2}K	0.2 W/m^{2}K
U-value ground floor	0.41 W/m^{2}K	0.3 W/m^{2}K
U-value windows and doors	3.14 W/m^{2}K	2.4 W/m^{2}K
Normalised thermal bridge	0.2 W/m^{2}K	0.1 W/m^{2}K
Air leakage	3 h^{-1}	1.5 h^{-1}
Specific fan power (SFP) ventilation system	2.5 kW/(m^3/s)	2.5 kW/(m^3/s)
Heat recovery temperature efficiency	70%	70%

Table 16. Energy simulations input values according to TEK 1969 and 1987 [222], [223]

Regarding energy carriers, Trondhjems Hospital's energy is delivered through direct electricity. The dementia wings also have a heat pump system for heating and cooling with radiators and ductless split units, respectively. In the *sykehjem*, indoor comfort is achieved with an HVAC central air-conditioned/forced air system. The heated and cooled air is supplied to the rooms with air ducts.

Apart from a general description and a visual inspection of the energy systems obtained during the site visit, the staff in Trondhjems Hospital have not shared additional material about the energy performance of the nursing home. However, the reported situation in Trondjems Hospital is similar to the data reported in the Enova Building Statistics report from 2017 [224]. According to Enova, the delivered energy to nursing homes in Norway comes mainly from electricity (84.6%) and secondary from district heating (14.9%).

4.1.2.2 Scenario 1: External insulation

Scenario 1 (S1) consists of improving the thermal envelope of the *sykehjem* unit by externally insulating the outer walls, roof and ground floor. The nursing home extension is the only building in Trondhjems Hospital that is not part of the Norwegian cultural heritage. For this reason, it is possible to change the façade and roof aesthetics.

This scenario analyses several construction products and solutions to offer a diverse catalogue of renovation measures. Regarding the external cladding, S1 compares the GHG emissions between reusing the existing brick cladding (keeping the façade aesthetics of Trondhjems Hospital) or adding a new wood cladding (highlighting the *sykehjem* renovation while keeping the same aesthetics as the surrounding residential buildings). Concerning insulation, the GHG emissions of wood fibre insulation (lower impact but uncommon construction product) are evaluated against mineral wool insulation (higher impact but widespread construction product). The exchange in the insulation thickness required by the two energy standards (PH and TEK) is also considered.

In total, S1 takes into account eight scenario variations, represented in Table 17. The code of each scenario variation is used to designate the findings in the results section.

The ground floor building component involves demolishing the linoleum flooring and the intermediate layer of polyvinyl chloride (PVC) and adding a new linoleum layer on top of the expanded polystyrene (XPS) insulation, encapsulated between two PVC vapour barriers.

The external wall building component encompasses demolishing the brick cladding and the existing mineral wool insulation to install the new insulation layer (wood fibre or mineral wool), followed by the reused brick cladding or the wood cladding system (vapour barrier and wind barrier between the insulation, double wood battens and vertical wood cladding). In the case of the basement walls, the new layers added are XPS insulation and drainage membrane.

The roof building component involves demolishing the existing ceiling and mineral wool insulation to replace them with new insulation (wood fibre and mineral wool) and a suspended plasterboard ceiling system.

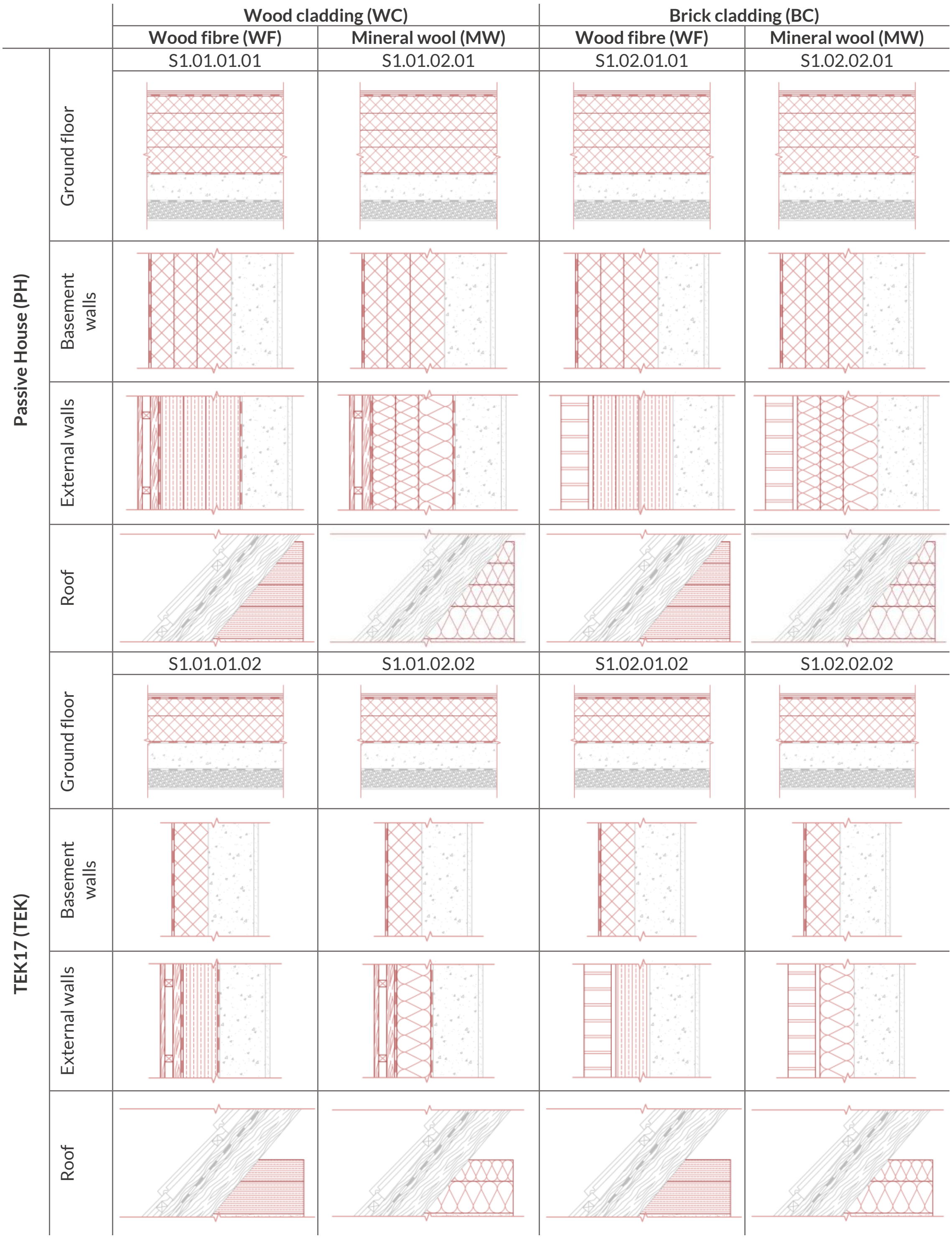


Table 17. LCI of S1 per scenario variation and building part

4.1.2.3 Scenario 2: Internal insulation

Scenario 2 (S2) consists of improving the thermal envelope of the dementia wings by internally insulating the external walls, roof and ground floor. In contrast with the *sykehjem*, the old wings in Trondhjems Hospital are protected, so the envelope can only be insulated on the inside.

As S1, S2 analyses several construction products and components to provide a wide range of solutions. For the internal cladding, S2 compares the GHG emissions between plasterboard (higher impact but widespread construction product) and clay board (lower impact but uncommon construction product). Regarding insulation, S2 also evaluates the GWP of mineral wool against wood fibre, as well as the insulation thickness variation due to PH and TEK requirements.

In total, S2 takes into account eight scenario variations, represented in Table 18. The code of each scenario variation is used to designate the findings in the results section.

The ground floor, basement walls and roof building components are equal in S1 and S2. The external wall building component does not include demolishing parts of the existing wall. It adds new materials to the inner side: vapour barrier, insulation (wood fibre or mineral wool) between wood studs, and an internal cladding (plasterboard or clay board).

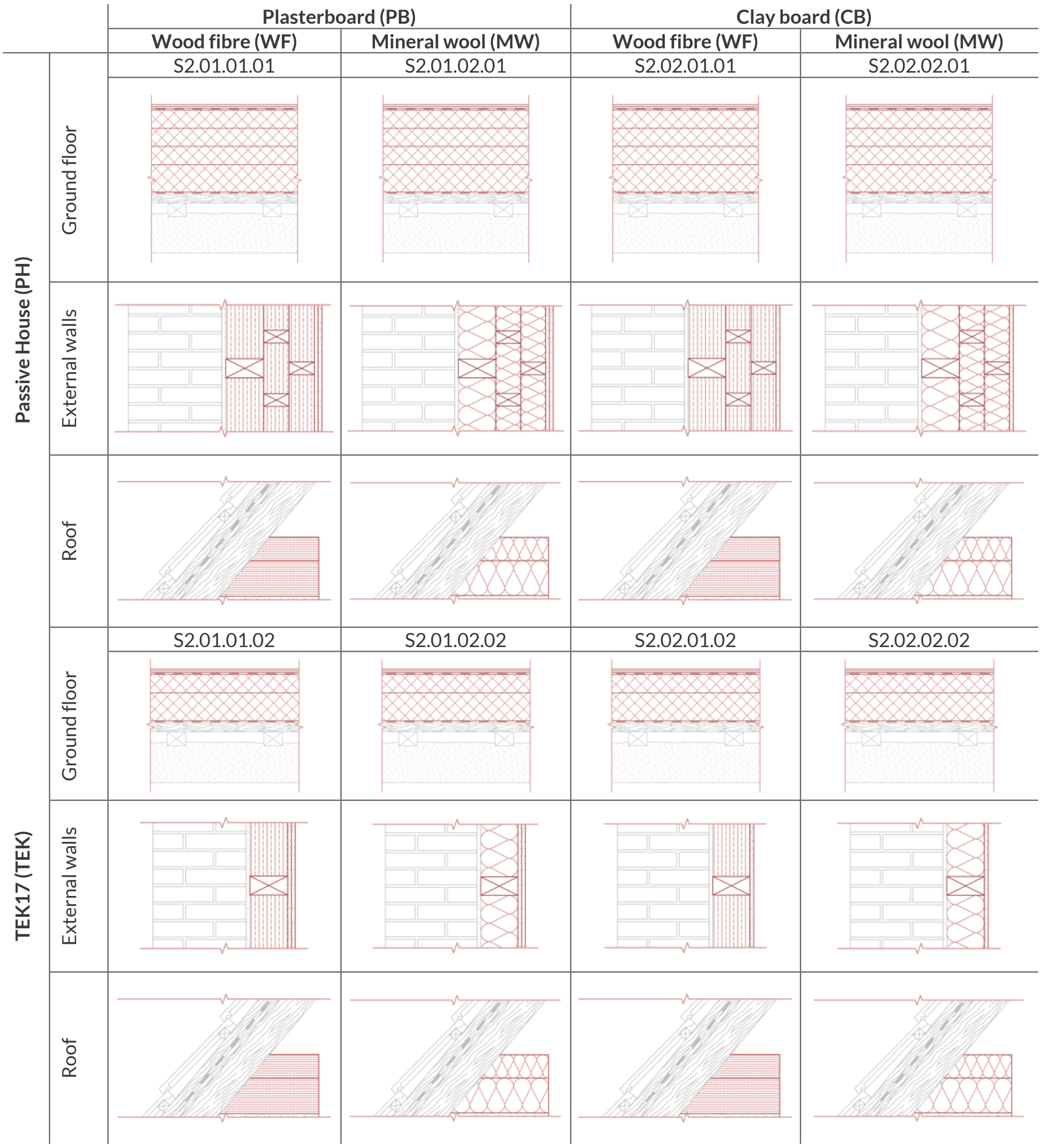


Table 18. LCI of S2 per scenario variation and building part

4.1.2.4 Scenario 3: Changing windows

Scenario 3 (S3) involves retrofitting the windows in both the *sykehjem* and the dementia wings. The energy efficiency of the new wood windows depends on the U-value requirements of the standards evaluated: 0.8 W/m$_2$K in PH and 1.2 W/m$_2$K in TEK.

There are 219.3 m^2 of curtain walls and 1830.2 m^2 of windows in the *sykehjem*, 92.2 m^2 of curtain walls and 613.4 m^2 of windows in the north wing, 345.4 m^2 of windows in the west wing, and 171.6 m^2 of windows in the east wing.

4.1.2.5 Scenario 4: Dementia-friendly environment

Scenario 4 (S4) applies to the internal layout of the *sykehjem* and dementia wings. In the case of the *sykehjem*, the measures are oriented to transform a typical hospital-like nursing home into a dementia-friendly environment. The renovation of the dementia wings involves low-impact measures focused on selecting new finishing materials, colours and textures based on the dementia-enabling environmental principles studied in the literature review section. The *sykehjem*'s scenario is a heavy conversion (external envelope replacements + demolishing and building new partitions + dementia-friendly interior design), and the dementia wings' scenario is a light conversion (interior design).

Table 19 lists the renovation measures based on the key principles applied in the *sykehjem* and the dementia wings (only the measures marked with an asterisk). The sections (Figure 22 and Figure 24), the floorplans (Figure 23) and the material takeoff (Figure 25) of the *sykehjem* unit show the before and after of the dementia-friendly measures.

Low-impact dementia-friendly renovation measures

Measure		Location	Type	Dementia principle	
1	Exchange the existing glazed system in the unused balconies for a high energy-efficient curtain wall to replace the external doors with cased openings to provide connection, daylight and views	Balconies	Heavy conversion: Curtain wall replacement	3	Allow people to see and be seen
				6	Support movement and engagement
				8	Provide a variety of places to be alone or with others in the unit
2*	Hide external and service doors with a continuous wood cladding	Corridor	Light conversion: New wall and door cladding	4	Reduce unhelpful stimulation
3	Bookcase and reading corner in service corridor	Corridor	Light conversion: new bookcase	6	Support movement and engagement
4*	Install handrail	Corridor	Ligh conversion: New handrail	1	Unobtrusively reduce risks
				6	Support movement and engagement
5	Create a new common area in the east corridor	Corridor	Medium conversion: Demolish partitions	2	Provide a human scale
				6	Support movement and engagement
				7	Create a familiar place
				8	Provide a variety of places to be alone or with others in the unit
6*	Exchange glazed partitions with opaque partition wall	Living room	Medium conversion: Demolish and build partitions	1	Unobtrusively reduce risks
				4	Reduce unhelpful stimulation
7*	Substitute doors for cased opening and new slatted wood ceiling	Living room	Medium conversion: Demolish doors and new ceiling	3	Allow people to see and be seen
				6	Support movement and engagement
8	New windows in the dining room and offices to provide daylight and visual access for users and staff	Dining room Offices	Medium conversion: Install windows	3	Allow people to see and be seen
				6	Support movement and engagement
9	Reorganisation of offices and new quiet room for dementia patients	Offices	Light conversion: furniture rearrangement	7	Create a familiar place
				10	Design in response to a vision for a way of life
10	Exchange bathroom door for a cased opening in front of the bed to improve orientation	Bedroom	Medium conversion: Demolish and build partitions	5	Optimise helpful stimulation
11	New integrated bedroom wardrobe with a daily display clothing cabinet	Bedroom	Light conversion: new wardrobe	4	Reduce unhelpful stimulation
				5	Optimise helpful stimulation
12*	Highlight bedroom entrances with singular colors in the doors and new slatted wood ceiling	Bedrooms	Ligh conversion: New door paint and ceiling	5	Optimise helpful stimulation
13*	Add plants and homelike furniture and decoration that residents can relate with	Unit	Light conversion: interior design	7	Create a familiar place
				10	Design in response to a vision for a way of life

Table 19. Dementia-friendly renovation measures

Figure 22. Existing and proposed sections in S4 (*sykehjem*)

Figure 23. Material takeoff from demolish (left) and new materials (right) in S4 (*sykehjem*)

Figure 24. Existing and proposed sections in S4 (*sykehjem*)

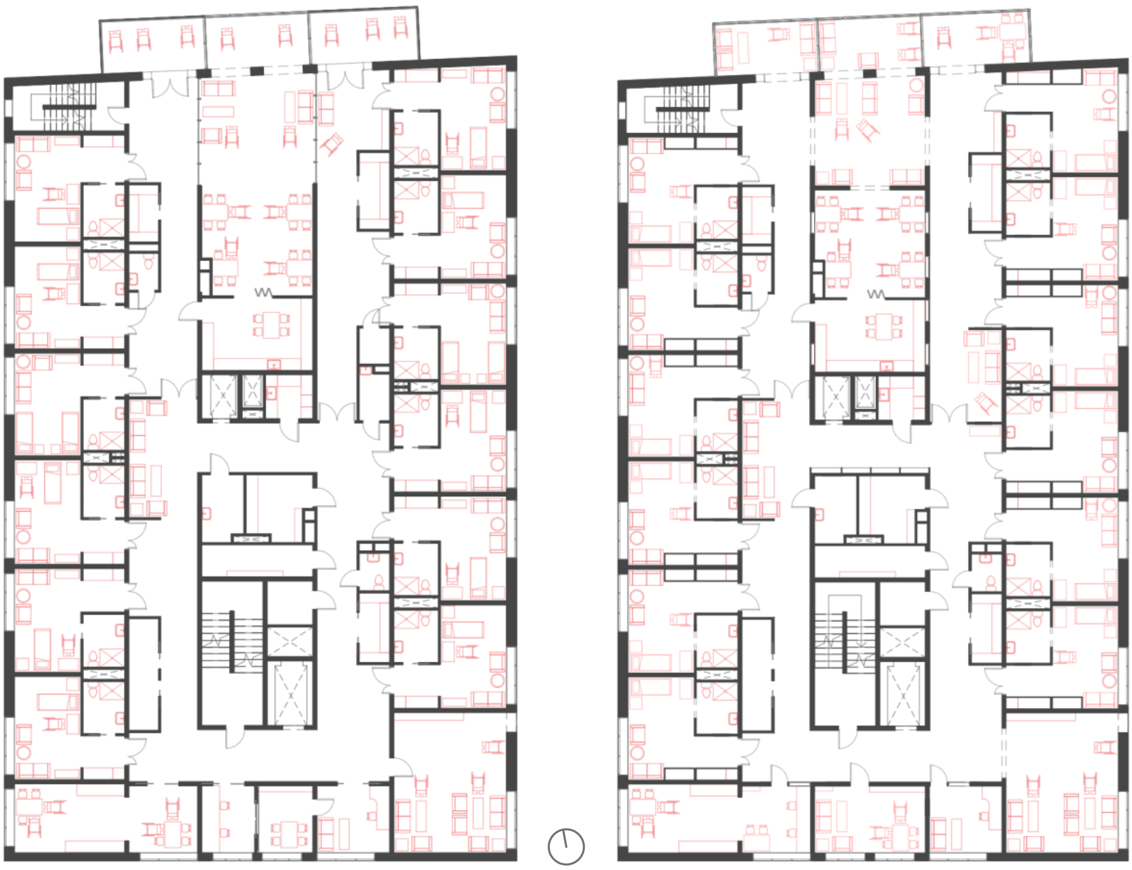


Figure 25. Existing (left) and proposed (right) floorplans in S4 (sykehjem)

4.1.2.6 Scenario 5: Energy performance

Scenario 5 (S5) considers the renovation measures of S1, S3 and S4 (*sykehjem*) and of S2, S3 and S4 (dementia wings) to assess the energy use (kWh/m^2/year) and the operational energy emissions (kgCO_2eq/m^2/year) according to PH and TEK energy standards.

Regarding energy delivery, Scenario 5 considers a heat pump system that supplies 80% of room heating and hot water, while the remaining 20% is covered by grid electricity. 765 m^2 of photovoltaic (PV) panels are also installed on the *sykehjem*'s rooftop to reduce energy demand. However, the dementia wings do not have PV panels because the buildings are part of Norwegian cultural heritage.

4.1.2.7 Summary scenario: Sustainable renovation

The summary scenario (SS) aims to calculate the GHG emissions of renovating the thermal envelope of a nursing home in Norway to improve its energy efficiency (architectural-environmental perspective) and simultaneously transform the facility into a dementia-friendly environment with a person-centred approach (social perspective).

This scenario takes into account all renovation measures, like S5. Nevertheless, instead of evaluating the energy use, it is focused on the operational energy emissions (kgCO_2eq/m^2/year) of the *sykehjem* and the dementia wings.

4.2 Life cycle cost assessment

As defined by *ISO 15686-5:2017 Buildings and constructed assets — Service life planning — Part 5: Life-cycle costing* [225], life cycle cost analysis (LCCA) is a methodology to assess the investment cost of a building during its entire life cycle, which includes construction, operation, maintenance and end-of-life phases. An LCCA usually includes an economic comparison between alternatives or estimating future costs.

In Norway, the LCCA methodology framework is defined by the national standards *NS 3453:2016 Specifications of costs in building projects* [226] and *NS 3454:2013 Life cycle costs for construction works – Principles and classification* [227].

The LCCA of Trondhjems Hospital uses the scenarios of the LCA, except for the baseline (Table 20). Scenarios 1, 2, 3, and 4 evaluate the construction costs of several renovation measures: Scenarios 1 and 2 improve the building envelope (externally or internally) according to Norwegian energy standards; Scenario 3 considers the costs of changing the windows; and Scenario 4 consists of low-impact interior measures to transform the nursing home into a dementia-friendly environment. Scenario 5 assesses the operational energy costs of adapting the nursing home to Norwegian energy standards. The last scenario (SS) is the summary of the previous scenarios, considering the effect of the architectural (S1, S2, and S3) and interior renovation measures (S4) on the energy performance of the building (S5).

Scenario	BS Baseline scenario	S1 External insulation	S2 Internal insulation	S3 Changing windows	S4 Dementia-friendly environment	S5 Energy performance
Unit	Sykehjem Dementia wings	Sykehjem	Dementia wings	Sykehjem Dementia wings	Sykehjem Dementia wings	Sykehjem Dementia wings
Material costs		X	X	X	X	
Energy costs	X					X

	Scenario	**Unit**	**Material** costs	**Energy costs**
SS	Sustainable renovation (S1/S2+S3+S4+S5)	Sykehjem Dementia wings	X	X

Table 20. LCCA scenarios by unit and type of cost assessed

4.2.1 Goal and scope

The goal of the LCCA is to evaluate the economic feasibility of the low-impact renovation measures to transform Trondhjems Hospital into a dementia-friendly environment. The assessment also aims to investigate the trade-offs between the GHG emissions of these measures and their affordability, comparing the costs of reaching high energy-efficiency standards against material savings (benefit-cost approach, equivalent to ZEN KPI ØKO6.3 Overall performance) [228].

The cost results are given in Norwegian kroner (NOK) and Norwegian kroner per square meter of gross floor area per year (NOK/m^2_{GFA}/year). The analysis period is 60 years.

The cost data for material use is collected from the Norwegian price book 2023 (*Norsk prisbok* 2023) [195]. All products are selected from the category 02 Building (NS 3453:2016) in the section 'Elements' in the Norwegian price book. When product cost data was unavailable from the price book, prices were taken from the industry. For the labour cost, the assumption is 6.3 working hours/m^2 for the TEK scenario and 6.6 working hours/m^2 for the PH, with an hourly price of 620 NOK/hour in both scenarios [2]. In S3 and S4, a 50% reduction in labour cost (3.1 and 6.3 working hours/m^2, respectively) has been assumed because the renovation measures do not require heavy conversions. PH has a higher hourly cost than TEK because construction workers are assumed to spend more time erecting a building with thicker walls and better sealing.

Regarding energy costs, the delivered electricity price is 1.88 NOK/kWh, and exported energy price from the photovoltaic system is 1.2 NOK/kWh. The energy prices were obtained from the FME-ZEN Research Centre Ydalir pilot project [2]. The delivered electricity price considers the average energy prices in Norway in the first quarter of 2022 for households, including power, network rental and taxes. The exported energy price comes from the agreement with Ohmia Energy to operate Ydalir's solar plant. Therefore, the system boundaries of this LCCA only involve '1 Acquisition and residual costs – 13 Major renovation' and '5 Supply costs – 51 Energy' cost classifications according to NS 3454:2013 (Table 21). This cost framework is equivalent to ZEN KPI ØKO6.1 Investment costs and ZEN KPI ØKO6.2 Operating costs [228].

LCCA Cost classification (NS 3454:2013)

1 Acquisition and residual costs	11 Plot	
	12 New construction	
	13 Major renovation	X
	14 Residual cost	
2 Administrative costs	21 Taxes and fees	
	22 Insurance	
	23 Property management	
3 Operational and maintenance costs	31 Operation	
	32 Maintenance	
	33 Damage repair	
4 Replacement and development costs	41 Replacement	
	42 Development	
5 Supply costs	51 Energy	X
	52 Water and sewer	
	53 Renovation	
6 Cleaning costs	61 Regular cleaning	
	62 Periodic cleaning	
	63 Extraordinary cleaning	
	64 Cleaning related tasks	

Table 21. LCCA Cost classification scope according to NS 3454:2013 [227]

4.2.1 Life cycle inventory

The LCCA employs the same material inventory as the LCA. The cost assessment is limited to the material and labour costs for the property owner and operational costs for the property user. Costs exclude 25% of the Norwegian value-added tax (VAT). The interest rate has not been taken into account. The life cycle cost inventory is described in Appendix 5.

4.3 Environmental quality assessment

In order to assess the impacts on the residents (social perspective) caused by the dementia-friendly renovation measures, an environmental quality assessment is carried out. Several audit tools have been developed to evaluate the environmental qualities of nursing homes with the purpose of achieving a person-centred care model. The systematic literature review by Calkins et al. [25] found 13 environmental assessment tools for shared residential units with a dementia-specific focus (Table 22):

Environmental assessment tool	Acronym	Developer and year	Country of origin
Therapeutic Environment Screening Survey for Nursing Homes	TESS-NH	Sloane et al., 2002 [229]	USA
Environment-behaviour model	E-B Model	Zeisel et. al., 1994 [230]	USA
Nursing Unit Rating Scale	NURS	Grant, 1996 [82]	USA
Professional Environmental Assessment Protocol	PEAP	Lawton et al., 2000 [231]	USA
Sheffield Care Environment Assessment Matrix	SCEAM	Parker et al., 2004 [232]	UK
Environmental Quality Assessment for Living	EQuAL	Cutler et al., 2006 [233]	USA
Artifacts of Culture Change	ACC	Bowman & Schoeneman, 2006 [234]	USA
Experience of Home	EOH	Molony, 2007 [235]	USA
Evaluation of Older People's Living Environments	EVOLVE	Lewis et al., 2010 [236]	UK
Environmental Audit Tool	EAT	Fleming & Bennet, 2003 [151]	Australia
Dementia Design Audit Tool	DDAT	Kelly et al., 2011 [237]	UK
Dining Environment Audit Protocol	DEAP	Chaudhury et al., 2017 [238]	USA
Enhancing Healing Environment	EHE	Waller, 2017 [239]	UK

Table 22. Environmental assessment tools for dementia units [25].

The Environmental Audit Tool-High Care (EAT-HC), the actualised version of the Environmental Assessment Tool (EAT) developed by Richard Fleming and Kirsty A. Bennett [15], [151], [152], is the audit tool selected to estimate the environmental quality of the case study considering the needs of residents living with dementia.

4.3.1 Goal and scope

The EAT-HC is structured around the ten key design principles studied in the literature review, the 'Dementia Enabling Environment Principles' [15], which are graphically described in Figure 26.

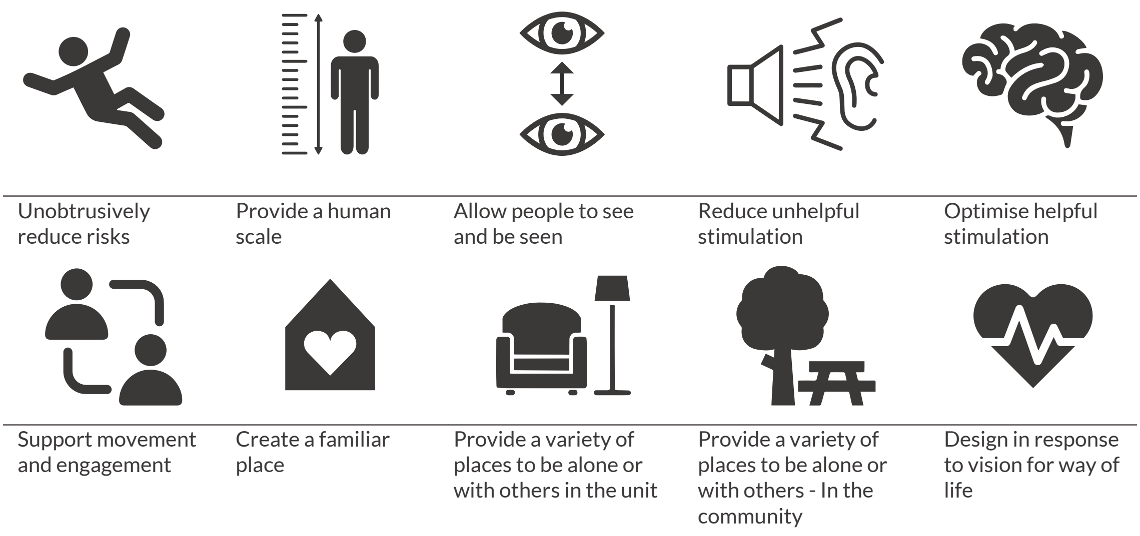


Figure 26. Dementia Enabling Environment Principles [15].

This audit tool is selected due to its higher reliability and usability, according to Calkins et al. [25]. The assessment tool is easy to use and can be conducted on the app BEAT-D (Building Environmental Assessment Tool-Dementia), developed by the University of Wollongong and Dementia Training Australia. It is elaborated to be completed by a non-design professional that is familiar with the dementia principles.

The evaluation consists of 72 questions, mostly answered yes/no, organised around the ten dementia principles. The BEAT-D app generates two reports: a table with the actual scores based on answers supplied through BEAT-D and a 'Room for Improvement Report', where items are ranked by the lowest score obtained during the assessment. The questionnaire has been validated in 22 dementia-specific settings and eight dementia-inclusive units (residents with diverse diagnoses). Handbooks and spreadsheets are also available to assist users [152], [240].

Although the unit assessed receives a numerical score, the goal of the audit tool is not to achieve a particular grade but “to provide a framework for reviewing the environment and identifying areas for improvement”[240, p. 203].

The environmental quality assessment in Trondhjems Hospital considers two scenarios (Table 23) in the *sykehjem* and the dementia wings. In the baseline scenario (SB), the audit tool evaluates the current environmental quality of the nursing home. In the proposal scenario (SP), the EAT-HC is used to calculate the impact of the dementia-friendly renovation measures. In total, four environmental assessments are developed, two in the *sykehjem* and two in the dementia wings.

Scenario			Unit	Before the renovation	After the renovation
	SB	Baseline scenario	Sykehjem and dementia wings	X	
	SS	Sustainable renovation	Sykehjem and dementia wings		X

Table 23. Environmental quality assessment (EQA) scenarios

4.3.2 Questionnaire

The questions and the answers to the EAT-HC audit tool are described in Appendix 6. The questionnaire is organised in three columns. The first column has the number and description of the questions (organised by dementia principle), the second has the scores of the dementia wings, and the third has the scores of the *sykehjem*.

The score columns are divided into three categories: the actual score is the punctuation given during the evaluation. The maximum score is the highest possible score for a specific question. The room for improvement (RFI) score is obtained after subtracting the actual score to the maximum score. After the assessment, the RFI score is added to obtain an RFI graphic with the areas to improve per key dementia principle.

5 Results

5.1 Life cycle assessment

5.1.1 Baseline scenario

The energy demand of Trondhjems Hospital is 264.6 kWh/m^2/year in the *sykehjem* and 278 kWh/m^2/year in the dementia wings. The delivered energy to the *sykehjem* is 281.1 kWh/m^2/year (direct electricity) and 202.1 kWh/m^2/year to the dementia wings (direct electricity and heat pump). Using the same CO_2 conversion factor as the ZEB Research Centre (136 gCO_2eq/kWh), the global warming potential of the operational energy use (B6 life cycle module) is 38.2 kgCO_2eq/m^2/year in the *sykehjem* and 27.5 kgCO_2eq/m^2/year in the dementia wings. Assuming a delivered energy price of 1.88 kr/kWh, the annual energy cost of the *sykehjem* is 3,362,061 kr/year (528.5 kr/m^2/year) and 628,662 kr/year (379.9 kr/m^2/year) for the dementia wings. Figure 27 summarises the energy consumption, environmental impact and energy cost of Trondhjems Hospital.

Trondhjems Hospital presents a slightly higher energy demand than Norwegian nursing homes' reference values. The reference levels (Figure 28) from the last decades range between 236 and 266 kWh/m^2/year, according to a 2016 report from the Norwegian Directorate of Water and Energy Resources (*Norges vassdrags- og energidirektorat*, NVE) [241]. Enova Building Statistics 2017 situated the energy demand of nursing homes at 234 kWh/m^2/year [224].

Considering that the nursing home was built in the 19th century and the 1970s and renovated on several occasions in the 1990s, the results obtained from the energy performance calculations can be a reasonable approach to the actual energy consumption of Trondhjems Hospital. Furthermore, the actual energy demand could be even higher; the staff complained during the site visit about the elevated monthly energy cost and the need to use electric heaters in several rooms in winter.

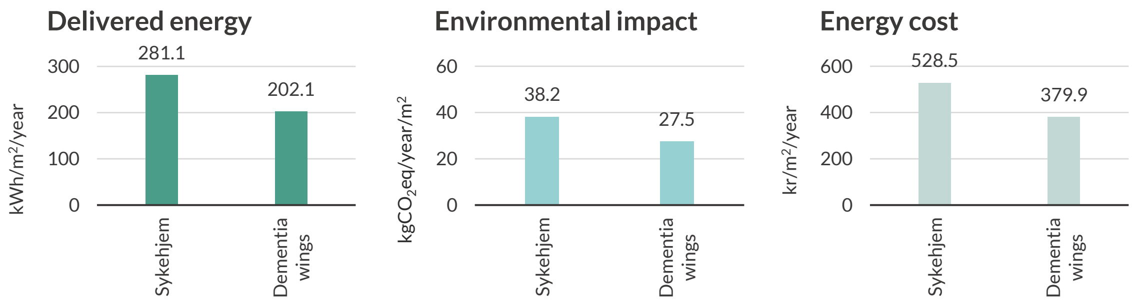


Figure 27. Delivered energy, environmental impact and energy cost in BS

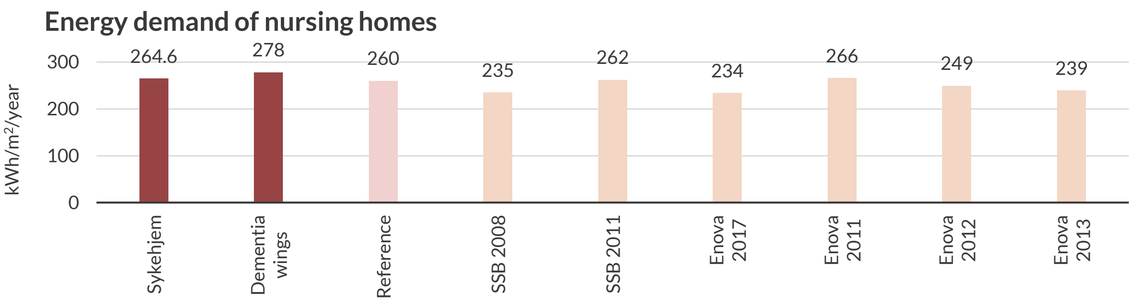


Figure 28. Energy demand of nursing care homes in statistic databases [241]

5.1.2 Scenario 1: External insulation

Table 24 shows the GHG embodied emissions results of externally insulating the *sykehjem*. With the NS3720 calculation method, the findings show a GWP ranging between 0.21-0.44 $kgCO_2eq/year/m^2_{GFA}$ and 26.2-55.9 $kgCO_2eq/year/person$. Considering FBZ, the GWP varies between 0.08-0.22 $kgCO_2eq/year/m^2_{GFA}$ and 10.7-28.4 $kgCO_2eq/year/person$. The calculation method used has a crucial impact on the GHG emissions outcome. Due to its dynamic approach, FBZ results are approximately 50% lower than NS3720. Wood cladding with wood fibre insulation and TEK standard produces the lowest GHG emissions, and reused brick cladding with mineral wool and PH standard generates the highest. PH has higher emissions than TEK due to the thicker building elements and insulation.

		Wood cladding (WC)		Brick cladding (BC)	
		Wood fibre (WF)	**Mineral wool (MW)**	**Wood fibre (WF)**	**Mineral wool (MW)**
PH		***S1.01.01.01***	***S1.01.02.01***	***S1.02.01.01***	***S1.02.02.01***
	NS 3720	0.34 $kgCO_2e/yr/m^2$	0.42 $kgCO_2e/yr/m^2$	0.36 $kgCO_2e/yr/m^2$	0.44 $kgCO_2e/yer/m^2$
		43.8 $kgCO_2e/yr/pers$	53.7 $kgCO_2e/yr/pers$	46.4 $kgCO_2e/yr/pers$	55.9 $kgCO_2e/yr/pers$
	FBZ	0.14 $kgCO_2e/yr/m^2$	0.20 $kgCO_2e/yr/m^2$	0.17 $kgCO_2e/yr/m^2$	0.22 $kgCO_2e/yr/m^2$
		18.1 $kgCO_2e/yr/pers$	25.8 $kgCO_2e/yr/pers$	21.1 $kgCO_2e/yr/pers$	28.4 $kgCO_2e/yr/pers$
TEK		***S1.01.01.02***	***S1.01.02.02***	***S1.02.01.02***	***S1.02.02.02***
	NS 3720	0.21 $kgCO_2e/yr/m^2$	0.25 $kgCO_2e/yr/m^2$	0.23 $kgCO_2e/yr/m^2$	0.27 $kgCO_2e/yr/m^2$
		26.2 $kgCO_2e/yr/pers$	31.4 $kgCO_2e/yr/pers$	28.8 $kgCO_2e/yr/pers$	33.9 $kgCO_2e/yr/pers$
	FBZ	0.08 $kgCO_2e/yr/m^2$	0.11 $kgCO_2e/yr/m^2$	0.11 $kgCO_2e/yr/m^2$	0.14 $kgCO_2e/yr/m^2$
		10.7 $kgCO_2e/yr/pers$	14.6 $kgCO_2e/yr/pers$	13.7 $kgCO_2e/yr/pers$	17.6 $kgCO_2e/yr/pers$

Table 24. Total embodied GWP results in S1

Table 25 collects the GHG emissions results per building category, visually displayed in Figure 30. The ground floor component produces the highest emissions due to the XPS insulation. The roof component has the lowest GWP because it only exchanges two construction products (insulation and ceiling board).

The calculation method influences the results obtained, especially in wood fibre scenarios. The emissions from the external walls with wood fibre insulation are around 30% lower than mineral wool insulation when using FBZ but only 10% lesser than mineral wool when calculating with the NS3720 method.

		Wood cladding (WC)				Brick cladding (BC)			
		Wood fibre (WF)		**Mineral wool (MW)**		**Wood fibre (WF)**		**Mineral wool (MW)**	
PH		***S1.01.01.01***		***S1.01.02.01***		***S1.02.01.01***		***S1.02.02.01***	
		NS3720	FBZ	NS3720	FBZ	NS3720	FBZ	NS3720	FBZ
	21 Ground floor	0.24	0.10	0.24	0.10	0.24	0.10	0.24	0.10
	23 External walls	0.09	0.03	0.10	0.05	0.11	0.06	0.12	0.08
	26 Roof	0.01	0.01	0.08	0.05	0.01	0.01	0.07	0.05
TEK		***S1.01.01.02***		***S1.01.02.02***		***S1.02.01.02***		***S1.02.02.02***	
	21 Ground floor	0.15	0.06	0.15	0.06	0.15	0.06	0.15	0.06
	23 External walls	0.04	0.02	0.05	0.03	0.06	0.04	0.07	0.05
	26 Roof	0.01	0.01	0.04	0.03	0.01	0.01	0.04	0.03

Table 25. Embodied GWP ($kgCO_2e/yr/m^2$) in S1 per building component

The GWP of the scenario variations is displayed in Figure 29 for each life cycle module and calculation method used. The highest environmental impacts concentrate in modules A1-A3 (Product) and C3 (Waste processing) in NS 3720. In FBZ, C3 is offset by the biogenic carbon uptake in B1 (Use).

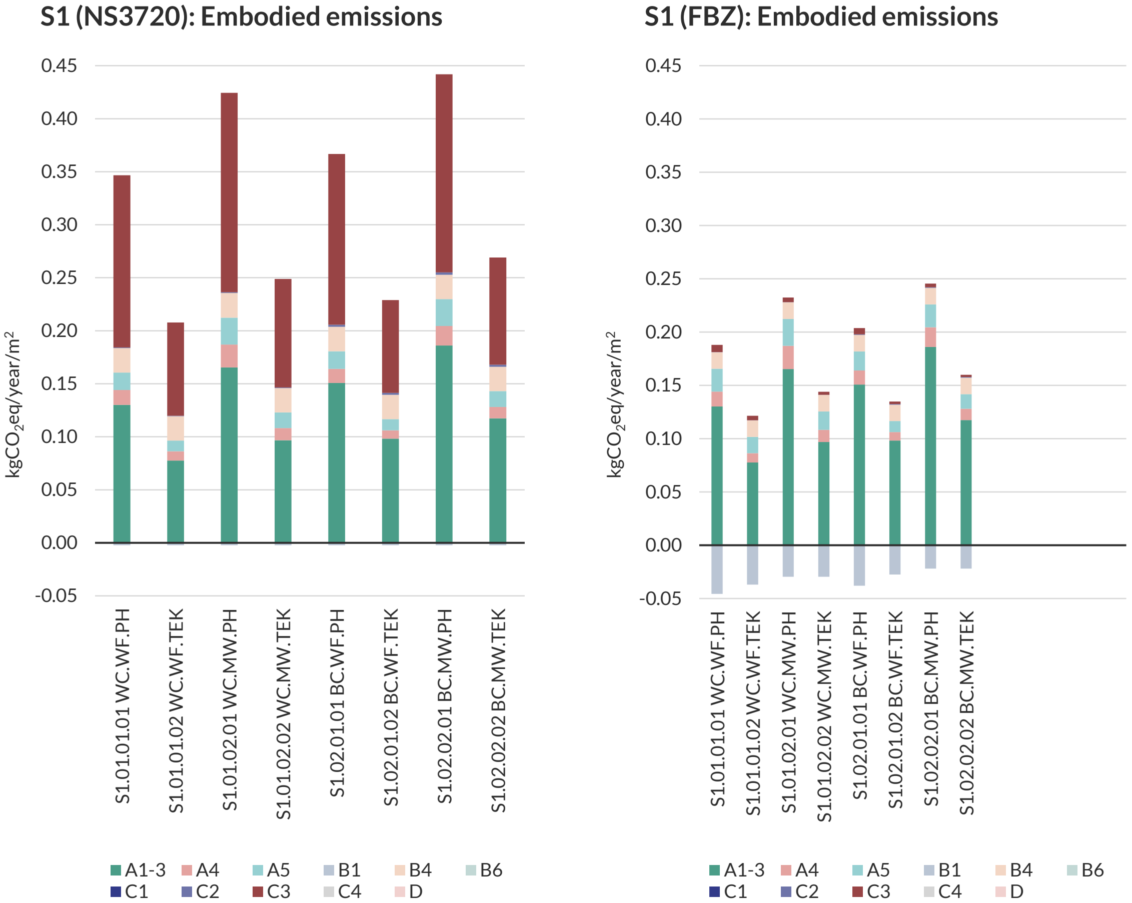


Figure 29. Embodied GWP results in S1 per life cycle module and calculation method

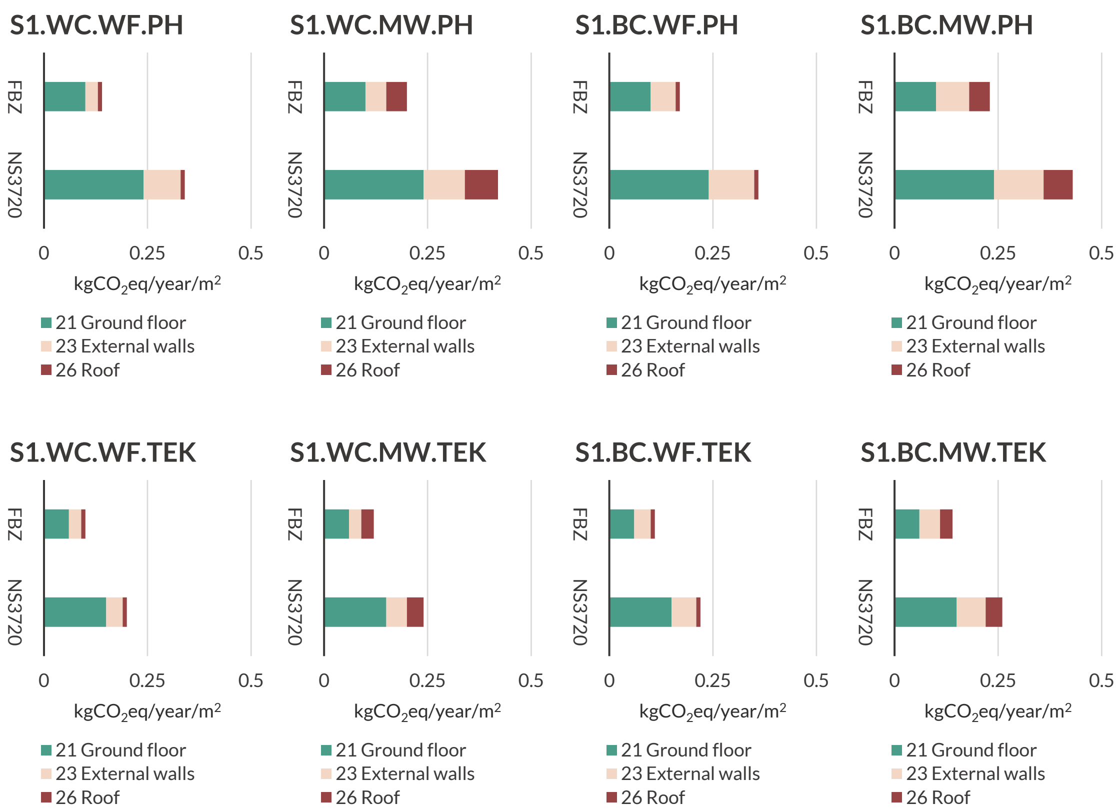


Figure 30. Embodied GWP results in S1 per building component and calculation method

5.1.3 Scenario 2: Internal insulation

Table 26 shows the GHG embodied emissions results of internally insulating the dementia wings. With the NS3720 calculation method, the findings show a GWP ranging between 0.51-1.06 $kgCO_2eq/year/m^2_{GFA}$ and 36.3-75.9 $kgCO_2eq/year/person$. Considering FBZ, the GWP varies between 0.22-0.65 $kgCO_2eq/year/m^2_{GFA}$ and 15.5-46.5 $kgCO_2eq/year/person$. As in S1, the calculation method used has a crucial impact on the GHG emissions outcome. Due to its dynamic approach, FBZ results are approximately 40-50% lower than NS3720. Clay board interior cladding with wood fibre insulation and TEK standard produces the lowest GHG emissions, while plasterboard with mineral wool insulation and PH standard generates the highest. PH has higher emissions than TEK due to the thicker building elements and insulation.

Compared with S1, improving the thermal envelope of dementia wings produces higher environmental impacts due to the building morphology and the lower gross floor area. If the square meters are not considered, the GHG emissions of S2 range from 364 to 1753.9 $kgCO_2eq/year$, whereas S1 emissions are significantly higher, between 509 and 2799.2 $kgCO_2eq/year$.

		Plasterboard (PB)		Clay board (CB)	
		Wood fibre (WF)	Mineral wool (MW)	Wood fibre (WF)	Mineral wool (MW)
PH		*S2.01.01.01*	*S2.01.02.01*	*S2.02.01.01*	*S2.02.02.01*
	NS 3720	0.84 $kgCO_2e/yr/m^2$ 60.2 $kgCO_2e/yr/pers$	1.06 $kgCO_2e/yr/m^2$ 75.9 $kgCO_2e/yr/pers$	0.81 $kgCO_2e/yr/m^2$ 58.1 $kgCO_2e/yr/pers$	1.03 $kgCO_2e/yr/m^2$ 73.8 $kgCO_2e/yr/pers$
	FBZ	0.36 $kgCO_2e/yr/m^2$ 26.2 $kgCO_2e/yr/pers$	0.56 $kgCO_2e/yr/m^2$ 40.1 $kgCO_2e/yr/pers$	0.34 $kgCO_2e/yr/m^2$ 24.4 $kgCO_2e/yr/pers$	0.53 $kgCO_2e/yr/m^2$ 38.4 $kgCO_2e/yr/pers$
TEK		*S2.01.01.02*	*S2.01.02.02*	*S2.02.01.02*	*S2.02.02.02*
	NS 3720	0.53 $kgCO_2e/yr/m^2$ 38.5 $kgCO_2e/yr/pers$	0.65 $kgCO_2e/yr/m^2$ 46.5 $kgCO_2e/yr/pers$	0.51 $kgCO_2e/yr/m^2$ 36.3 $kgCO_2e/yr/pers$	0.62 $kgCO_2e/yr/m^2$ 44.3 $kgCO_2e/yr/pers$
	FBZ	0.24 $kgCO_2e/yr/m^2$ 17.3 $kgCO_2e/yr/pers$	0.33 $kgCO_2e/yr/m^2$ 24.1 $kgCO_2e/yr/pers$	0.22 $kgCO_2e/yr/m^2$ 15.5 $kgCO_2e/yr/pers$	0.31 $kgCO_2e/yr/m^2$ 22.3 $kgCO_2e/yr/pers$

Table 26. Total embodied GWP results in S2

Table 27 collects the GHG emissions results per building category, visually shown in Figure 32. As in S1, the ground floor component produces the highest environmental impacts due to the XPS insulation. The roof component has the lowest GHG emissions because it only exchanges two construction products (insulation and ceiling board). The calculation method influences the results, especially in wood fibre scenarios. The emissions from the external walls with wood fibre insulation are 50% lower than mineral wool insulation when using FBZ but only 30% lesser than mineral wool when calculating with the NS3720 method.

		Plasterboard (PB)				Clay board (CB)			
		Wood fibre (WF)		Mineral wool (MW)		Wood fibre (WF)		Mineral wool (MW)	
PH		*S2.01.01.01*		*S2.01.02.01*		*S2.02.01.01*		*S2.02.02.01*	
		NS3720	FBZ	NS3720	FBZ	NS3720	FBZ	NS3720	FBZ
	21 Ground floor	0.59	0.24	0.59	0.24	0.59	0.24	0.59	0.24
	23 External walls	0.22	0.11	0.30	0.21	0.19	0.08	0.27	0.19
	26 Roof	0.03	0.02	0.16	0.11	0.03	0.02	0.16	0.11
TEK		*S2.01.01.02*		*S2.01.02.02*		*S2.02.01.02*		*S2.02.02.02*	
	21 Ground floor	0.37	0.15	0.37	0.15	0.37	0.15	0.37	0.15
	23 External walls	0.14	0.08	0.18	0.12	0.11	0.06	0.15	0.10
	26 Roof	0.02	0.01	0.10	0.06	0.02	0.01	0.10	0.06

Table 27. Embodied GWP ($kgCO_2e/yr/m^2$) in S2 per building component

The GWP of the scenario variants is displayed in Figure 31 for each life cycle module and calculation method. The highest environmental impacts in S2 also concentrate in modules A1-A3 (Product) and C3 (Waste processing) in NS 3720. In FBZ, C3 is offset by the biogenic carbon uptake in B1 (Use).

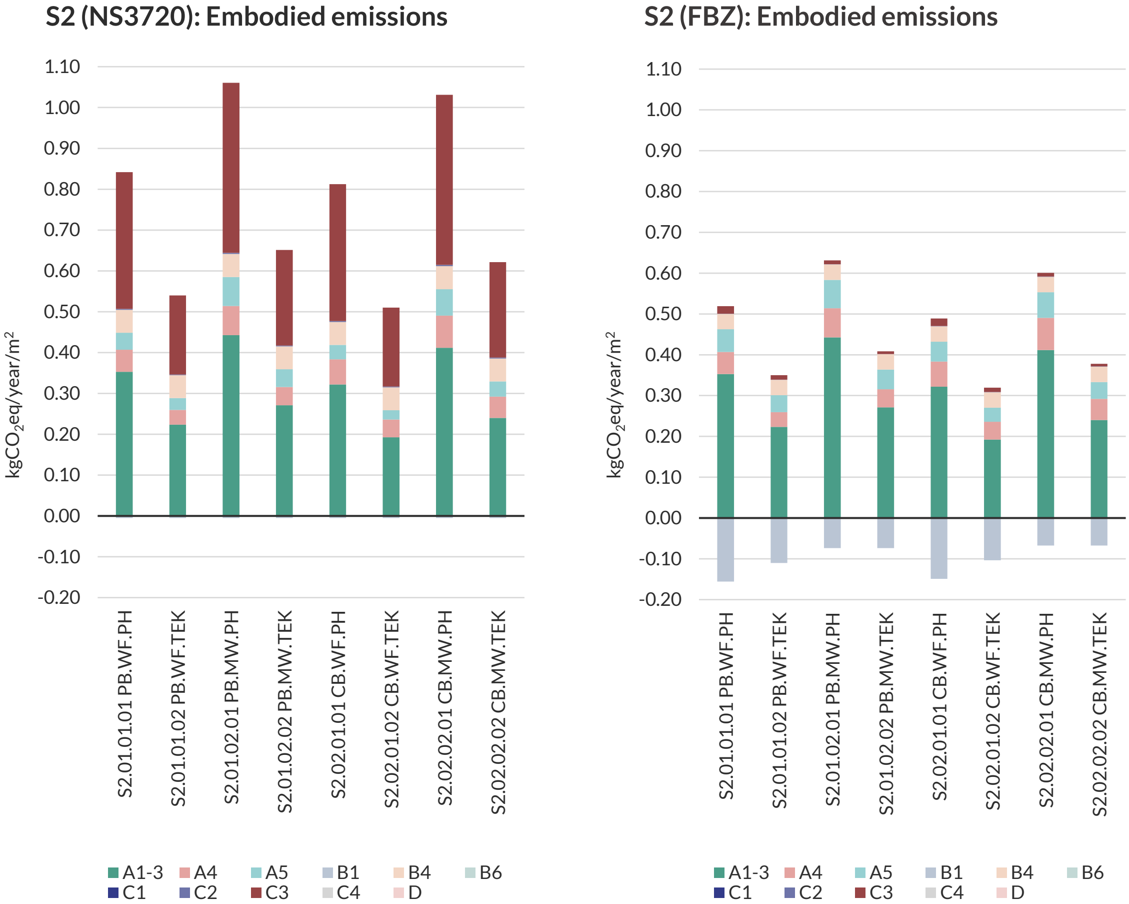


Figure 31. Embodied GWP results in S2 per life cycle module and calculation method

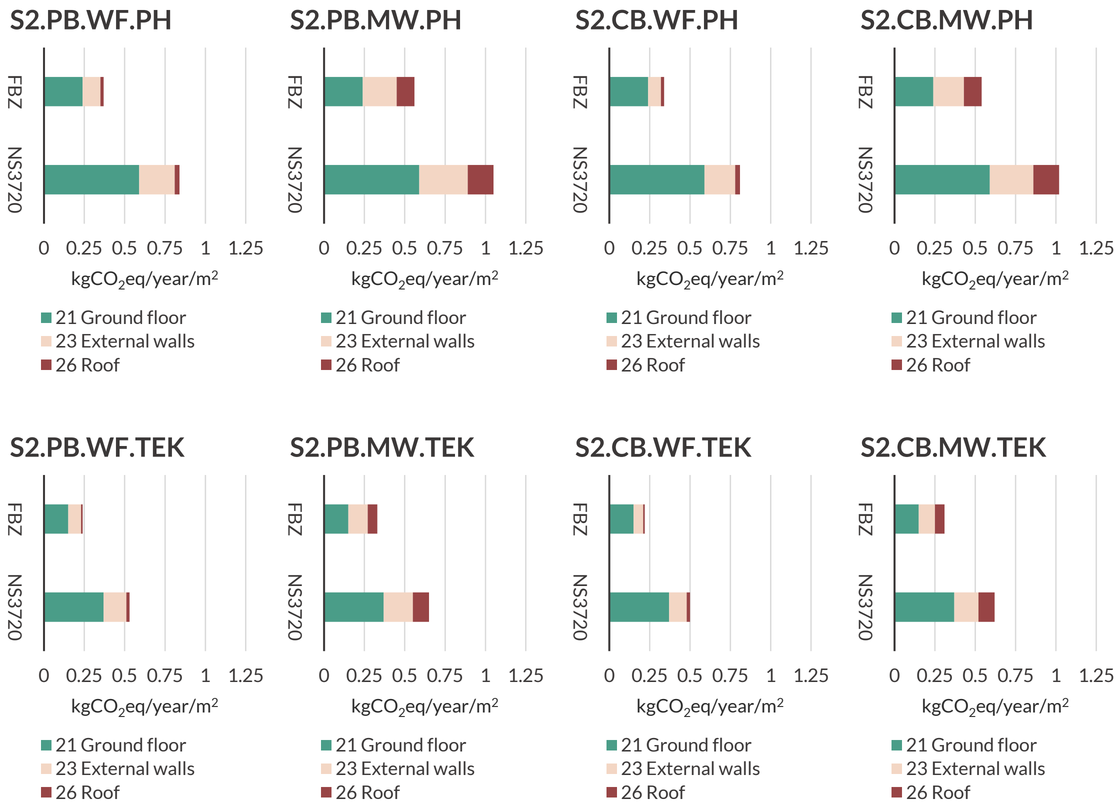


Figure 32. Embodied GWP results in S2 per building component and calculation method

5.1.4 Scenario 3: Changing windows

Table 28 shows the GHG embodied emissions results of changing the windows in the *sykehjem* unit (S3.01) and the dementia wings (S3.02). The calculation only considers the environmental impact of the windows and curtain wall materials, regardless of their U-value. With the NS3720 calculation method, the findings show a GWP of 0.92 $kgCO_2eq/year/m^2_{GFA}$ and 117.2 $kgCO_2eq/year/person$ in the *sykehjem*, and a GWP of 2.32 $kgCO_2eq/year/m^2_{GFA}$ and 166.7 $kgCO_2eq/year/person$ in the dementia wings. Considering FBZ, the GWP is 0.62 $kgCO_2eq/year/m^2_{GFA}$ and 79.4 $kgCO_2eq/year/person$ in the *sykehjem*, whereas 1.59 $kgCO_2eq/year/m^2_{GFA}$ and 114.3 $kgCO_2eq/year/person$ in the dementia wings. The impact of the calculation method on GHG emissions is lower (around 30% fewer impacts in FBZ) than S1 and S2, but it still plays a significant role in the results obtained. The GWP of changing windows is higher in the dementia wings because the window per GFA ratio (68.3%) is superior to the ratio in the *sykehjem* (28.8%).

Scenario	Unit	NS3720	FBZ
S3.01	Sykehjem (SH)	0.92 $kgCO_2e/year/m^2$ 117.2 $kgCO_2e/year/pers$	0.62 $kgCO_2e/year/m^2_{GFA}$ 79.4 $kgCO_2e/year/pers$
S3.02	Dementia wings (DW)	2.32 $kgCO_2e/year/m^2$ 166.7 $kgCO_2e/year/person$	1.59 $kgCO_2e/year/m^2$ 114.3 $kgCO_2e/year/pers$

Table 28. Total embodied GWP results in S3

Regarding building components (Table 29), curtain walls account for fewer emissions (0.14-0.64 $kgCO_2eq/year/m^2_{GFA}$) than windows (0.47-1.64 $kgCO_2eq/year/m^2_{GFA}$). However, curtain walls have more than double the environmental impact of windows, and if the material takeoff were equal, curtain walls would be responsible for 69% of the total GHG emissions.

Scenario	Unit	Component	NS3720	FBZ
S3.01	Sykehjem (SH)	Windows	0.72	0.47
		Curtain walls	0.19	0.14
S3.02	Dementia wings (DW)	Windows	1.64	1.08
		Curtain walls	0.64	0.49

Table 29. Embodied GWP ($kgCO_2e/yr/m^2$) in S3 per building component

The GWP of the scenario variants is displayed in Figure 33 for each life cycle module and method. The highest impacts in S3 concentrate in modules A1-A3 (Product) and B4 (Replacements) in NS 3720. In FBZ, B4 is offset by the biogenic carbon uptake in B1 (Use). The substantial emissions on B4 are due to the service life of windows and curtain walls, 35 and 30 years, respectively.

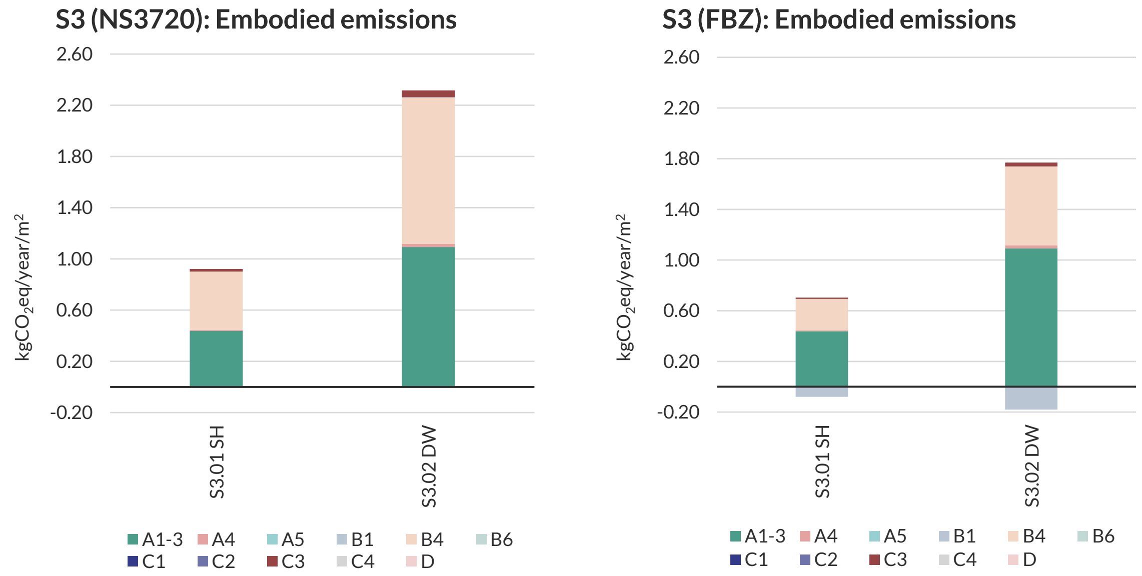


Figure 33. Embodied GWP results in S3 per life cycle module and calculation method

5.1.5 Scenario 4: Dementia-friendly environment

Table 30 shows the GHG embodied emissions results of transforming the *sykehjem* unit (S3.01) and the dementia wings (S3.02) to a dementia-friendly environment. With the NS3720 calculation method, the findings show a GWP of 0.22 $kgCO_2eq/year/m^2_{GFA}$ and 28.6 $kgCO_2eq/year/person$ in the *sykehjem*, and a GWP of 0.15 $kgCO_2eq/year/m^2_{GFA}$ and 18.6 $kgCO_2eq/year/person$ in the dementia wings. Considering FBZ, the GWP is 0.06 $kgCO_2eq/year/m^2_{GFA}$ and 4.5 $kgCO_2eq/year/person$ in the *sykehjem*, whereas 0.04 $kgCO_2eq/year/m^2_{GFA}$ and 3.0 $kgCO_2eq/year/person$ in the dementia wings. Compared to the previous scenarios, the calculation method has the most significant impact on the results. The GHG emissions of S4 in the FBZ method are approximately 75% lower than NS3720 because most renovation measures involve wood products and FBZ considers the biogenic carbon uptake.

Scenario	Unit	NS3720	FBZ
S4.01	Sykehjem (SH)	 0.22 $kgCO_2e/year/m^2_{GFA}$ 28.6 $kgCO_2e/year/pers$	 0.06 $kgCO_2e/year/m^2_{GFA}$ 4.5 $kgCO_2e/year/person$
S4.02	Dementia wings (DW)	 0.15 $kgCO_2e/year/m^2_{GFA}$ 18.6 $kgCO_2e/year/pers$	 0.04 $kgCO_2e/year/m^2$ 3.0 $kgCO_2e/year/pers$

Table 30. Total embodied GWP results in S4

Regarding building components, Table 31 collects the GHG emissions results per building category, visually displayed in Figure 34. The curtain walls in the *sykehjem* unit account for the highest emissions (0.08-0.11 $kgCO_2eq/year/m^2_{GFA}$), followed by windows, doors, internal walls, fixed inventory (bedroom wardrobes) and ceiling in the NS3720 calculation method. The GHG emissions of adding a new slatted wood ceiling are almost negligible (0.002 $kgCO_2eq/year/m^2_{GFA}$). In FBZ, windows, doors and internal walls have 50% less GWP due to the biogenic carbon uptake of the internal wood cladding. In the dementia wings, renovating doors have the highest GHG emissions, followed by internal walls and ceiling.

Scenario	Unit	Component	NS3720	FBZ
S4.01	Sykehjem (SH)	Doors	0.028	0.011
		Windows	0.043	0.029
		Curtain walls	0.109	0.082
		Internal walls	0.022	0.013
		Ceiling	0.002	0.002
		Fixed inventory	0.009	0.001
S4.02	Dementia wings (DW)	Doors	0.025	0.017
		Internal walls	0.035	0.023
		Ceiling	0.002	0.002

Table 31. Embodied GWP ($kgCO_2e/yr/m^2$) in S4 per building component

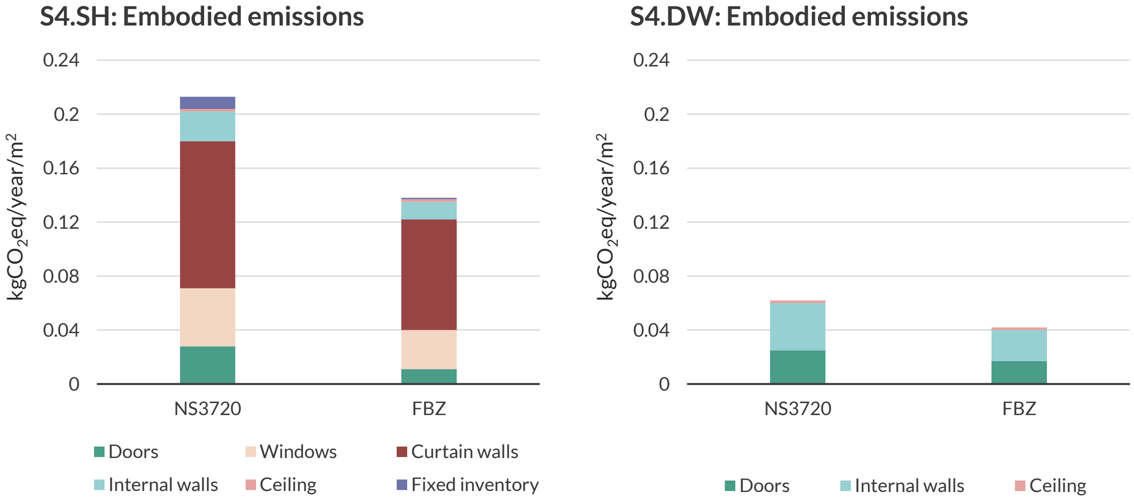


Figure 34. Embodied GWP results in S4 per building component

The GWP of the scenario is displayed in Figure 35 for each life cycle module and method. As in S3, the highest GHG emissions in S4 are in modules A1-A3 (Product) and B4 (Replacements) in NS 3720. In FBZ, B4 is offset by the biogenic carbon uptake in B1 (Use). The substantial emissions on B4 are due to the service life of windows and curtain walls, 35 and 30 years, respectively. The sykehjem produces higher environmental impacts on C3 (Waste processing) than the dementia wings because the renovation involves demolishing partitions, doors and curtain walls.

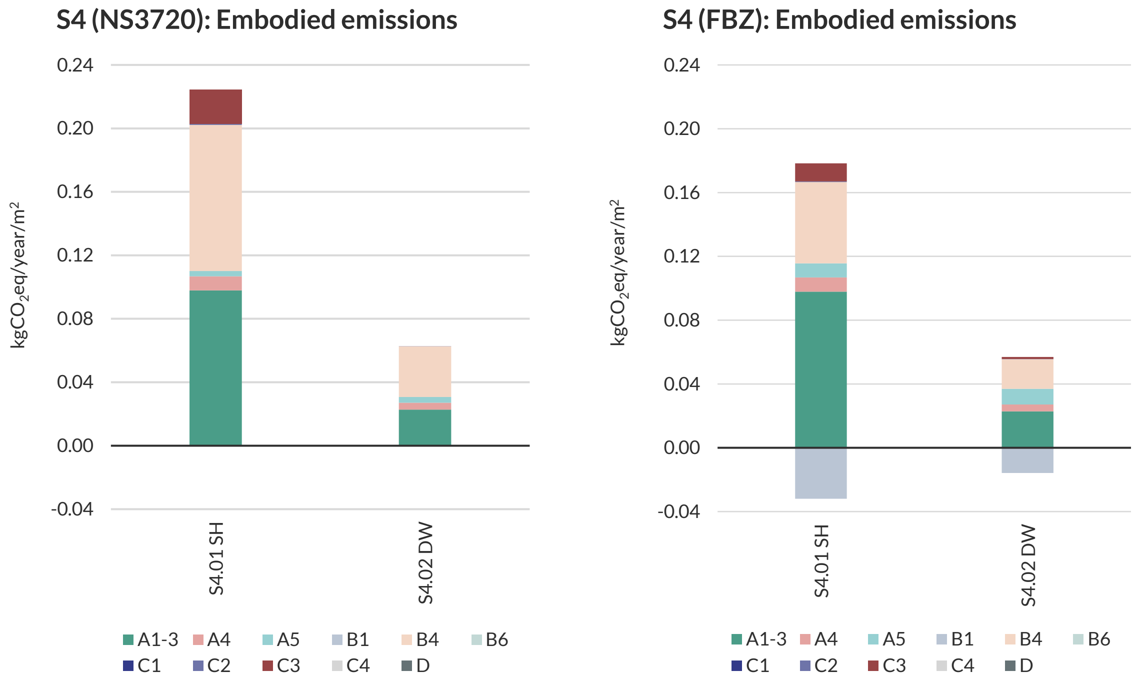


Figure 35. Embodied GWP results in S4 per life cycle module and calculation method

5.1.6 Scenario 5: Energy performance

Table 32 shows the GHG emissions, energy demand and delivered energy results of transforming the *sykehjem* unit (S5.01) and the dementia wings (S5.02) to a dementia-friendly environment.

			NS3720	FBZ
PH	S5.01.01 Sykehjem	GHG emissions	10.3 $kgCO_2e/year/m^2_{GFA}$ 1311.4 $kgCO_2e$/year/person	10.3 $kgCO_2e/year/m^2_{GFA}$ 1305.5 $kgCO_2e$/year/person
		Energy use	121.9 $kWh/year/m^2_{GFA}$	
		Delivered energy	71.5 $kWh/year/m^2_{GFA}$	
	S5.02.01 Dementia wings	GHG emissions	10.9 $kgCO_2e/year/m^2_{GFA}$ 783.2 $kgCO_2e$/year/person	10.9 $kgCO_2e/year/m^2_{GFA}$ 783.2 $kgCO_2e$/year/person
		Energy use	123.6 $kWh/year/m^2_{GFA}$	
		Delivered energy	94.9 kWh $/year/m^2_{GFA}$	
TEK	S5.01.02 Sykehjem	GHG emissions	13.3 $kgCO_2e/year/m^2_{GFA}$ 1696.2 $kgCO_2e$/year/person	13.3 $kgCO_2e/year/m^2_{GFA}$ 1690.3 $kgCO_2e$/year/person
		Energy use	151.9 $kWh/year/m^2_{GFA}$	
		Delivered energy	97.5 kWh $/year/m^2_{GFA}$	
	S5.02.02 Dementia wings	GHG emissions	15.6 $kgCO_2e/year/m^2_{GFA}$ 1119.2 $kgCO_2e$/year/person	15.6 $kgCO_2e/year/m^2_{GFA}$ 1119.2 $kgCO_2e$/year/person
		Energy use	179.1 kWh $/year/m^2_{GFA}$	
		Delivered energy	135.6 kWh $/year/m^2_{GFA}$	

Table 32. Total GHG emissions, energy use, and delivered energy results in S5

The findings show a GWP of 10.3 $kgCO_2eq/year/m^2_{GFA}$ and 1305.5-1311.4 $kgCO_2eq$/year/person in the PH scenario and 13.3 $kgCO_2eq/year/m^2_{GFA}$ and 1690.3-1696.2 $kgCO_2eq$/year/person in the TEK scenario for the *sykehjem* unit. For the dementia wings, the GWP is 10.9 $kgCO_2eq/year/m^2_{GFA}$ and 783.2 $kgCO_2eq$/year/person in the PH scenario and 15.6 $kgCO_2eq/year/m^2_{GFA}$ in the TEK scenario. The calculation method does not impact the results because the only embodied emissions assessed are from the PV panels in the *sykehjem*. The dementia wings have a higher environmental impact per square meter but a lower GWP per person than the *sykehjem* unit.

Table 33 displays the detailed energy use and delivered energy, visually represented in the graphics from Figure 36. PH scenario uses 20-30% less energy and 27-30% delivered energy than the TEK scenario. PH scenario dedicates 1.9-10.6 kWh/yr/m^2 to space heating and 23.4 kWh/yr/m^2 to lighting, whereas the energy use in TEK is 8.4-43.5 kWh/yr/m^2 and 46.7 kWh/yr/m^2, respectively. The dementia wings use more delivered energy because they do not have a PV panel installation. The annual PV panel energy production in the *sykehjem* is 25.1 kWh/yr/m^2. The exported solar energy is 60% higher in the PH standard (3.2 kWh/yr/m^2) than in TEK (1.3 kWh/yr/m^2).

		PH		TEK	
		S5.01.01 Sykehjem	S5.02.01 Dementia wings	S5.01.02 Sykehjem	S5.02.02 Dementia wings
Energy use	1a Space heating	1.9	10.6	8.4	43.5
	1b Ventilation heat (heating coils)	15.5	13.5	16.6	8.2
	2 Hot water (tap water)	29.8	29.8	29.8	29.8
	3a Fans	25.7	21.0	24.3	24.3
	3b Pumps	0.8	0.8	1.1	1.7
	4 Lighting	23.4	23.4	46.7	46.7
	5 Technical equipment	23.4	23.4	23.4	23.4
	6a Space cooling	0	0	0	0
	6b Ventilation cooling (cooling coils)	1.5	1.2	1.5	1.5
Net energy use		**121.9**	**123.6**	**151.9**	**179.1**
Energy demand	1a Direct electricity	83.8	80.5	107.9	114.8
	1b Electricity to heat pump system	12.8	14.5	147	20.8
	7 Solar power for own use	-21.9	0	-23.8	0
	Solar power for export	-3.2	0	-1.3	0
Net delivered energy		**71.5**	**94.9**	**97.5**	**135.6**

Table 33. Operational energy (kWh/yr/m2) in S5

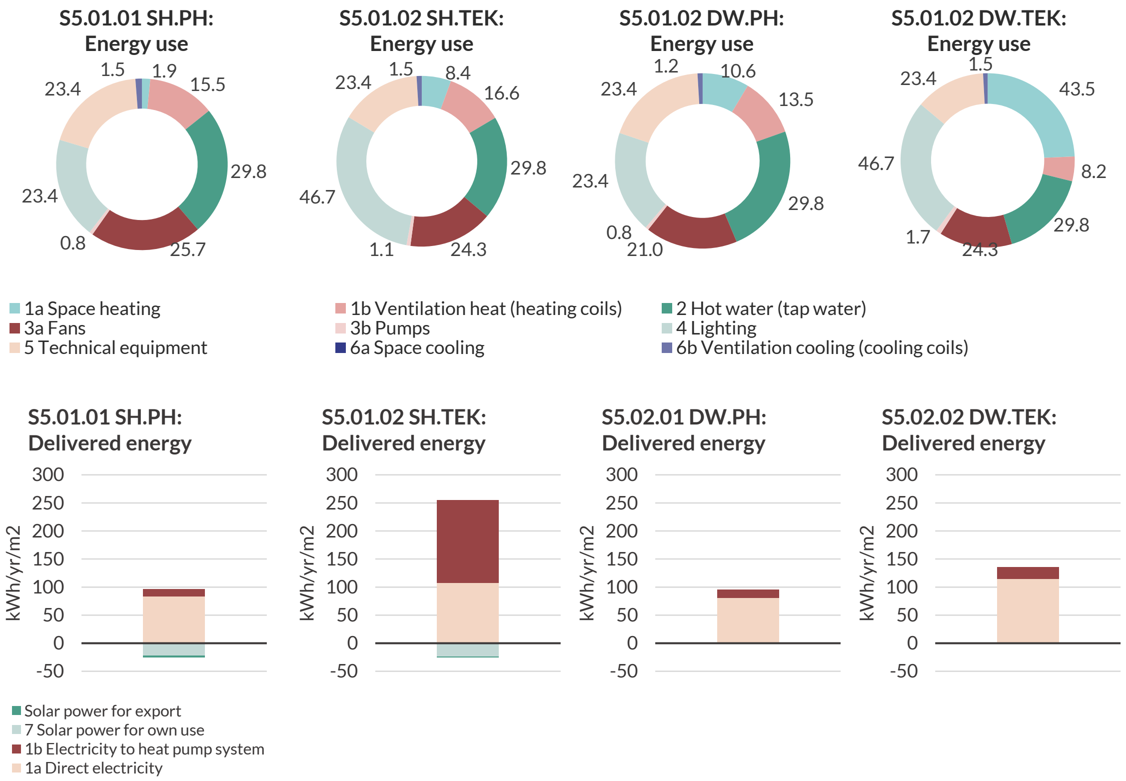


Figure 36. Energy use and delivered energy (kWh/yr/m2) in S5

The GWP of S5 is displayed in Figure 37 for each life cycle module and method. Almost all GWP is concentrated in B6 (Operational energy use). For this reason, the calculation method does not influence the GHG emissions results. The sykehjem unit counterbalance emissions in D life cycle stage (Benefits and loads) due to the exported solar power from the PV panels. The small GWP concentration in modules A1-A3 (Product), B4 (Replacements) and C3 (Waste processing) is produced by the embodied material emissions from the PV panels.

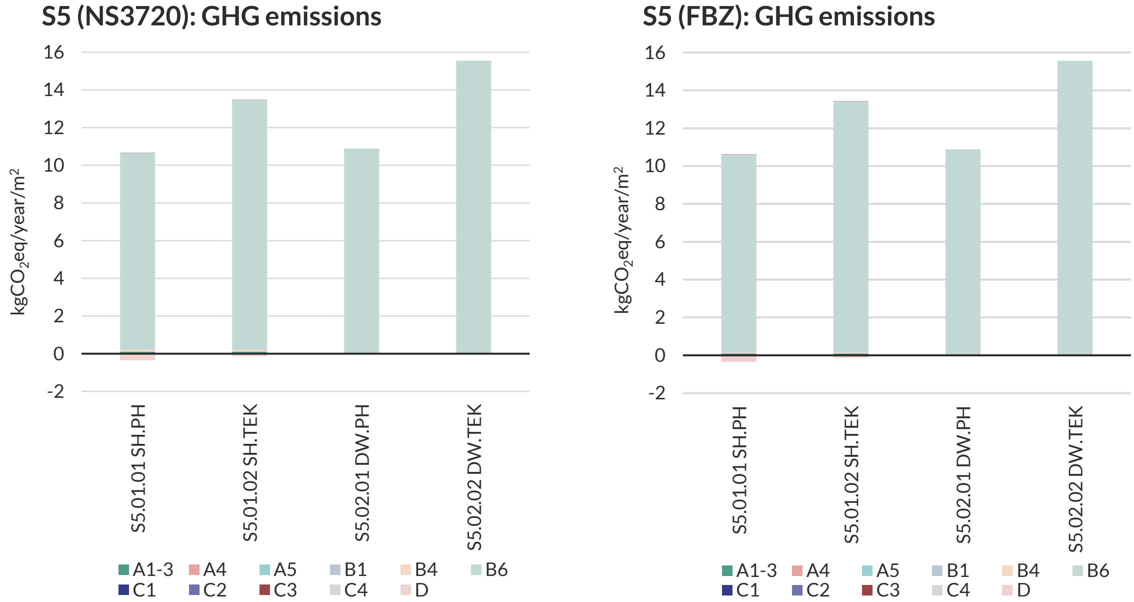


Figure 37. Total GWP results in S5 per life cycle module and calculation method

5.1.7 Summary scenario: Sustainable renovation

Table 34 shows the total GWP, embodied and operational energy emissions, of externally insulating (S1), changing windows (S3), and transforming the *sykehjem* to a dementia-friendly environment (S4) to improve the energy efficiency of the unit (S5) and the quality of life of the residents.

		Wood cladding (WC)		Brick cladding (BC)	
		Wood fibre (WF)	Mineral wool (MW)	Wood fibre (WF)	Mineral wool (MW)
PH		*SS.SH.01.01.01*	*SS.SH.01.02.01*	*SS.SH.02.01.01*	*SS.SH.02.02.01*
	NS 3720	11.8 kgCO₂e/yr/m²	11.9 kgCO₂e/yr/m²	11.8 kgCO₂e/yr/m²	11.9 kgCO₂e/yer/m²
		1501.0 kgCO₂e/yr/pers	1510.9 kgCO₂e/yr/per	1503.6 kgCO₂e/yr/per	1513.1 kgCO₂e/yr/per
	FBZ	11.2 kgCO₂e/yr/m²	11.2 kgCO₂e/yr/m²	11.2 kgCO₂e/yr/m²	11.3 kgCO₂e/yr/m²
		1421.7 kgCO₂e/yr/pers	1429.4 kgCO₂e/yr/pers	1424.7 kgCO₂e/yr/per	1432.0 kgCO₂e/yr/per
TEK		*SS.SH.01.01.02*	*SS.SH.01.02.02*	*SS.SH.02.01.02*	*SS.SH.02.02.02*
	NS 3720	14.7 kgCO₂e/yr/m²	14.7 kgCO₂e/yr/m²	14.7 kgCO₂e/yr/m²	14.7 kgCO₂e/yr/m²
		1868.1 kgCO₂e/yr/pers	1873.3 kgCO₂e/yr/pers	1870.8 kgCO₂e/yr/per	1875.9 kgCO₂e/yr/per
	FBZ	14.1 kgCO₂e/yr/m²	14.2 kgCO₂e/yr/m²	14.2 kgCO₂e/yr/m²	14.2 kgCO₂e/yr/m²
		1799.1 kgCO₂e/yr/pers	1802.9 kgCO₂e/yr/pers	1802.0 kgCO₂e/yr/per	1805.9 kgCO₂e/yr/per

Table 34. Total embodied and operational energy GWP results in SS (*sykehjem*)

With the NS3720 calculation method, the findings in the *sykehjem* unit show a GWP ranging between 11.8-11.9 kgCO₂eq/year/m²GFA and 1501.0-1875.9 kgCO₂eq/year/person. Considering FBZ, the GWP varies between 11.2-14.2 kgCO₂eq/year/m²GFA and 1421.7-1805.9 kgCO₂eq/year/person. The calculation method used is not as crucial as in S1 due to the operational energy use emissions. FBZ results are around 10% lower than NS3720. Wood cladding with wood fibre insulation and PH standard produces the lowest GHG emissions, and reused brick cladding with mineral wool and TEK standard generates the highest. PH has lower emissions than TEK in the summary scenario due to the higher energy efficiency. When embodied emissions and operational energy use emissions are assessed together, the cladding choice (wood or brick) does not affect the results. On the other hand, wood fibre insulation has a lower impact (0.1 $kgCO_2e/yr/m^2$ less) than mineral wool.

Table 35 displays the total GWP, embodied and operational energy emissions, of internally insulating (S2), changing windows (S3), and transforming the dementia wings to a dementia-friendly environment (S4) to improve the energy efficiency (S5) and the quality of life of the residents.

Considering NS3720, the dementia wing results indicate a GWP ranging between 14.1-18.6 $kgCO_2eq/year/m^2_{GFA}$ and 1014.6-1334.5 $kgCO_2eq/year/person$. Considering FBZ, the GWP varies between 12.9-17.5 $kgCO_2eq/year/m^2_{GFA}$ and 926.6-1258.7 $kgCO_2eq/year/person$. Compared to the *sykehjem* unit, the results follow the same pattern regarding material choices and calculation methods. The GWP of the renovation measures per meter is higher in the dementia wings but lower if it is calculated per user, due to the bigger ratio of square meters per user in the *sykehjem* (127.2 m^2/person) than in the dementia wings (71.9 m^2/person).

		Plasterboard (PB)		Clay board (CB)	
		Wood fibre (WF)	Mineral wool (MW)	Wood fibre (WF)	Mineral wool (MW)
PH		*SS.DW.01.01.01*	*SS.DW.01.02.01*	*SS.DW.01.01.01*	*SS.DW.01.02.01*
	NS 3720	14.1 $kgCO_2e/yr/m^2$	14.3 $kgCO_2e/yr/m^2$	14.1 $kgCO_2e/yr/m^2$	14.3 $kgCO_2e/yr/m^2$
		1014.6 $kgCO_2e/yr/pers$	1030.1 $kgCO_2e/yr/pers$	1012.3 $kgCO_2e/yr/per$	1028.0 $kgCO_2e/yr/per$
	FBZ	12.9 $kgCO_2e/yr/m^2$	13.1 $kgCO_2e/yr/m^2$	12.9 $kgCO_2e/yr/m^2$	13.0 $kgCO_2e/yr/m^2$
		926.6 $kgCO_2e/yr/pers$	940.5 $kgCO_2e/yr/pers$	924.8 $kgCO_2e/yr/pers$	938.8 $kgCO_2e/yr/pers$
TEK		*SS.DW.01.01.02*	*SS.DW.01.02.02*	*SS.DW.02.01.02*	*SS.DW.02.02.02*
	NS 3720	18.5 $kgCO_2e/yr/m^2$	18.6 $kgCO_2e/yr/m^2$	18.4 $kgCO_2e/yr/m^2$	18.6 $kgCO_2e/yr/m^2$
		1328.6 $kgCO_2e/yr/pers$	1336.7 $kgCO_2e/yr/pers$	1326.5 $kgCO_2e/yr/per$	1334.5 $kgCO_2e/yr/per$
	FBZ	17.4 $kgCO_2e/yr/m^2$	17.5 $kgCO_2e/yr/m^2$	17.4 $kgCO_2e/yr/m^2$	17.5 $kgCO_2e/yr/m^2$
		1253.7 $kgCO_2e/yr/pers$	1260.5 $kgCO_2e/yr/pers$	1251.9 $kgCO_2e/yr/per$	1258.7 $kgCO_2e/yr/per$

Table 35.Total embodied and operational energy GWP results in SS (dementia wings)

Table 36 displays the GHG emissions results per scenario. In the PH scenario, S5 (Energy performance) produces 87% of the GWP of the complete renovation, followed by changing windows in S3 (8%), upgrading the thermal envelope in S1 or S2 (3%) and transforming the unit in a dementia-friendly environment (1%). In TEK scenario, the influence of the operational energy emissions is even more crucial, producing 91% of the GHG emissions of the whole renovation due to the GWP of improving the thermal envelope is 40% smaller in TEK. PH standard requires thicker materials and better sealing; for this reason, the operational emissions are lower and the embodied emissions are higher in PH.

		Sykehjem								Dementia wings							
		Wood cladding (WC)				Brick cladding (BC)				Wood cladding (WC)				Brick cladding (BC)			
		WF		MW		WF		MW		WF		MW		WF		MW	
PH		*SS.SH.01.01.01*		*SS.SH.01.01.01*		*SS.SH.01.02.01*		*SS.SH.02.01.01*		*SS.DW.01.01.01*		*SS.DW.01.02.01*		*SS.DW.02.01.01*		*SS.DW.02.01.01*	
		NS 3720	FBZ	NS 3720	FBZ	NS 3720	FBZ	NS 3720	FBZ	NS 3720	FBZ	NS 3720	FBZ	NS 3720	FBZ	NS 3720	FBZ
	S1-2	0.34	0.14	0.42	0.20	0.36	0.17	0.44	0.22	0.84	0.36	1.06	0.56	0.81	0.34	1.03	0.53
	S3	0.92	0.62	0.92	0.62	0.92	0.62	0.92	0.62	2.32	1.59	2.32	1.59	2.32	1.59	2.32	1.59
	S4	0.22	0.06	0.22	0.06	0.22	0.06	0.22	0.06	0.22	0.06	0.22	0.06	0.22	0.06	0.22	0.06
	S5	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9
TEK		*SS.SH.01.01.02*		*SS.SH.01.02.02*		*SS.SH.02.01.02*		*SS.SH.02.02.02*		*SS.DW.01.01.02*		*SS.DW.01.02.02*		*SS.DW.02.01.02*		*SS.DW.02.02.02*	
	S1-2	0.21	0.08	0.25	0.11	0.23	0.11	0.27	0.14	0.53	0.24	0.65	0.33	0.51	0.22	0.62	0.31
	S3	0.92	0.62	0.92	0.62	0.92	0.62	0.92	0.62	2.32	1.59	2.32	1.59	2.32	1.59	2.32	1.59
	S4	0.22	0.06	0.22	0.06	0.22	0.06	0.22	0.06	0.22	0.06	0.22	0.06	0.22	0.06	0.22	0.06
	S5	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6

Table 36. Total GWP ($kgCO2e/yr/m^2$) in SS per scenario

The GWP of SS is displayed in Figure 38 for each life cycle module and calculation method. Almost all GWP is concentrated in B6 (Operational energy use), followed by A1-A3 (Product), B4 (Replacements) and C3 (Waste processing). D (Benefits and loads) is only present in the *sykehjem* because it considers the emissions that the PV panels compensate for. The calculation method does not significantly influence the GHG emissions results.

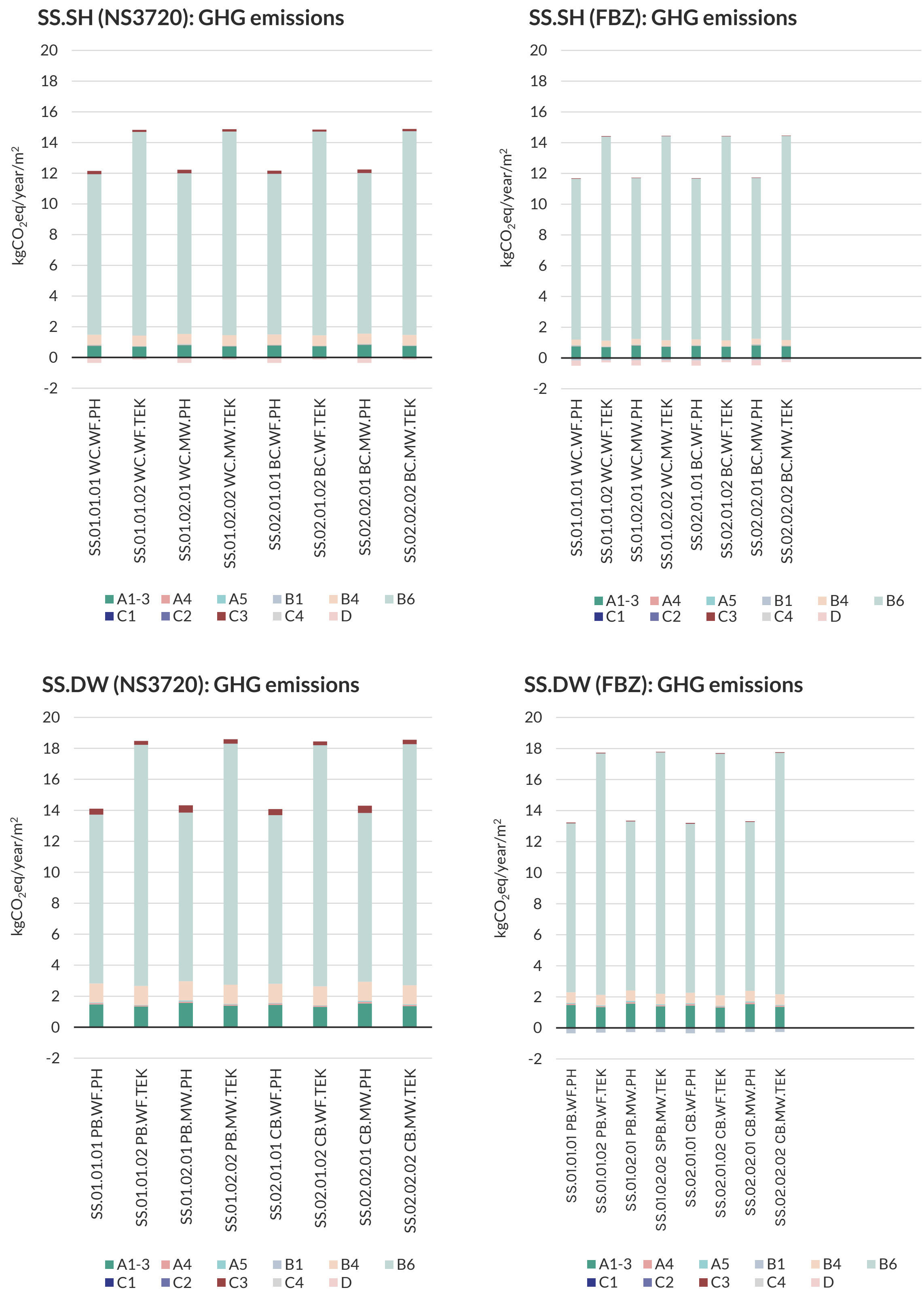


Figure 38. Total GWP results in SS per life cycle module and calculation method

5.2 Life cycle cost assessment

Table 37 shows the total costs, material, energy and labour costs, of externally insulating (S1), changing windows (S3), and transforming the *sykehjem* to a dementia-friendly environment (S4) to improve the energy efficiency of the unit (S5) and the quality of life of the residents. The costs are in NOK/yr/m² and NOK/yr/person. The cost range in the first year of operation (year 0) of the *sykehjem* varies between 7,871-8,241 NOK/m² in PH standard and 7,088-7,397 NOK/m² in TEK standard. The labour cost accounts for 50% of the total costs in PH and 57% in TEK.

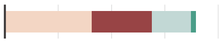
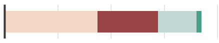
		Wood cladding (WC)		**Brick cladding (BC)**	
		Wood fibre (WF)	**Mineral wool (MW)**	**Wood fibre (WF)**	**Mineral wool (MW)**
PH		***SS.SH.01.01.01***	***SS.SH.01.02.01***	***SS.SH.02.01.01***	***SS.SH.02.02.01***
	S1	3,727	3,595	3,966	3,834
		474,197	457,455	504,573	487,832
	S3	2,590	2,590	2,590	2,590
		329,573	329,573	329,573	329,573
	S4	1,545	1,545	1,545	1,545
		196,632	196,632	196,632	196,632
	S5	140	140	140	140
		177,775	177,775	177,775	177,775
	SS				
		8,002 NOK/yr/m²	7,871 NOK/yr/m²	8,241 NOK/yr/m²	8,109 NOK/yr/m²
		1,018,177 NOK/yr/pers	1,001,436 NOK/yr/pers	1,048,554 NOK/yr/p	1,031,813 NOK/yr/p
TEK		***SS.SH.01.01.02***	***SS.SH.01.02.02***	***SS.SH.02.01.02***	***SS.SH.02.02.02***
	S1	3,257	3,187	3,495	3,425
		414,366	405,446	444,743	435,823
	S3	2,265	2,265	2,265	2,265
		288,230	288,230	288,230	288,230
	S4	1,454	1,454	1,454	1,454
		185,052	185,052	185,052	185,052
	S5	182	182	182	182
		23,094	23,094	23,094	23,094
	SS				
		7,158 NOK/m²	7,088 NOK/m²	7,397 NOK/m²	7,326 NOK/m²
		910,743 NOK/person	901,822 NOK/person	941,119 NOK/person	932,199 NOK/person

Table 37. Total costs in SS per scenario assessed (*sykehjem*)

Figure 39 displays the cost per scenario assessed in the first year of operation (year 0). Externally insulating (S1) the *sykehjem* unit has the highest economic impact, followed by changing windows (S3), the dementia-friendly renovation (S4) and the operational energy cost (S5). Scenarios with mineral wool and wood cladding show a lower material cost than scenarios with reused brick cladding and wood fibre.

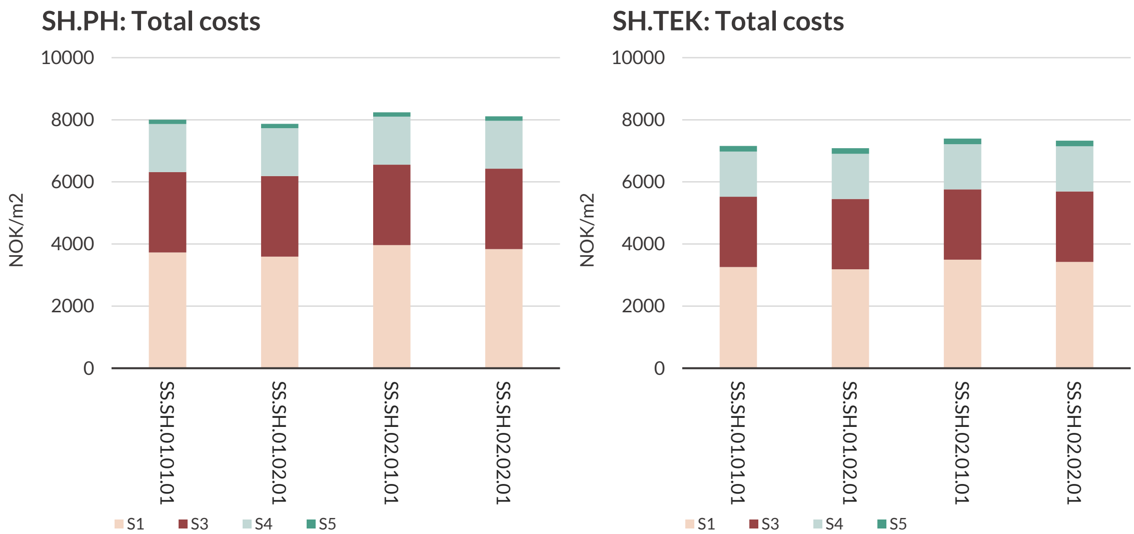


Figure 39. Total costs in SS per scenario assessed (sykehjem)

Table 38 shows the total costs, material, energy and labour costs, of internally insulating (S2), changing windows (S3), and transforming the dementia wings to a dementia-friendly environment (S4) to improve the energy efficiency of the unit (S5) and the quality of life of the residents. The costs are in NOK/yr/m^2 and NOK/yr/person. The cost in the first year of operation (year 0) of the dementia wings ranges between 18,459-19,120 NOK/m^2 in PH standard and 16,549-16,979 NOK/m^2 in TEK standard. The labour cost accounts for 59% of the total costs of the dementia wings in PH and 65% in TEK.

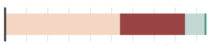
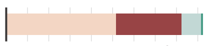
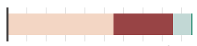
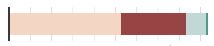
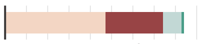
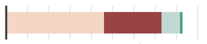
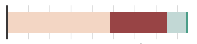
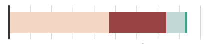
		Plasterboard (PB)		Clay board (CB)	
		Wood fibre (WF)	**Mineral wool (MW)**	**Wood fibre (WF)**	**Mineral wool (MW)**
PH		***SS.DW.01.01.01***	***SS.DW.01.02.01***	***SS.DW.02.01.01***	***SS.DW.02.02.01***
	S2	10,781	10,315	10,976	10,510
		775,577	742,037	789,588	756,048
	S3	6,159	6,159	6,159	6,159
		443,058	443,058	443,058	443,058
	S4	1834	1,834	1,834	1834
		131,972	131,972	131,972	131,972
	S5	150	150	150	150
		10,826	10,826	10,826	10,826
	SS				
		18,925 NOK/yr/m^2	18,459 NOK/yr/m^2	19,120 NOK/yr/m^2	18,653 NOK/yr/m^2
		1,361,433 NOK/yr/pers	1,327,893 NOK/yr/pers	1,375,444 NOK/yr/p	1,341,904 NOK/yr/p
TEK		***SS.DW.01.01.02***	***SS.DW.01.02.02***	***SS.DW.02.01.02***	***SS.DW.02.02.02***
	S2	9,451	9,216	9,646	9,410
		679,887	662,960	693,898	676,971
	S3	5,379	5,379	5,379	5,379
		386,966	386,966	386,966	386,966
	S4	1,739	1,739	1,739	1,739
		125,119	125,119	125,119	125,119
	S5	215	215	215	215
		15,471	15,471	15,471	15,471
	SS				
		16,784 NOK/m^2	16,549 NOK/m^2	16,979 NOK/m^2	16,744 NOK/m^2
		1,207,442 NOK/person	1,190,515 NOK/person	1,221,453 NOK/pers	1,204,526 NOK/pers

Table 38. Total costs in SS per scenario assessed (dementia wings)

Figure 40 displays the cost per scenario assessed in the first year of operation (year 0). Internally insulating (S2) the dementia wings has the highest economic impact, followed by changing windows (S3), the dementia-friendly renovation (S4) and the operational energy cost (S5). Scenarios with mineral wool and clay board show a lower material cost than scenarios with plasterboard and wood fibre. PH scenario is 12% more expensive than the TEK scenario due to the thicker construction components and better building sealing.

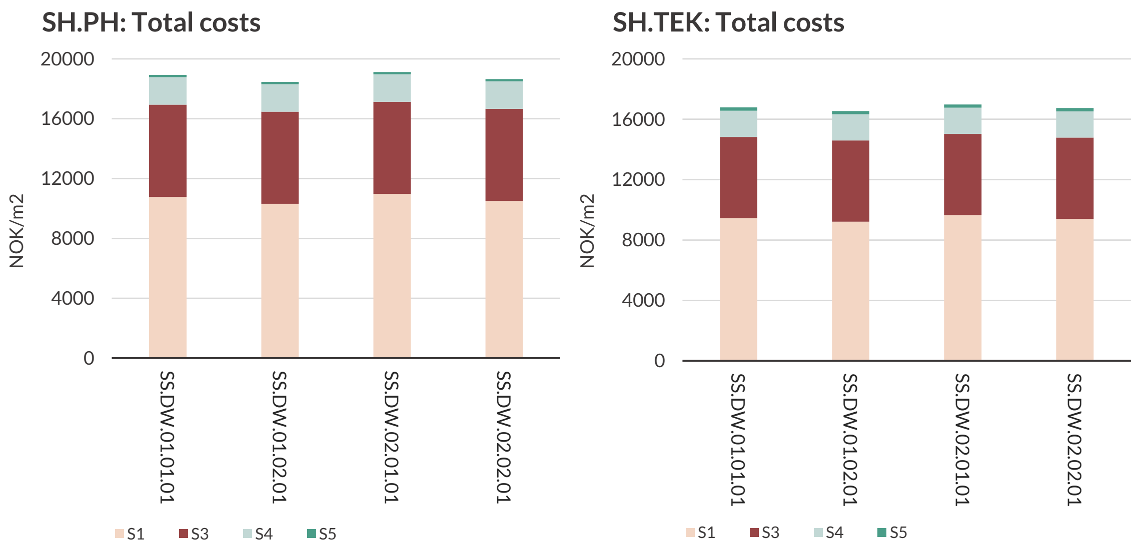


Figure 40. Total costs in SS per scenario assessed (dementia wings)

5.3 Break-even analysis

Figure 41 shows the break-even analysis of GHG emissions during 60 years (study period of the LCA) for PH and TEK standards, considering wood fibre and mineral wool insulation. The net balance line displays the GWP compensated by the PV panel production (credit exported PV line). Although TEK has around 50% less embodied emissions than PH before start using the building, the break-even point is reached in the 1.6-2.4 years of operation due to the impact of energy emissions on the GWP of both units. In year 60, PH saves 164 $kgCO_2eq/year/m^2_{GFA}$ in the *sykehjem*, and 270 $kgCO_2eq/year/m^2_{GFA}$ in the dementia wings.

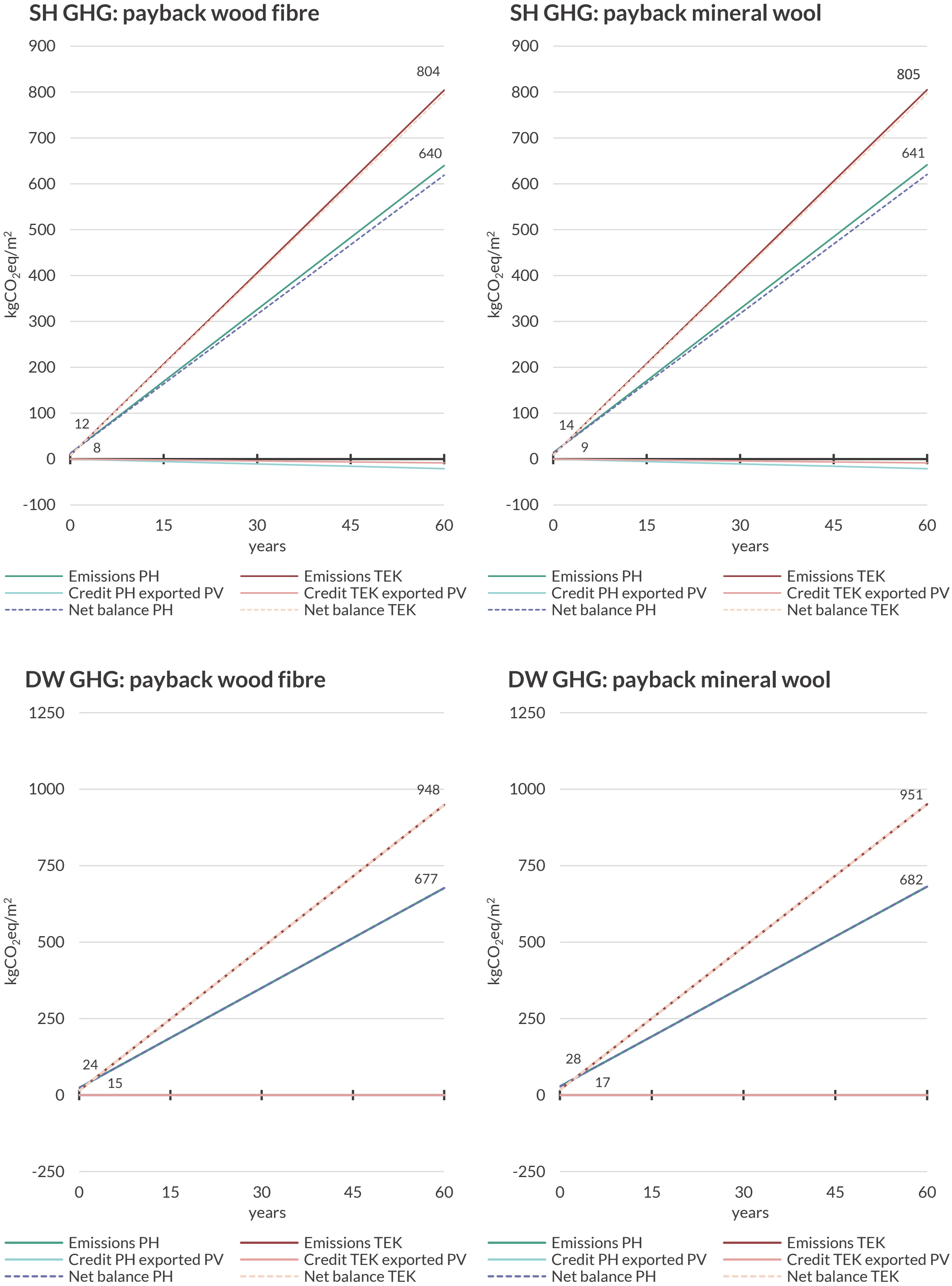


Figure 41. Emissions break-even analysis of TEK and PH for wood fibre and mineral wool

Figure 42 shows the cost break-even analysis during 60 years (study period) for PH and TEK standards, considering wood fibre and mineral wool insulation. The net balance line displays the cost compensated by the PV panel production (credit exported PV line). Although TEK has around 12% fewer material costs than PH in year 0, the break-even point is reached halfway through the building's life cycle due to the energy cost impact in both units. The break-even point of the *sykehjem* is 21.2 years for wood fibre and 19.7 for mineral wool. For the dementia wings, the break-even point is 34.2 (wood fibre) and 30.6 years (mineral wool). In year 60, PH saves 1,622-1,683 NOK/m^2 in the *sykehjem*, and 1,668-1,899 NOK/m^2 in the dementia wings.

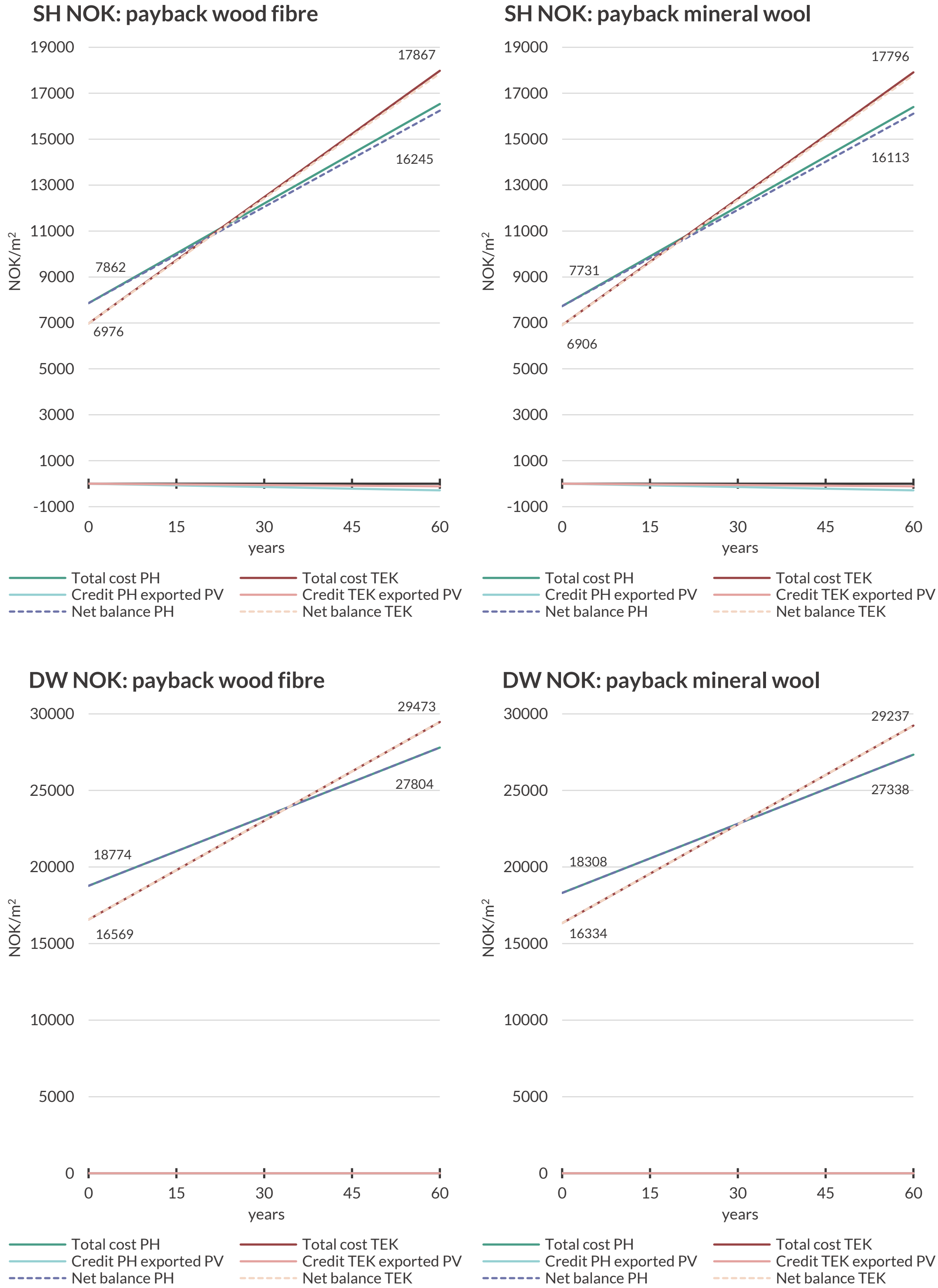


Figure 42. Total cost break-even analysis of TEK and PH standards for wood fibre and mineral wool

Table 39 summarise the savings and payback periods obtained on the previous GHG emissions and cost break-even analysis.

	Sykehjem				Dementia wings			
	Wood fibre (WF)		Mineral wool (MW)		Wood fibre (WF)		Mineral wool (MW)	
	Year 0	*Year 60*	*Year 0*	*Year 60*	*Year 0*	*Year 60*	*Year 0*	*Year 60*
GHG saved ($kgCO_2eq/m^2$)	-4.47	164.27	-5.16	163.59	-8.69	271.54	-11.01	269.22
NOK saved (NOK/m^2)	-886.16	1622.03	-824.70	1683.50	-2205.13	1668.63	-1974.20	1899.56
GHG payback (years)	1.59		1.83		1.86		2.36	
Cost payback (years)	21.20		19.73		34.15		30.58	

Table 39. GHG emissions savings, total cost savings and payback periods

Figure 43 compares the GHG emissions and costs of the operational energy before the renovation and after the proposed high energy-efficient measures in PH and TEK scenarios. For the break-even cost analysis, the renovation payback time is reached in 30 years for the *sykehjem* unit, while the dementia payback time is longer than the estimated service life of the building. For the break-even GWP analysis, both units lower the emissions of the baseline scenario in the first days of operation.

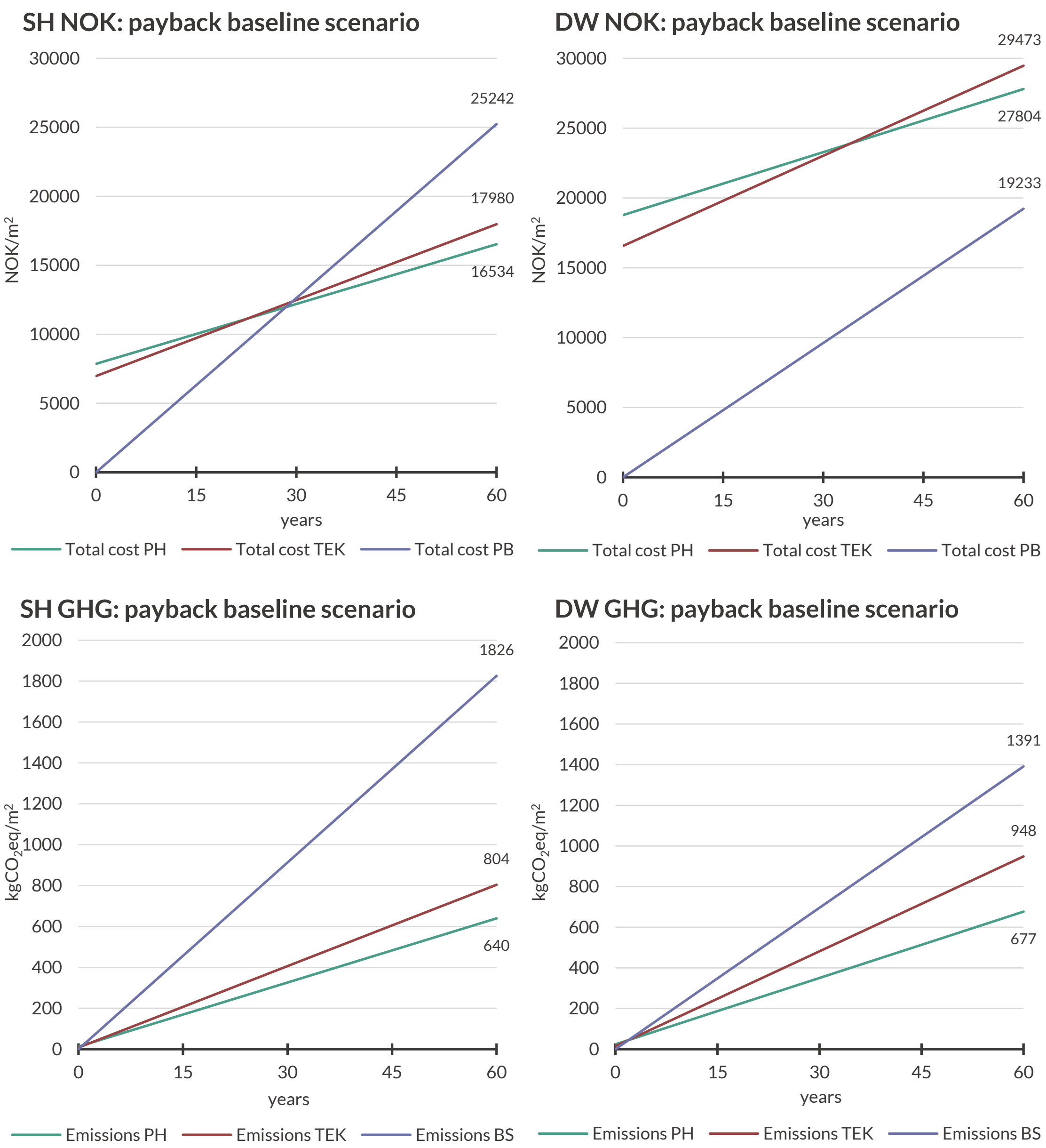


Figure 43. Break-even analysis (cost and emissions) between PH, TEK and BS

5.4 Environmental quality assessment

5.4.1 Baseline scenario

Table 40 shows the scores of the dementia wings and the *sykehjem* unit in Trondhjems Hospital before the renovation measures. The complete questions and the weighted score of the EAT-HC environmental audit tool are described in Appendix 6.

Dementia Enabling Environment Principles before the renovation		Dementia wings			Sykehjem		
		Actual Score	Max. Score	RFI Score	Actual Score	Max. Score	RFI Score
1	Unobtrusively reduce risks	7	18	11	11	18	7
2	Provide a human scale	3	4	1	2	4	2
3	Allow people to see and be seen	6	16	10	5	16	11
4	Reduce unhelpful stimulation	4	6	2	5	6	1
5	Optimise helpful stimulation	14	23	9	10	23	13
6	Support movement and engagement	8	9	1	7	9	2
7	Create a familiar place	6	8	2	8	8	0
8	Provide a variety of places to be alone or with others in the unit	9	10	1	7	10	3
9	Provide a variety of places to be alone or with others - In the community	3	3	0	3	3	0
10	Design in response to vision for way of life	6	6	0	4	6	2
	SUM	**66**	**103**	**37**	**62**	**103**	**41**

Table 40. EQA of the sykehjem and dementia wings in BS

Figure 44 displays the proportion of room for improvement (RFI) per key design principles analysed in the environmental assessment. On average, the dementia wings have less RFI (26.7%) than the *sykehjem* (31.6%), presenting a better built environment for people with dementia. The highest RFI ratios for both units are the design principles referring to the human scale, allowing people to see and be seen, unobtrusively reducing risks, and optimizing helpful stimulation. On the other hand, both built environments successfully support movement and engagement, create a familiar place, provide a variety of places to be alone or with others in the unit or the community, and respond to the nursing home's vision and residents' way of life.

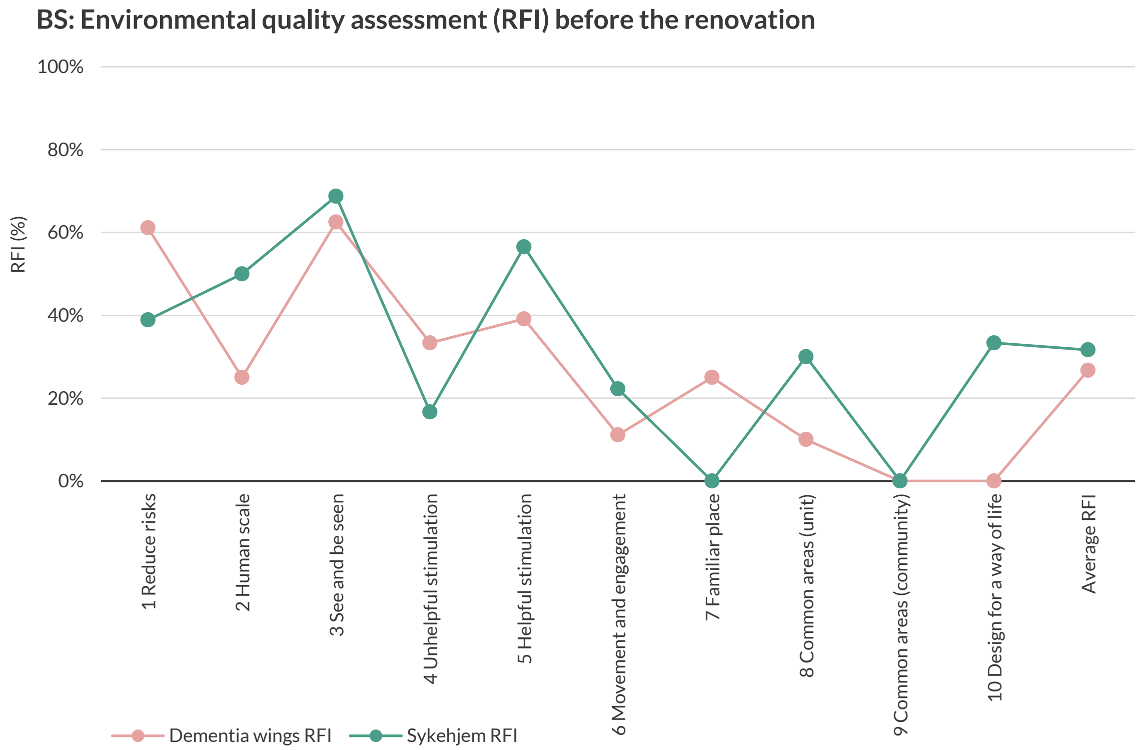


Figure 44. Room For Improvement (RFI) score in BS scenario (before renovation)

5.4.2 Summary scenario: Sustainable renovation

Table 41 shows the scores of the dementia wings and the *sykehjem* unit in Trondhjems Hospital after the renovation measures. The complete questions and the weighted score of the EAT-HC environmental audit tool are described in Appendix 6.

Dementia Enabling Environment Principles after the renovation		Dementia wings			Sykehjem		
		Actual Score	Max. Score	RFI Score	Actual Score	Max. Score	RFI Score
1	Unobtrusively reduce risks	8	18	10	13	18	5
2	Provide a human scale	3	4	1	3	4	1
3	Allow people to see and be seen	6	16	10	11	16	5
4	Reduce unhelpful stimulation	5	6	1	5	6	1
5	Optimise helpful stimulation	19	23	4	19	23	4
6	Support movement and engagement	8	9	1	9	9	0
7	Create a familiar place	8	8	0	8	8	0
8	Provide a variety of places to be alone or with others in the unit	9	10	1	10	10	0
9	Provide a variety of places to be alone or with others - In the community	3	3	0	3	3	0
10	Design in response to vision for way of life	6	6	0	6	6	0
	SUM	**75**	**103**	**28**	**87**	**103**	**16**

Table 41. EQA of the sykehjem and dementia wings in SS

Figure 45 displays the proportion of room for improvement (RFI) per key design principles analysed in the environmental assessment after implementing the dementia-friendly actions. After the renovation, the *sykehjem* has less average RFI (11.8%) than the dementia wings (19.8%), presenting a better built environment for people with dementia. The most considerable reductions of the RFI ratios for both units are the design principles that refer to reducing risks, optimising helpful stimulation, creating a familiar place and providing a variety of places to be alone or with others in the unit. The dementia principle 'allow people to see and be seen' is only improved in the *sykehjem* unit because the questions are related to the architectural layout, which is not altered in the dementia wings.

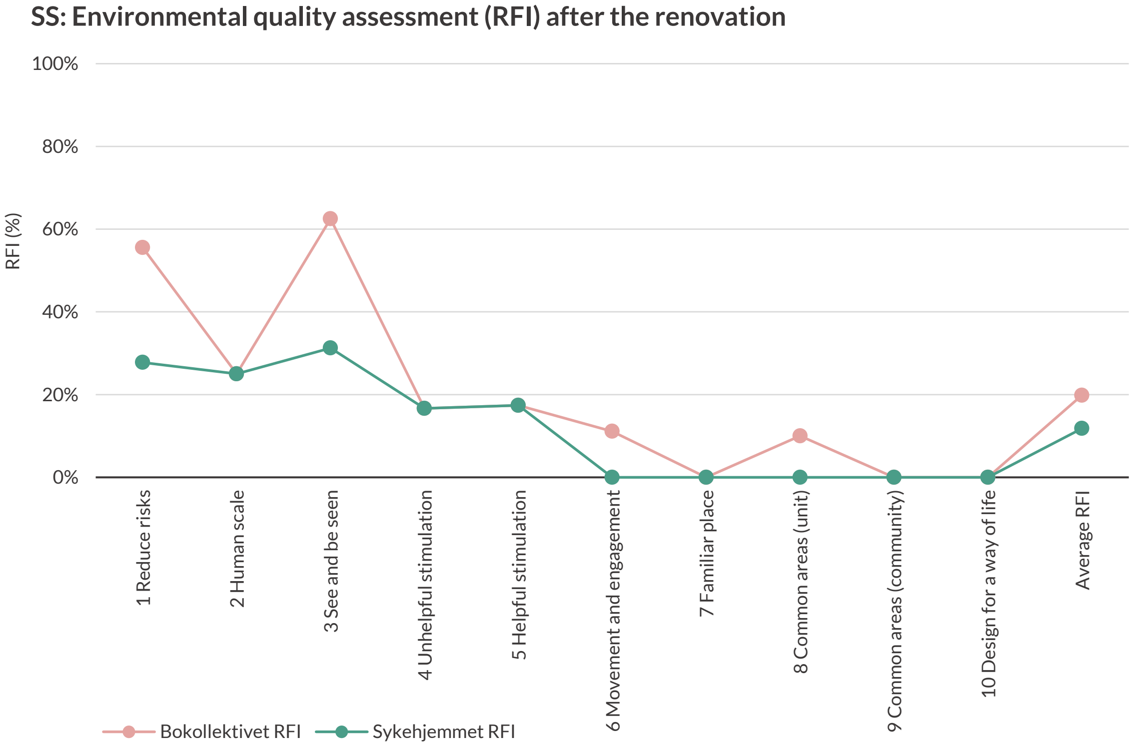


Figure 45. Room For Improvement (RFI) score in SS scenario (after renovation)

6 Discussion

The discussion section addresses the influence of the methodological assumptions in the calculations performed in the life cycle assessment (LCA) and the life cycle cost analysis (LCCA): the energy and material price, the CO_2 energy emission factors, the material choices to improve the thermal envelope (cladding and insulation), the calculation method (NS 3720 or FBZ), and the energy standard (Passive House or TEK17).

Lastly, the results obtained are discussed in relation to the research questions (RQ) stated in the introduction, taking into consideration the limitations and future work of the thesis.

6.1 Influence of methodological assumptions

6.1.1 Energy and material price

The LCCA of Trondhjems Hospital offers valuable information for project developers and construction companies about the payback time of more expensive building solutions in terms of construction cost, but more affordable regarding operational cost due to their higher energy efficiency. Withal, the LCCA analysis only provides a snapshot of the cost at a specific time without considering price fluctuations of building materials and energy.

Norwegian energy prices have changed over the last three years (Figure 46), reaching their maximum in the third quarter of 2022, with an electricity cost (excluding taxes) of 226 øre/kWh [242]. The surge in European energy prices is due to several factors, such as economic activity picking up after the COVID-19 pandemic, lower gas supplies, unfavourable conditions to produce renewable energy, increased carbon prices, and Russia's invasion of Ukraine [243].

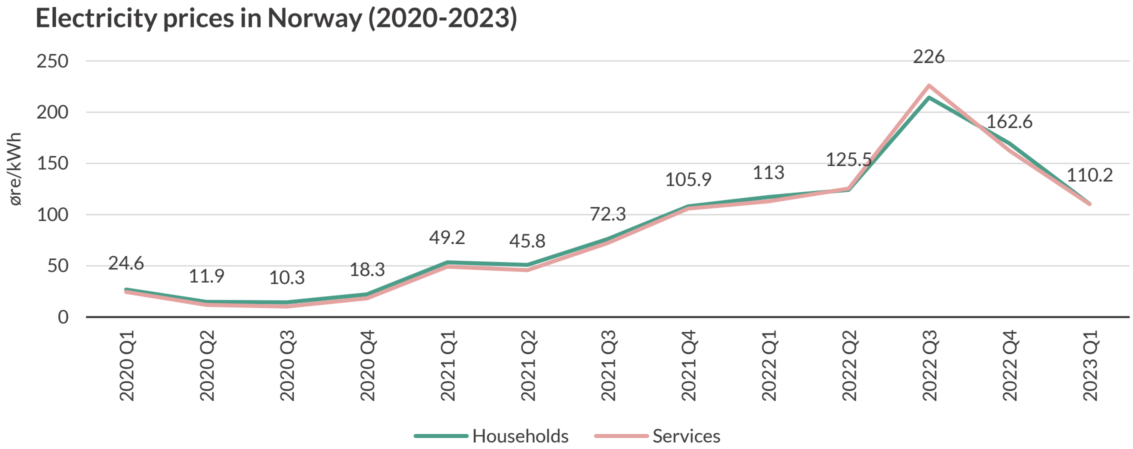


Figure 46. Electricity prices in Norway (2020-2023) [242]

In Norway, building materials and labour costs have also increased constantly over the last three years (Figure 47). The construction cost index (CCI) is an indicator that shows the cost tendency of new residential buildings. The Norwegian CCI of labour cost has grown by 10% since 2020, while the material cost has risen by 30% [244] due to supply chain disruptions after the COVID-19 pandemic and high energy prices.

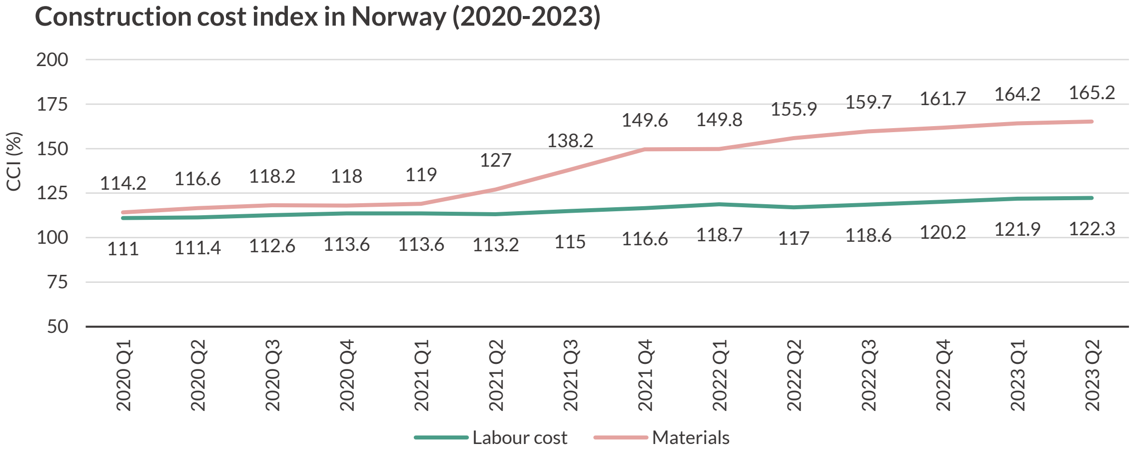


Figure 47. Construction cost index (CCI) in Norway (2020-2023) [244]

For this reason, a static LCCA might not be accurate if the prices keep fluctuating. However, it could also be argued that the electricity price used in the LCCA of Trondhjems Hospital (188 øre/kWh) is a conservative assumption that can cover future increases in electricity prices. On the other hand, European governments are releasing policies (REPowerEU plan) to lower the electricity cost for households and companies by saving energy, producing clean energy and diversifying energy supplies [243]. All things considered, there is high uncertainty about how the energy market and electricity prices will behave in the following years. Future work on this subject could involve a sensitive life cycle costing analysis to investigate the payback times when energy and material price fluctuation are considered.

6.1.2 Emission factor

The results obtained in the summary scenario (SS) show energy's crucial impact on the building's operation during its entire life cycle, both in terms of GHG emissions (environmental impacts) and total costs (economic impacts).

The CO_2 emission factor for electricity from the grid assumed in the thesis is 136 gCO_2eq/kWh, as the ZEB Research Centre recommends. ZEB has a conservative CO_2 factor that takes into account the GHG emissions from the European consumption mix (309 gCO_2eq/kWh) and the Norwegian mix (18 gCO_2eq/kWh). Although the Norwegian energy system has extremely low carbon emissions due to the contribution of hydropower (2-20 gCO_2eq/kWh), Norway is integrated into the Nord Pool power market, which has a CO_2 emission factor of 100 gCO_2eq/kWh. Furthermore, the research centre considers a scenario where Norway will become more integrated into the European power grid. If a yearly decrease in the European CO_2 factor (309 gCO_2eq/kWh) is assumed due to climate neutrality policies (Eurostat and EU's Roadmap 2050), the average weighting factor from 2015 to 2075 period would be 136 gCO_2eq/kWh [2], [210].

However, the research centre has an ongoing discussion about the electricity weighting factor that should be used. When high CO_2 factors are implemented in the GHG emissions calculations, operational emissions dominate embodied emissions, whilst low CO_2 factors cause the opposite effect. Therefore, the total GWP of a building is strongly influenced by the weighting factor chosen for electricity, as can be seen from the environmental impact results in Trondhjems Hospital [186].

If the calculation assumed that Norway is an isolated energy system (Scenario 1 – NO of NS 3720:2018), instead of the European consumption mix (Scenario 2 – EU28+NO from NS 3720:2018), the CO_2 factor for electricity from the grid would be 18 gCO_2eq/kWh [210]. With the Norwegian consumption mix, the operational GHG emissions in S5 would have been 87% lower (Figure 48), decreasing the operational energy GWP from 10.1-15.6 $kgCO_2eq/year/m^2_{GFA}$ to 1.3-1.8 $kgCO_2eq/year/m^2_{GFA}$.

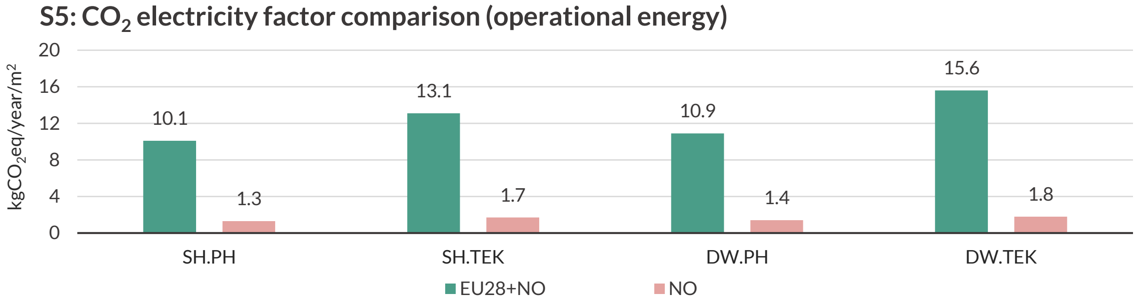


Figure 48. Comparison of operational energy emissions with EU28+NO and NO CO_2 factor

For the summary scenario (SS), Figure 49 shows the complete reduction of GHG emissions when the Norwegian consumption mix is assumed. The GWP of the renovation measures is 75% lower with a CO_2 factor of 18 gCO_2eq/kWh, reducing the CO2 emissions from 11.2-18.5 $kgCO_2eq/year/m^2_{GFA}$ to 2.4-4.7 $kgCO_2eq/year/m^2_{GFA}$. In the EU28+NO mix, the embodied emissions account for 15% of the total GWP of the renovation. In contrast, when the NO mix is considered, the operational energy emissions are balanced with the embodied emissions in a 55-45 proportion, respectively.

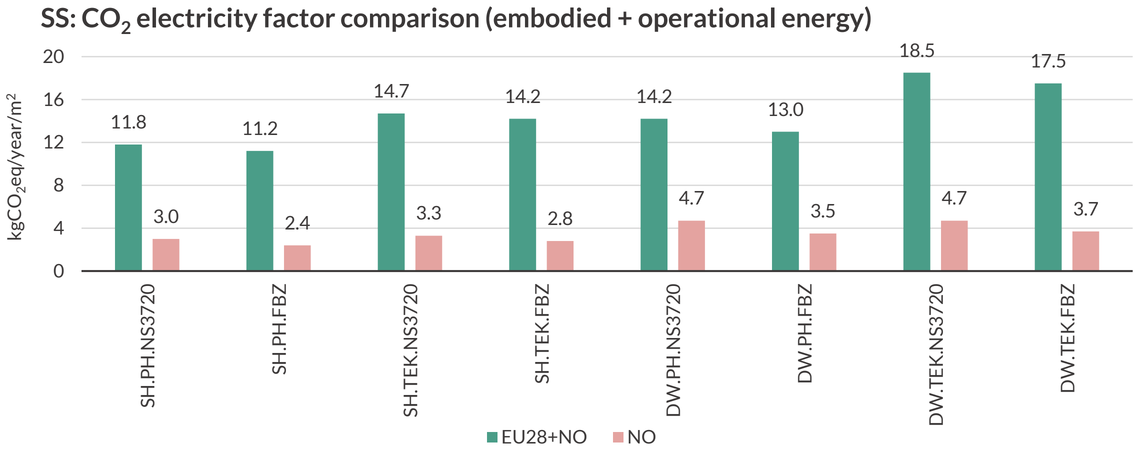


Figure 49. Emission comparison (embodied + operational) with EU28+NO and NO CO_2 factors

The choice of the CO_2 factor affects the GWP but not the possibility of reaching ZEB ambition levels. If the embodied and operational emissions are 75% lower in the NO mix scenario, the building's renewable production will also need to compensate for 75% lesser emissions from the life cycle of the building. The CO_2 factor would only determine how larger the renewable energy installation has to be if the factors for delivered energy and PV panel production are different.

The weighting factor also affects the payback periods of energy standards. If the operational emissions are 87% lower in the NO mix scenario, the importance of having a highly energy-efficient building is slightly reduced. The PH payback period is around 1.5-2.5 years with the EU28+NO emission factor and 12-14 years with the NO emission factor.

6.1.3 Material choice

Insulation is the material choice with the highest impact on the CO_2 emissions results in Trondhjems Hospital. The LCA focuses on mineral wool and wood fibre insulation because mineral wool is the most widespread insulation in the construction industry, and wood fibre is a common insulation material in Norwegian passive house buildings due to its low environmental impact.

The GWP results show that wood fibre has 20% to 36% fewer emissions than mineral wool insulation, depending on the calculation method. The difference between the insulation GWP is less in TEK than in the PH scenario because PH uses almost double the amount of insulation. In terms of material costs, the LCCA findings show that wood fibre is 30% more expensive than mineral wool, which increases the total costs by 4% in PH scenarios and 3% in TEK scenarios.

For this reason, although wood fibre insulation is more costly than mineral wool, the impact of the insulation price on the total construction cost is not that significant. If the break-even analysis of costs and emissions is taken into consideration, the mineral wool cost payback period is one and a half years early for the *sykehjem* and three and a half years early for the dementia wings. The GWP payback period is almost the same for both insulations (1.6-1.9 years for wood fibre and 1.8-2.4 years for mineral wool) because the operational energy emissions account for 85% of the total GHG emissions of the renovation. Considering the Norwegian consumption mix CO_2 factor (18 gCO_2eq/kWh), wood fibre has a shorter payback period (12 years) than mineral wool (14 years).

Regarding external cladding in S1 and internal cladding in S2, the GHG emissions and material costs are quite different when isolated, as shown in Appendix 5. However, the strong influence of insulation on the environmental and economic impacts of construction materials, added to the crucial effect of operational energy emissions in the total GWP of the renovation, diminishes the importance of the cladding choice. Lower CO_2 emission factors can increase its contribution.

Apart from insulation and cladding choice, the estimated service life, transport distance and wastage of a product can affect the GWP of the renovation. A more detailed LCA could also look into long-lasting materials to diminish the need for replacements (B4) local materials to decrease emissions during transportation (A4), prefabricated and easy-to-assemble products to reduce installation emissions (A5) and waste processing (C3).

Implementing recycled materials and design proposals that plan for the future reuse of construction products also contributes to lower the overall environmental impact. Future work on this matter can focus on working with the municipality to implement reused construction products from demolished buildings in Trondheim.

6.1.4 Calculation method

Due to the impact of embodied energy emissions on the total GWP of Trondhjems Hospital, choosing NS3720 or FBZ as the calculation method does not affect the results significantly because the operational energy emissions were directly reported in life cycle modules B6 and D. This decision was taken due to the fact that Reduzer is still being developed. The software cannot yet perform dynamic operational energy emission calculations, and instead, the GWP was calculated with CO_2 emissions factors solely.

However, if the energy emissions calculations were performed according to FBZ, the break-even analysis should have included a time weighting factor. As explained in the methodology section, FBZ is a dynamic LCA calculation method in which the GWP is weighted depending on when it was emitted. The time horizon factor defines the period (usually 100 years) when emissions effects will be accounted for. The further into the time horizon period the emissions occur, the less GWP will be allocated. Therefore, the choice of the calculation method might also impact the operational energy emissions [245].

In partial scenarios where only embodied emissions from materials were considered (S1, S2, S3 and S4), the calculation method plays an important role in evaluating GHG emissions. The methodology is especially significant in products that contain wood due to the different approaches to biogenic carbon. In NS3720, there are no emissions from the biogenic carbon. In FBZ, the biogenic carbon is uptaken and limited to a maximum offset of the sum of combustion emissions and 75% of product emissions [245]. For this reason, scenarios with wood cladding and wood fibre insulation have 40% lower emissions than those with mineral wool and brick cladding using FBZ calculation method and the same energy standard. In NS3720, the percentage of saved emissions is reduced to 23%.

The different methods to assess carbonation uptake can also impact the GWP of the renovation. However, no product containing cement was used in the building components. Future work on this subject can evaluate the environmental and economic impact of demolishing concrete structures or using low-carbon concrete in nursing home extensions.

6.1.5 Energy performance and standards

The biggest challenge of Trondhjems Hospital's energy calculations was the lack of information about the actual energy performance of the building. The baseline scenario in the LCA responds to this problem by assuming the building component's U-values and energy carriers' efficiency to simulate the energy performance in Simien. Hence, the obtained energy use (264.6 kWh/m^2/year in the *sykehjem* and 278 kWh/m^2/year in the dementia wings) and delivered energy (281.1 kWh/m^2/year and 202.1 kWh/m^2/year, respectively) might not be accurate. However, the current energy performance of Trondhjems Hospital does not influence the GHG emissions or cost analysis of the renovation proposal because the LCA and LCCA solely evaluate the new components, U-values and energy carriers.

Besides the CO_2 factor, the energy standard selection is the methodological assumption that significantly influences the GWP and cost results. Considering the CO_2 embodied emissions, PH scenarios have a higher environmental impact (around 40% more) due to thicker building components (around the double insulation than TEK standard) and better sealing (60% less air leakage and 67% fewer thermal bridges according to requirements). If the total GWP is taken into account (embodied and operational energy emissions), the higher energy efficiency in PH compensates for the greater embedded material emissions. Global CO_2 emissions are 20% smaller in PH than in TEK standard.

The same situation happens in the life cycle costing analysis. PH scenario is 12% more expensive due to the high energy-efficiency requirements and larger labour costs. As explained in the LCCA methodology, TEK uses a 6.3 working hours/m^2 factor while PH employs 6.6 hours/m^2. The factors have a 50% reduction for scenarios S3 and S4. Nevertheless, when the whole life cycle of the building is evaluated, the break-even cost analysis shows a payback period of approximately 20 years in the *sykehjem* and 30.5-34 years in the dementia wings. Thus, PH is more costly at the beginning of the building operation, but the superior energy efficiency recovers the investment halfway through the building's life cycle. By the end-of-life stage, PH has saved around 1,700 NOK/m^2).

However, PH construction requirements might not be achievable in all renovation projects. If the pos-insulation is done internally due to regulation constraints (the building is part of cultural heritage or the municipal laws protect the façade aesthetics), the gross internal area (GIA) will be significantly reduced. In the case of the dementia wings, the GIA is reduced by 5.5% with the TEK standard, and decreased by 11.5% using the PH standard. Future work on this matter could investigate the percentage of GIA cut down in PH and TEK for different geometries and building typologies in order to assess if the internal insulation measures are feasible in all nursing homes in Trondheim, according to the *Functional and area program* [162].

6.2 Climate-neutral dementia-friendly nursing homes in Norway

6.2.1 RQ1: Environmental and economic benchmarks

The benchmark values analysed in the environmental perspective section are from Enova for the GHG emissions and from the Norwegian price book for total costs. Figure 50 compares the results obtained in the *sykehjem* and the dementia wings. The GWP of the sykehjem is below the benchmark of renovated low-energy buildings for both energy standards and calculation methods. With the PH scenario and NS3720, the CO_2 emissions are 47% lower than the benchmark, 60% smaller in the case of the TEK scenario and FBZ calculation method. The renovation in the dementia wings is also below the renovated low-energy building's benchmark. However, the PH scenarios with both calculation methods produce more emissions on A1-3 module (1.35 $kgCO_2eq/year/m^2_{GFA}$) than the recommended value (1.25 $kgCO_2eq/year/m^2_{GFA}$). The overall benchmark is achieved due to the lower emissions on modules A4 and B4.

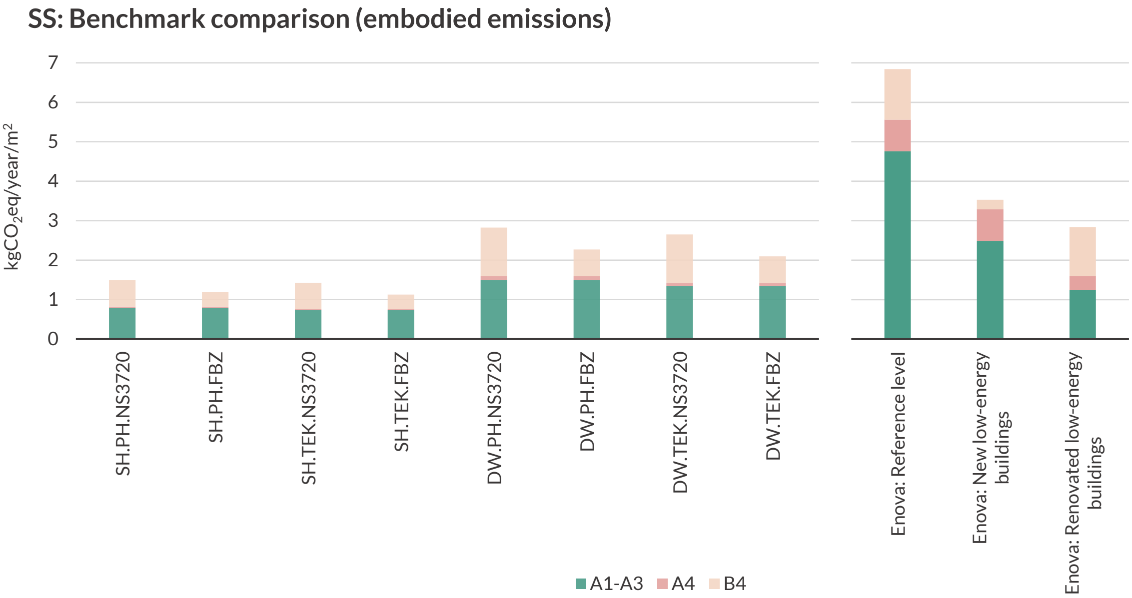


Figure 50. Benchmark comparison (embodied emissions)

Therefore, the renovation project developed in the *sykehjem* and the dementia wings fulfil the embodied emissions benchmarks for renovated low-energy buildings. This situation reinforces the argument that the intervention in Trondhjem Hospital's units successfully satisfies zero-emission requirements, but the high CO_2 factors and the impossibility of having renewable energy production in the building hamper the nursing home from reaching the ZEB ambition level.

Regarding economic benchmarks, the reference values obtained from the Norwegian price book are based on material costs for new buildings with TEK and PH standards. The material cost of the *sykehjem*'s renovation is 73% lower for the PH benchmark and 80% smaller for the TEK reference. In the case of the dementia wings, the reduction is 50% (PH) and 60% (TEK). Research literature about the costs of renovating versus demolishing and building new found that renovations have a cost saving of 30-40% compared to new constructions [246]. Therefore, the obtained results might be too optimistic. However, it can also be argued that the cost analysis does not include VAT; if added, the material cost would be increased and closer to the reference values from the literature.

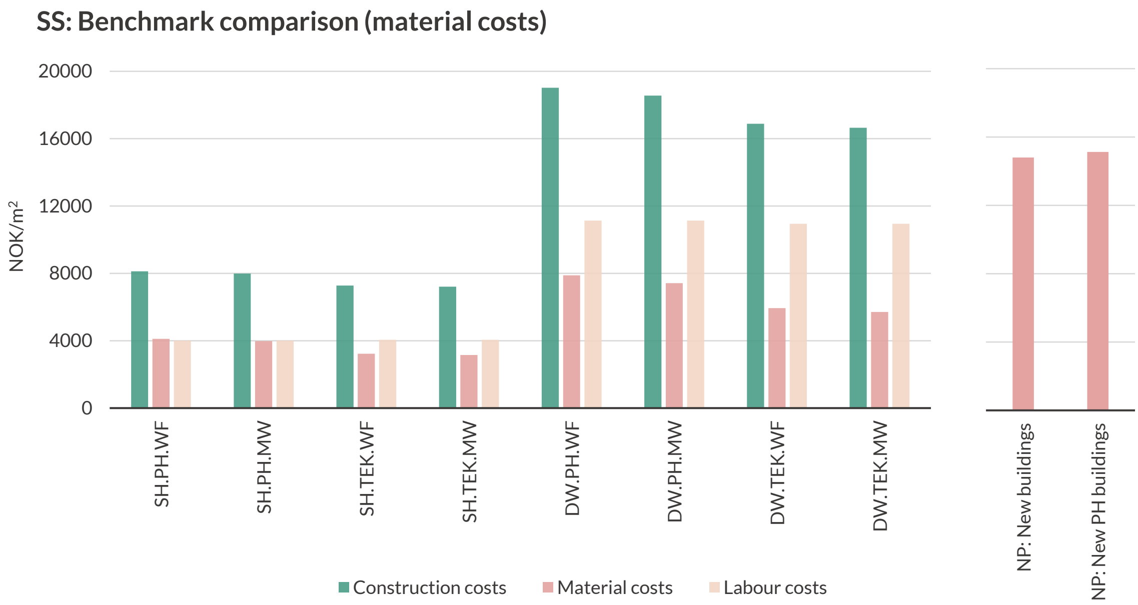


Figure 51. Benchmark comparison (material costs)

6.2.2 RQ1: Renovating the Norwegian nursing home stock

Compared with the available benchmarks, the low-impact renovation measures in Trondhjems Hospital have proved that renovating an existing nursing home is less costly from an economic and environmental perspective.

However, there are no reference values to assess the CO_2 emissions of renovating nursing homes. The studied benchmarks are general indicators for all types of renovation projects, but they do not address the particularities of the building typology. Most benchmarks are focused on evaluating new residential buildings [247], while public building refurbishment is left behind. Furthermore, the PH standard is mainly implemented in new nursing homes, and old facilities are being demolished instead of transformed into dementia-friendly environments.

Norwegian nursing homes are well-known for their quality of life among residents and staff. The quick response to the COVID-19 pandemic demonstrated its spatial quality and architectural resilience against emergencies. With all, care homes are not prepared to host more dependent older adults suffering from physical and cognitive impairments, as expected in the following decades. Nursing home designs from the past century do not consider how people with dementia perceive the built environment and, consequently, can negatively impact the well-being of their residents. The literature review about the effects of the built environment on patients with dementia reveals that low-impact measures, such as improving the homelike feeling or changing colours, materials and textures, can have a meaningful effect on their orientation and comfort.

Taking everything into consideration, the current nursing home stock in Norway offers an excellent framework to convert the existing non-specific units to dementia-friendly environments while saving emissions and economic resources. Figure 52 shows the estimated economic impact of renovating Norway's nursing home stock to reach climate-neutralilty by 2050. The calculation considers the cost per square meter of the *sykehjem* (8,000 NOK/ m^2) and the dementia wings (18,800 NOK/ m^2) in PH scenario and two estimated renovation rates (50% and 75%) of the building stock. According to Enova's building report from 2017, nursing homes in Norway have an average of 5,387 m^2. Taking into account the 923 nursing homes in Norway, the total number of square meters to renovate is 2,486,101 m^2 (50% renovation rate) and 3,729,151 m^2 (75% renovation rate).

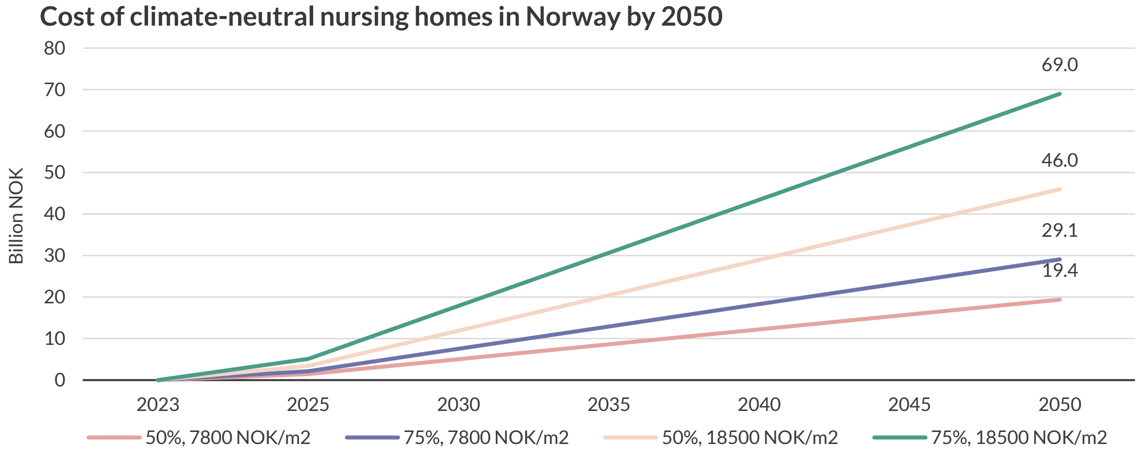


Figure 52. Cost of climate-neutral nursing homes in Norway by 2050

The yearly cost of achieving climate neutrality in Norwegian nursing homes is 0.7 billion NOK/year in the best-case scenario (7,800 NOK/m^2) and 2.5 billion NOK/year in the worst-case scenario (18,500 NOK/m^2). The total cost reached in 2050 would be between 19.4 and 69 billion NOK.

6.2.3 RQ2: ZEB ambition levels

The ZEB Research Centre states that a zero-emission building (ZEB) produces enough renewable energy to compensate for the building's greenhouse gas emissions over its life span [185]. The results obtained in the LCA of the *sykehjem* unit show a GWP of 11.2 kgCO_2eq/year/m^2_{GFA} in the best-case scenario (wood cladding with wood fibre insulation using FBZ calculation method) using PH standard (Figure 53). TEK has a lower environmental impact, but buildings aiming for ZEB ambition level must satisfy at least the PH energy requirements. The CO_2 emissions are reduced to 11.1 kgCO_2eq/year/m^2_{GFA} (ZEB-COM), 11.0 kgCO_2eq/year/m^2_{GFA} (ZEB-OM) and 10.1 kgCO_2eq/year/m^2_{GFA} (ZEB-O) for the different ZEB definitions.

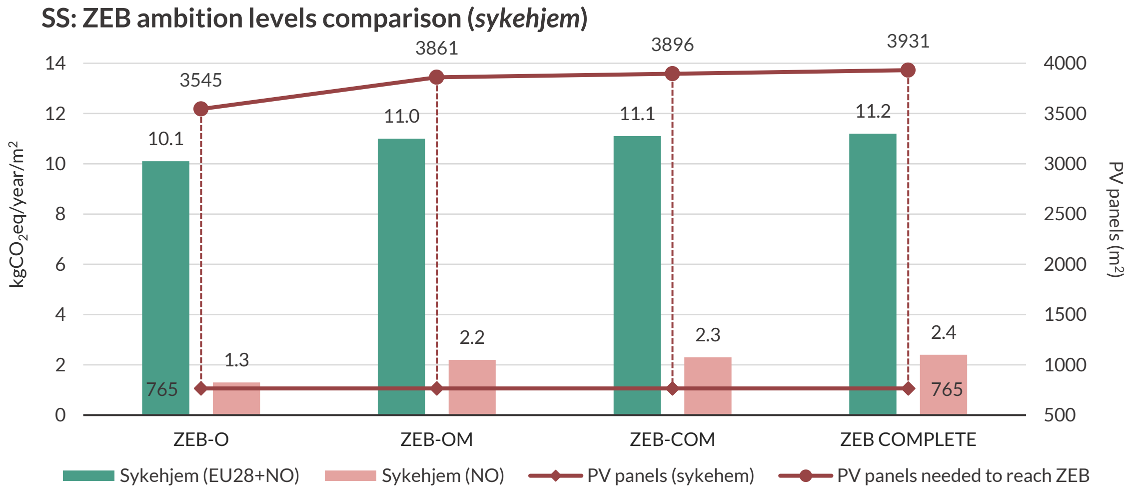


Figure 53. ZEB ambition levels comparison (sykehjem)

The *sykehjem* unit cannot reach the ZEB ambition level for any ZEB definition because it only has space for 765 m^2 of PV panels on the roof, which is insufficient to compensate for the building's greenhouse gas emissions. Figure 53 represents the amount of PV panels required to compensate for the renovation of the *sykehjem* unit. The square meters needed range between 3,545 and 3,931 m^2. In terms of scale, the PV installation to offset emissions would have to be around the size of Hospitalskirka Park if the ZEB-O definition is considered. For ZEB COMPLETE, the photovoltaic installation would need to have the size of the park and the elderly-apartment complex west of Hospitalskirka (Kongens gate 72).

The dementia wings are even farther away from ZEB ambition levels. The buildings do not have a PV panel installation because the façades and roofs are protected by the Norwegian Directorate for Cultural Heritage Management. Figure 54 represents the GHG emissions of the dementia wings in the best-case scenario in PH standard (plasterboard or clay board with wood fibre insulation using FBZ calculation method) for EU28+NO and NO consumption mix.

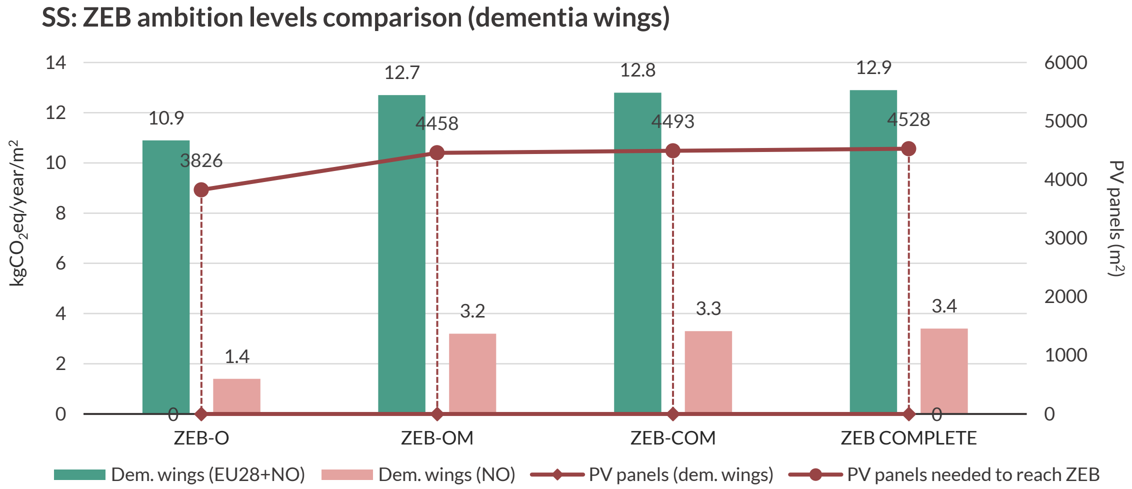


Figure 54. ZEB ambition levels comparison (dementia wings)

The PV panels required to reach ZEB ambition levels are 3,826 m^2 for ZEB-O and 4528 m^2 for ZEB COMPLETE definition. The size of the PV panel installation would need to have the same footprint as Trondhjems Hospital.

The results from the *sykehjem* unit and the dementia wings demonstrate how challenging it is to renovate a building to become zero emissions or zero energy. Although embodied emissions could be reduced, to a certain extent, using locally sourced, long-lasting, and easy-to-assemble recycled and reused material, the CO_2 emissions are principally released by the operational energy (B6). Nursing homes that need to be renovated cannot host sizeable renewable energy production technologies, especially if the building is situated in an urban context like Trondhjems Hospital.

Therefore, achieving a climate-neutral nursing home stock in Norway depends on lowering the GWP of the delivered energy to the building rather than improving the construction's energy efficiency. Renewable energy production should be addressed on a neighbourhood or municipal scale. For this reason, the former ZEB Research Centre was transformed into the FME-ZEN Research Centre to reach zero-emission neighbourhoods (ZEN) instead of zero-emission buildings (ZEB). In these Smart Cities and Communities (SCC), the goal of reducing GHG emissions towards zero is tackled holistically from the early design, detailed design, construction and operational phases, involving researchers, partners and users in the development. Besides lowering the GWP, ZEN aim to become energy efficient by using renewable energy, managing flexible energy flows, promoting sustainable transport and economics and stimulating sustainable behaviour thanks to cooperation and innovation. The scope of ZEN is translated into seven key performance indicators (KPI).

In Trondheim, the *Quality programme for Nyhavna* by Trondheim Kommune and Trondheim Havn presents the Nyhavna master plan's strategic goals, which include reaching the ZEN ambition level through local thermal energy production, district heating and energy exchanges with ZEB buildings in Brattøra area [248]. Future work on this subject could involve connecting nursing homes to district heating and promoting energy exchanges between municipal buildings. New renewable energy production technologies can also be implemented, such as seawater heat pump systems, geothermal heat pumps, and building-integrated wind turbines.

6.2.4 RQ3: Dementia-friendly environments in Norway

The renovation of Trondhjems Hospital is not solely focused on reducing environmental and economic impacts but also on improving the holistic well-being of residents and workers. The measures to achieve a dementia-friendly environment, calculated in S4, have the lowest GWP of all scenarios analysed. In total, the measures account for 1-2% of the total emissions (operational and embodied) and 5-15% of the embodied emissions, depending on the calculation method. The emissions in S4 with FBZ methodology are 70% smaller than in NS3720 because most renovation actions implement wood materials.

Despite the low GWP of S4, enhancing the environmental quality can have a substantial positive effect on the daily life of people with dementia living in nursing homes. The EQA shows a 26% improvement in the dementia wings and a 63% in the *sykehjem*. The higher environmental quality increase in the *sykehjem* is due to the greater alteration of the unit, which included medium to heavy conversion measures such as demolishing partitions, adding new windows and creating common areas in the corridors. Dementia wings are also hampered in the EAQ because the unit is not accessible. However, the staff has stated that the unit's human scale and home-likeness positively affect the patient's well-being and quality of life, compared to the *sykehjem* users. The results from the EQA in the dementia wings open several crucial discussions about prioritising accessibility and fulfilling the building regulation counter to creating a home-like environment for patients with dementia. Many modern nursing homes have the same design as a hospital in terms of scale, material choice, decoration and internal layout because they need to satisfy regulatory requirements. The dementia-friendly renovation in the *sykehjem* has demonstrated that achieving higher levels of spatial quality in previous hospital-like environments is possible. Nonetheless, building codes need to be reviewed to cover the particular needs of vulnerable groups. Care homes for patients with dementia require a specific dementia-friendly construction regulation.

On the other hand, several questions from the EQA were focused on the outside areas. In Trondhjems Hospital, the outdoor spaces were not renovated because residents and staff were satisfied with their quality. To lower the RFI in the EQA even more, further work on this matter could include an LCA and LCCA scenario about creating dementia-friendly courtyards.

Another crucial issue about renovating nursing homes in Norway is the current tendency of deinstitutionalising the health care system, allowing older people to age in place. Institutional-based care has been heavily questioned in the last decades. Nursing home residents live in a mono-generational isolated setting which can decrease their physical and mental health. Future work could investigate intergenerational housing typologies (Figure 55) that can be integrated into Norway's renovated nursing home stock. In a student town like Trondheim, nursing homes and student residences could be transformed into intergenerational communities for students and older people, lowering rental costs, combating loneliness and strengthening social links [249].

Figure 55. Adrian Hill Architects' proposal for Intergenerational Competition by Enfield Council [250]

7 Conclusions

The thesis performs a holistic calculation of the environmental, economic and social impacts of renovating the nursing home stock in Norway, considering the current social (demographic ageing), architectural (dementia and the built environment) and environmental (climate neutrality by 2050) challenges. Trondhjems Hospital was selected as the representative case study to assess a catalogue of sustainable dementia-friendly measures, investigating different materials, energy standards and building systems typically implemented in Norwegian renovation projects. The methodology involves an LCA of GHG emissions and operational energy use, an LCCA of construction and energy costs, and an EQA of spatial qualities according to dementia-friendly design principles.

The thesis has answered the research questions, stated in the introduction and discussed in Chapter 6:

RQ1. What are the environmental (carbon emissions and operational energy use) and economic impacts (construction and energy costs) of renovating and transforming Norway's nursing homes into dementia-friendly environments with low-impact measures?

The embodied carbon emissions of renovating a standard hospital-like nursing home unit (*sykehjem*) are 1.7 $kgCO_2eq/yr/m^2_{GFA}$ with PH standard and NS3720 calculation method, 1.1 $kgCO_2eq/yr/m^2_{GFA}$ (PH and FBZ method), 1.6 $kgCO_2eq/yr/m^2_{GFA}$ (TEK standard and NS3720), and 1.1 $kgCO_2eq/yr/m^2_{GFA}$ (TEK and FBZ). The operational energy use emissions are 10.1 $kgCO_2eq/yr/m^2_{GFA}$ (PH) and 13.1 $kgCO_2eq/yr/m^2_{GFA}$ (TEK). The net energy use is 121.9 $kWh/yr/m^2$ (PH) and 151.9 $kWh/yr/m^2$ (TEK), a 54% and 43% reduction compared to the baseline scenario (BS). The net delivered energy is 71.5 $kWh/yr/m^2$ (PH) and 97.5 $kWh/yr/m^2$ (TEK), a 75% and 65% decrease. The construction cost is 7,800 NOK/m^2 (PH) and 6,900 NOK/m^2 (TEK). The total costs during 60 years of service life are 16,200 NOK/m^2 (PH) and 17,800 NOK/m^2 (TEK). Compared to TEK, the payback period of the PH standard is 1.6-1.8 years (CO_2 emissions) and 19.7-21.2 years (total costs).

To renovate a unit in a protected building (dementia wings), the embodied carbon emissions are 3.3 $kgCO_2eq/yr/m^2_{GFA}$ with PH standard and NS3720 calculation method, 2.1 $kgCO_2eq/yr/m^2_{GFA}$ (PH and FBZ method), 2.9 $kgCO_2eq/yr/m^2_{GFA}$ (TEK standard and NS3720), and 1.9 $kgCO_2eq/yr/m^2_{GFA}$ (TEK and FBZ). The operational energy use emissions are 10.9 $kgCO_2eq/yr/m^2_{GFA}$ (PH) and 15.6 $kgCO_2eq/yr/m^2_{GFA}$ (TEK). The net energy use is 123.6 $kWh/yr/m^2$ (PH) and 179.1 $kWh/yr/m^2$ (TEK), a 66% and 36% reduction compared to the baseline scenario (BS). The net delivered energy is 94.9 $kWh/yr/m^2$ (PH) and 135.6 $kWh/yr/m^2$ (TEK), a 53% and 33% decrease. The construction cost is 18,500 NOK/m^2 (PH) and 16,400 NOK/m^2 (TEK). The total costs during 60 years of service life are 27,500 NOK/m^2 (PH) and 29,300 NOK/m^2 (TEK). Compared to TEK, the payback period of the PH standard is 1.8-2.4 years (CO_2 emissions) and 30.1-30.6 years (total costs).

Extrapolating the PH scenario results from the two units for all nursing homes in Norway (923 with a total area of approximately 2,500,000 m^2), the total cost of renovating the building stock to be climate-neutral by 2050 is between 19.4 and 69 billion NOK, depending on the scenario assumed.

RQ2. What is the feasibility of renovating Norway's nursing home stock to reach zero-emissions/energy building (ZEB) ambition level?

The CO_2 emissions obtained in the PH scenario for the *sykehjem* and the dementia wings are below Enova's benchmark for renovated low-energy buildings. However, Trondhjems Hospital can only host a renewable energy installation of 765 m^2 PV panels on the *sykehjem* rooftop, which does not produce enough clean energy to compensate for the embodied and operational energy emissions. Therefore, Trondhjems Hospital cannon reach any of the ZEB ambition levels. The *sykehjem* unit would need 3,500-4,000 m^2 of PV panels to be zero emissions, 3,800-4,500 m^2 in the case of the dementia wings.

Answering the research question, the case of Trondhjems Hospital shows that it is not feasible to have a zero-emissions nursing home stock with the ZEB definition. In order to reach climate neutrality by 2050, policies should focus on lowering energy emissions and promoting renewable energy production technologies at a district level. Instead of aiming for ZEB, the municipalities must enhance sustainable communities and zero-emissions neighbourhoods (ZEN).

RQ3. What are the needs of older people with dementia living in nursing homes, and how can a dementia-friendly environment contribute to their comprehensive well-being?

Residents with dementia have a different perception of the built environment. A well-designed dementia-friendly unit can improve wayfinding, self-help skills, mobility, independence and interaction with other residents, and reduce agitation, confusion, depression, restlessness, wandering and attempts to leave the unit.

To design a dementia-friendly environment, the measures have to integrate the following design measures: (1) unobtrusively reduce risks, (2) provide a human scale, (3) allow people to see and be seen, (4) reduce unhelpful stimulation, (5) optimise helpful stimulation, (6) support movement and engagement, (7) create a familiar place, (8) provide a variety of places to be alone or with others in the unit, (9) provide a variety of places to be alone or with others in the community, and (10) design in response to a vision for a way of life. Implementing the dementia-friendly measures in the renovation project of Trondhjems Hospital represents 5% (NS3720) to 15% (FBZ) of the total embodied emissions. Enhancing the environmental quality has a low environmental and architectural impact but can make a substantial difference in the quality of life of residents with dementia, as demonstrated in the EQA.

Regarding the **outcome**, the master's thesis is a reference document for practitioners (researchers, architects, project developers and municipalities) to renovate nursing homes with a dementia-friendly and sustainable approach. The report provides a variety of renovation measures that can be applied in nursing homes from different construction periods. The scenarios cover several types of common improvements, such as externally insulating (S1), internally insulating (S2), changing windows (S3), layout rearrangement and bringing the interior design up-to-date (S4). At the same time, each upgrade studies different materials, standards and building systems. The comparison between GHG emissions reduction, operational energy use, material use and energy standard implemented also help practitioners to make informed decisions and promote a research-based design practice. The economic estimation of decarbonizing the nursing home stock in Norway can become research-based support for future policies and measures taken by public institutions.

The research carried out also contributes to the **field of study**. The literature about dementia and the built environment is addressed from a medical approach, while this thesis contributes to the area of knowledge from an architectural perspective. No literature was found about LCA and LCCA for renovating nursing homes. The available research concentrates on lowering new residential and office building emissions. There are not enough emissions benchmarks for renovations of public buildings. On the other hand, most LCA and LCCA about renovations focus on improving the energy efficiency of the building and lowering the GWP, but do not consider how the low-impact measures can create a better spatial quality and contribute to the well-being of the users.

Concerning **limitations**, the greatest constrain was the lack of information about the energy use and delivered energy in Trondhjems Hospital. A more accurate break-even analysis between the baseline scenario (BS), PH and TEK standards could have been carried out if the nursing home had provided sufficient data. However, the baseline information was not relevant to the GHG emissions and cost calculation of the renovation measures, but it could have been used to validate the correctness of the results. Other limitations were calculating the LCCA with static energy and material prices that do not consider the market fluctuation, not considering FBZ calculation method to calculate the GWP of operational energy use.

Summarising the **future work** tackled in the discussion section, further research could carry out a detailed investigation with more case studies from different locations (urban and rural areas), construction periods, building typologies and construction systems to provide a more accurate cost and emission estimation to the whole nursing home stock in Norway. To lower the embodied emissions (RQ1), reused, locally sourced, long-lasting and easy-to-assemble materials could be used. To decrease the operational energy use emissions (RQ1) and reach ZEB ambition level (RQ2), a collaboration with the municipality could be implemented to promote renewable energy production (PV panel installation, district heating, seawater and geothermal heat pumps) at a neighbourhood level. To create more dementia-friendly environments and enhance community links between younger and older generations (RQ3), new intergenerational housing typologies could be implemented in the renovated Norwegian nursing homes.

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Appendix 1: Functional areas

Recommended functional areas for a health and welfare centre in Trondheim with 70 residents in the nursing home and 30 residents in the elder-adapted apartments, according to the Functional and area program by Trondheim Kommune [162].

Nursing home

Zone	Room	Quantity	Dimension (m^2)	Total (m^2)
Common areas	Shared kitchen and dining room	9	45	405
	Shared living room	9	45	405
	Toilet	3	5	15
Residents room	Bedroom	66	25	1650
	Living room	6	25	150
	Toilet	72	7	468
Service area	Workplace	3	30	90
	Conversation room	3	10	30
	Examination room	3	14	42
	Medicine storage	3	6	18
	Waste room	3	10	30
	Cleaning room	3	10	30
	Linen storage	9	5	45
	Nursing supplies storage	3	7	21
	Technical aids storage	3	15	45
	Laundry room	3	15	45
	Toilet visitors	9	3	27
	Toilet staff	9	1	9
Total				**3525 m^2**
Total per resident				**49 m^2**

Administration

Zone	Room	Quantity	Dimension (m^2)	Total (m^2)
Administration	Landscape office staff	1	40	40
	Offices staff	1	12	12
	Quiet room	2	5	10
	Copy and supplies room	1	10	10
	Landscape office external	1	26	26
	Storage	1	10	10
	Meeting room	3	60	75
	Dining room	1	45	45
	Toilet	1	5	5
Changing room	Changing rooms female/male	1	200	200
	Laundry room	1	30	30
Total				**463 m^2**
Total per resident				**6 m^2**

Building management

Zone	Room	Quantity	Dimension (m^2)	Total (m^2)
	Good reception area	1	30	30
	Food room	1	15	15
	Laundry room	1	15	15
	Waste room	1	40	40
	Hazardous waste room	1	5	5
	Paper waste room	1	10	10
	Nursing supplies storage	1	110	110
	Storage room for users	1	20	20
	Furniture and equipment	2	35	70
	Workshop	1	20	20
	Building management equipment	1	10	10
	Central cleaning room	1	18	18
Total				**413 m^2**
Total per resident				**6 m^2**

Activity and culture centre

Zone	Room	Quantity	Dimension (m^2)	Total (m^2)
Main entrance	Lobby	1	50	50
	Cloakroom	1	20	20
	Toilet	2	5	10
	Seating area	1	130	130
	Kitchen	1	50	50
	Refrigerator	1	4	4
	Dry goods storage	1	3	3
	Kitchenette	1	10	10
	Office	1	6	6
	Changing rooms	1	8	8
Specialized rooms	Meeting room, event room and training room	1	190	190
	Storage	1	30	30
Beauty and self-care	Hairdresser	1	20	20
	Pedicurist	1	15	15
Activities for seniors	Kitchen	1	40	40
	Living room	1	50	50
	Activity room	1	40	40
	Cloakroom	1	20	20
	Toilet for users	3	3	9
	Toilet with shower for users	1	7	7
	Office	1	12	12
	Staff toilet	1	3	2
Total				**727 m^2**
Total per resident				**10 m^2**

Home-based services

Zone	Room	Quantity	Dimension (m^2)	Total (m^2)
Administration	Landscape office staff	1	35	35
	Quiet room	1	5	5
	Office	1	12	12
	Workplace	1	40	40
	Meeting room	1	45	45
	Examination room	1	20	20
	Medicine room	1	7	7
	Visitors room	1	8	8
	Storage	1	10	10
	Archive	1	7	7
Shared with health and welfare centre	Copy and supplies room	1	-	-
	Dining room	1	-	-
	Toilet staff	1	-	-
	Changing rooms female/male	1	-	-
Total				**189 m^2**

Home-based services

Zone	Room	Quantity	Dimension (m^2)	Total (m^2)
Main entrance	Entrance with mailboxes	1	-	-
	Entrance	30	5	150
	Living room and kitchen	30	23	690
	Bedroom	30	13	390
	Toilet	30	7	210
	Storage	30	3	90
	Basement storage	30	5	150
Common area	Collective kitchen and living room	1	50	50
	Meeting places	-	-	-
	Outdoor garden/balconies	-	-	-
	Storage for outdoor furniture	-	-	-
	Workplace	1	30	30
	Copy and supplies room	1	7	7
	Medicine room	1	10	10
	Storage	1	6	6
	Changing room	1	55	55
	Toilet	1	2	2
Building management	Cleaning room	-	3	3
	Cleaning supplies storage	1	6	6
Total				**1849 m^2**
Total per resident				**37 m^2**

Appendix 2: LCA inventory

The LCA inventory is organised in building category (C), component, product, Environmental Product Declaration (EPD), quantity (Q), transport distance (TD), service life (SL), wastage (W) and CO_2 factor.

Scenario 1: External insulation

C	Component	Product	EPD	Q	TD	SL	W	CO_2 factor
21	SH_GF_370 Sykehjem_ Ground floor 370 mm	Linoleum 3 mm	Linoleum – typical value [193]	1035 m^2	500 km	20 years	10%	2.8 $kgCO_2/m^2$
		Vapour barrier 0.2 mm	Gram Dampsperre [251]	1035 m^2	548 km	60 years	5%	0.399 $kgCO_2/m^2$
		XPS insulation 450 (PH) – 250 (TEK) mm	Finnfoam XPS Insulation [252]	1035 m^2	330 km	60 years	5%	4.318 $kgCO_2/m^2$
		Vapour barrier 0.2 mm	Gram Dampsperre [251]	1035 m^2	548 km	60 years	5%	0.399 $kgCO_2/m^2$
23	SH_BW_400 Sykehjem_ Basement wall 400 mm	Drainage membrane	Universal fuktmembran [253]	241.9 m^2	500 km	60 years	10%	1.09 $kgCO_2/m^2$
		XPS insulation 350 (PH) - 150 (TEK) mm	Finnfoam XPS Insulation [252]	241.9 m^2	330 km	60 years	5%	4.318 $kgCO_2/m^2$
23	SH_BW_500 Sykehjem_ Basement wall 500 mm	Drainage membrane	Universal fuktmembran [253]	126.7 m^2	500 km	60 years	10%	1.09 $kgCO_2/m^2$
		XPS insulation 350 (PH) – 150 (TEK) mm	Finnfoam XPS Insulation [252]	126.7 m^2	330 km	60 years	5%	4.318 $kgCO_2/m^2$
23	SH_EW_400 Sykehjem_ External wall 400 mm	*Wooden cladding 20 mm	Royalimpregnert trelast [254]	466.9 m^2	396 km	60 years	2%	0.1515 $kgCO_2/m$
		*Brick cladding 120 mm - Reused	Brick - typical value [193]	466.9 m^2	0 km	60 years	5%	33.1 $kgCO_2/m^2$
		**Double wood battens 70 mm	Royalimpregnert trelast [254]	28 m^2	136 km	60 years	15%	0.1722 $kgCO_2/m$
		**Wind barrier	Isola Soft Xtra [255]	466.9 m^2	500 km	30 years	10%	0.335 $kgCO_2/m^2$
		***Wood fibre insulation 350 (PH) – 150 (TEK) mm	Hunton Trefiberisolasjon Plate [256]	466.9 m^2	396 km	60 years	2%	0.566 $kgCO_2/m^2$
		*** Mineral wool insulation 350 (PH) – 150 (TEK) mm	Rockwool stone wool thermal insulation [257]	466.9 m^2	396 km	60 years	10%	2.8415 $kgCO_2/m^2$
		**Vapour barrier	Gram Dampsperre [251]	466.9 m^2	548 km	60 years	5%	0.399 $kgCO_2/m^2$
23	SH_EW_500 Sykehjem_ External wall 500 mm	*Wooden cladding 20 mm	Royalimpregnert trelast [254]	573 m^2	396 km	60 years	2%	0.1515 $kgCO_2/m$
		*Brick cladding 120 mm - Reused	Brick - typical value [193]	573 m^2	0 km	60 years	5%	33.1 $kgCO_2/m^2$
		**Double wood battens 70 mm	Royalimpregnert trelast [254]	34.4 m^2	136 km	60 years	15%	0.1722 $kgCO_2/m$
		**Wind barrier	Isola Soft Xtra [255]	573 m^2	500 km	30 years	10%	0.335 $kgCO_2/m^2$
		***Wood fibre insulation 350 (PH) – 150 (TEK) mm	Hunton Trefiberisolasjon Plate [256]	573 m^2	396 km	60 years	2%	0.566 $kgCO_2/m^2$
		*** Mineral wool insulation 350 (PH) – 150 (TEK) mm	Rockwool stone wool thermal insulation [257]	573 m^2	396 km	60 years	10%	2.8415 $kgCO_2/m^2$
		**Vapour barrier	Gram Dampsperre [251]	573 m^2	548 km	60 years	5%	0.399 $kgCO_2/m^2$
26	SH_R_350 Sykehjem_ Roof 350 mm	Wood cement board + paint 15 mm	Troldtekt Natural Wood [258]	1567.1 m^2	200 km	60 years	10%	1.292 $kgCO_2/m^2$
		***Wood fibre insulation 450 (PH) – 250 (TEK) mm	Blown-in wood fibre insulation [259]	1567.1 m^2	396 km	60 years	5%	0.246 $kgCO_2/m^2$
		***Mineral wool insulation 450 (PH) – 250 (TEK) mm	Rockwool stone wool thermal insulation [257]	1567.1 m^2	396 km	60 years	10%	2.8415 $kgCO_2/m^2$

Scenario 2: Internal insulation

C	Component	Product	EPD	Q	TD	SL	W	CO_2 factor
21	DW_GF Dementia wing_ Ground floors	Linoleum 3 mm	Linoleum – typical value [193]	658 m^2	500 km	20 years	10%	2.8 $kgCO_2/m^2$
		Vapour barrier 0.2 mm	Gram Dampsperre [251]	658 m^2	548 km	60 years	5%	0.399 $kgCO_2/m^2$
		XPS insulation 450 (PH) – 250 (TEK) mm	Finnfoam XPS Insulation [252]	658 m^2	330 km	60 years	5%	4.318 $kgCO_2/m^2$
		Vapour barrier 0.2 mm	Gram Dampsperre [251]	256.7 m^2	548 km	60 years	5%	0.399 $kgCO_2/m^2$
23	DW_EW_ Dementia wings_ External walls	*Wood fibre insulation 350 (PH) – 150 (TEK) mm	Hunton Trefiberisolasjon Plate [256]	1635.8 m^2	396 km	60 years	2%	0.566 $kgCO_2/m^2$
		* Mineral wool insulation 350 (PH) – 150 (TEK) mm	Rockwool stone wool thermal insulation [257]	1635.8 m^2	396 km	60 years	10%	2.8415 $kgCO_2/m^2$
		**Wood studs 50x50 mm	Royalimpregnert trelast [254]	229 m^2	136 km	60 years	15%	0.1722 $kgCO_2/m$
		Plasterboard 15 mm	Gyproc Normal – Standard Plasterboard [260]	1635.8 m^2	605 km	60 years	15%	1.93 $kgCO_2/m^2$
		Clay board 20 mm	Clay panel (thickness 0.02 m); 14 kg/m^2 [261]	1635.8 m^2	500 km	60 years	2%	0.053 $kgCO_2/m^2$
26	SH_R_350 Sykehjem_ Roof 350 mm	Wood cement board + paint 15 mm	Troldtekt Natural Wood [258]	911.5 m^2	200 km	60 years	10%	1.292 $kgCO_2/m^2$
		*Wood fibre insulation 450 (PH) – 250 (TEK) mm	Blown-in wood fibre insulation [259]	911.5 m^2	396 km	60 years	5%	0.246 $kgCO_2/m^2$
		*Mineral wool insulation 450 (PH) – 250 (TEK) mm	Rockwool stone wool thermal insulation [257]	911.5 m^2	396 km	60 years	10%	2.8415 $kgCO_2/m^2$

Scenario 3: Changing windows

C	Component	Product	EPD	Q	TD	SL	W	CO_2 factor
23	SH_W_B Sykehjem_Windows_Balcony	Window 2100x500 mm	Window – typical value [193]	83.7 m^2	200 km	35 years	0%	1.99 $kgCO_2/kg$
	SH_W_2900 Sykhjem_Windows 2900 mm	Window 2900x1500 mm	Window – typical value [193]	1611.5 m^2	200 km	35 years	0%	1.99 $kgCO_2/kg$
	SH_W_2000 Sykehjem_Windows 2000 mm	Window 2000x1500 mm	Window – typical value [193]	106 m^2	200 km	35 years	0%	1.99 $kgCO_2/kg$
	SH_W_S Sykehjem_Windows _Stairs	Window 1200x900 mm	Window – typical value [193]	18.4 m^2	200 km	35 years	0%	1.99 $kgCO_2/kg$
	SH_W_2000-1000 Sykehjem_Windows 2000-1000 mm	Window 2000x1000 mm	Window – typical value [193]	25.5 m^2	200 km	35 years	0%	1.99 $kgCO_2/kg$
	SH_W_2000-1200 Sykehjem_Windows 2000-1200 mm	Window 2000x1200 mm	Window – typical value [193]	29.4 m^2	200 km	35 years	0%	1.99 $kgCO_2/kg$
	SH_W_2800 Sykehjem_Windows 2800 mm	Window 2800x1200 mm	Window – typical value [193]	39.6 m^2	200 km	35 years	0%	1.99 $kgCO_2/kg$
28	SH_CW_NB Sykehjem_Curtain wall_New balcony	Curtain wall	Glass façade – typical value [193]	82.2 m^2	500 km	30 years	0%	155 $kgCO_2/m^2$
	SH_CW_B Sykehjem_Curtain wall_Balcony	Curtain wall	Glass façade – typical value [193]	137 m^2	500 km	30 years	0%	155 $kgCO_2/m^2$
23	NW_W_900 North wing_Windows 900 mm	Window 900x900 mm	Window – typical value [193]	23.9 m^2	200 km	35 years	0%	1.99 $kgCO_2/kg$
	EW_W_900 North wing_Windows 900 mm	Window 1100x900 mm	Window – typical value [193]	16 m^2	200 km	35 years	0%	1.99 $kgCO_2/kg$
	WW_W_900 West wing_Windows 900 mm	Window 1100x900 mm	Window – typical value [193]	16.8 m^2	200 km	35 years	0%	1.99 $kgCO_2/kg$
	WW_W_1800 West wing_Windows 1800 mm	Window 1100x1800 mm	Window – typical value [193]	329 m^2	200 km	35 years	0%	1.99 $kgCO_2/kg$
	EW_W_1400 North wing_Windows 1400 mm	Window 1100x1400 mm	Window – typical value [193]	156 m^2	200 km	35 years	0%	1.99 $kgCO_2/kg$
	NW_W_1600 North wing_Windows 1600 mm	Window 1100x1600 mm	Window – typical value [193]	263 m^2	200 km	35 years	0%	1.99 $kgCO_2/kg$
	NW_W_1400 North wing_Windows 1400 mm	Window 1100x1400 mm	Window – typical value [193]	327 m^2	200 km	35 years	0%	1.99 $kgCO_2/kg$
28	NW_CW_V North wing_Curtain wall_Veranda	Curtain wall	Glass façade – typical value [193]	120 m^2	500 km	30 years	0%	155 $kgCO_2/m^2$
	NW_CW_B North wing_Curtain wall_Balcony	Curtain wall	Glass façade – typical value [193]	72 m^2	500 km	30 years	0%	155 $kgCO_2/m^2$

Scenario 4: Dementia-friendly environment

Sykehjem unit

	Component	Product	EPD	Q	TD	SL	W	CO_2 factor
23	SH_W_WO Sykehjem_Windows _Workers offices	Window 1100x2000 mm	Window – typical value [193]	115 m^2	200 km	35 years	0%	1.99 $kgCO_2/kg$
	SH_D_850 Sykehjem_Doors 850 mm	Door wood cladding 15 mm	Panel av heitre gran/furu [262]	17.9 m^2	422 km	60 years	15%	0.1868 $kgCO_2/m$
	SH_D_RD Sykehjem_Doors _Room door	Door painting	JOTAPROFF Prima Clean [263]	383 m^2	645 km	15 years	10%	2.869 $kgCO_2/kg$
	SH_D_850 Sykehjem_Doors 850 mm	Wooden single door 2100x850	Interior door – typical value [193]	41.8 m^2	500 km	40 years	0%	30 $kgCO_2/m^2$
	SH_D_FD 2200 Sykehjem_Doors_ Fire door 2200 mm	Double wooden door 2100x2200	Interior door – typical value [193]	12.6 m^2	500 km	40 years	0%	30 $kgCO_2/m^2$
	SH_D_950 Sykehjem_Doors 950 mm	Wooden single door 2100x950	Interior door – typical value [193]	38.7 m^2	500 km	40 years	0%	30 $kgCO_2/m^2$
	SH_D_950 Sykehjem_Doors 950 mm	Door wood cladding 15 mm	Panel av heitre gran/furu [262]	168 m^2	422 km	60 years	15%	0.1868 $kgCO_2/m$
	SH_D_SD 100 Sykehjem_Doors _Sliding door 100 mm	Door wood cladding 15 mm	Panel av heitre gran/furu [262]	111 m^2	422 km	60 years	15%	0.1868 $kgCO_2/m$
24	SH_IW_200 Sykehjem_Internal wall 200 mm	CLT wall 180 mm Plaster and paint 20 mm	Krysslimt tre [264] Gyproc Normal – Standard Plasterboard [260]	171 m^2 171 m^2	531 km 605 km	60 years 60 years	0% 15%	90.3 $kgCO_2/m^3$ 1.93 $kgCO_2/m^2$
	SH_IW_100 Sykehjem_Internal wall 100 mm	Steel frame with mineral wool insulation 70 mm Gypsum board and paint 30 mm	Rockwool stone wool thermal insulation [257] Gyproc Normal – Standard Plasterboard [260]	93.4 m^2 93.4 m^2	396 km 605 km	60 years 60 years	10% 15%	2.8415 $kgCO_2/m^2$ 1.93 $kgCO_2/m^2$
	SH_WC_20 Sykehjem _Wood cladding 20 mm	Interior wood cladding 15 mm	Panel av heitre gran/furu [262]	1034.6 m^2	422 km	60 years	15%	0.1868 $kgCO_2/m$
25	SH_C_W Sykehjem_Ceiling _Wood	Wood batten 15x35 mm	Trelast av furu og gran [265]	238 m^2	422 km	60 years	15%	0.4571 $kgCO_2/m$
27	SH_W_20 Sykehjem_Wardrobe 20 mm	Wood board 20 mm	Chipboard – typical value [193]	627 m^2	50 km	60 years	15%	4.31 $kgCO_2/m^3$
28	SH_CW_NB Sykehjem_Curtain wall_New balcony	Curtain wall	Glass façade – typical value [193]	125 m^2	500 km	30 years	0%	155 $kgCO_2/m^2$

Dementia wings

C	Component	Product	EPD	Q	TD	SL	W	CO_2 factor
23	DW_D_O Dementia wings_Doors_Office	Door wood cladding 15 mm	Panel av heitre gran/furu [262]	142 m^2	422 km	60 years	15%	0.1868 $kgCO_2/m$
	DW_D_BR Dementia wings_Doors_Bedrooms	Door painting	JOTAPROFF Prima Clean [263]	120 m^2	640 km	15 years	10%	2.869 $kgCO_2/kg$
	DW_D_E Dementia wings_Doors_Exterior	Door wood cladding 15 mm	Panel av heitre gran/furu [262]	74.5 m^2	422 km	60 years	15%	0.1868 $kgCO_2/m$
	DW_D_LR Dementia wings_Doors_Living rooms	Door painting	JOTAPROFF Prima Clean [263]	98.6 m^2	640 km	15 years	10%	2.869 $kgCO_2/kg$
24	DW_P_5 Dementia wings_Painting_5 mm	Wall painting	JOTAPROFF Prima Clean [263]	253 m^2	640 km	15 years	10%	2.869 $kgCO_2/kg$
	DW_WC_15 Dementia wings_Wood cladding 15 mm	Interior wood cladding 15 mm	Panel av heitre gran/furu [262]	517 m^2	422 km	60 years	15%	0.1868 $kgCO_2/m$
25	DW_C_W Dementia wing_Ceiling_Wood	Wood batten 15x35 mm	Trelast av furu og gran [265]	66 m^2	422 km	60 years	15%	0.4571 $kgCO_2/m$

Scenario 5: Energy performance

C	Component	Product	EPD	Q	TD	SL	W	CO_2 factor
46	SH_PV Sykehjem_ PV panels	PV panels	Series 6 Photovoltaic Module	765 m^2	500 km	30 years	0%	117.885 $kgCO_2/pcs$

Appendix 3: Simien

Appendix 3 is formed by the energy reports and Simien files obtained after performing energy calculation in Simien software. The PDFs and SMI files are available in the attached folder of the thesis (sub-folder Appendix 3: Simien) with the following names:

- BS.DW Baseline scenario_Dementia wings (.smi and .pdf)
- BS.SH Baseline scenario_Sykehjem(.smi and .pdf)
- S5.DW.PH Energy performance_Dementia wings_Passive House(.smi and .pdf)
- S5.DW.TEK Energy performance_Dementia wings_TEK17(.smi and .pdf)
- S5.SH.PH Energy performance_Sykehjem_Passive House (.smi and .pdf)
- S5.SH.TEK Energy performance_Sykehjem_TEK17 (.smi and .pdf)

Appendix 4: Excel files

Appendix 4 is formed by the Excel files used to perform LCA, LCCA and EQA calculations. The data was previously extracted from Reduzer software. The XLS files are available in the attached folder of the thesis (sub-folder Appendix 4: Excel files) with the following names:

- EQA Environmental quality assessment.xls
- LCA.LCI Life cycle inventory.xls
- LCA.S1 LCA_Scenario 1_External insulation.xls
- LCA.S2 LCA_Scenario 2_Internal insulation.xls
- LCA.S3 LCA_Scenario 3_Exchanging windows.xls
- LCA.S4 LCA_Scenario 4_Dementia-friendly environment.xls
- LCA.S5 LCA_Scenario 5_Energy performance.xls
- LCCA Life cycle cost analysis.xls

Appendix 5: LCCA inventory

Scenario 1: External insulation

Wood cladding

Compon.	Product	Element	Q (m^2)	NOK /m^2	S1.SH.WC. WF.PH (NOK)	S1.SH.WC. WF.TEK (NOK)	S1.SH.WC. MW.PH (NOK)	S1.SH.WC. MW.TEK (NOK)
SH_GF_ 370 Sykehjem_ Ground floor 370 mm	Linoleum 3 mm	02.5.G.004 Linoleum, t = 2.5 mm	1035	586	606510	8606510	606510	606510
	Vapour barrier 0.2 mm	02.3.2.1.1210 Vapour barrier, t = 0.15 mm	1035	80	82800	82800	82800	82800
	XPS insulation 450 (PH) – 250 (TEK) mm	02.1.6.0800 Ground insulation, XPS, t = 50 mm 02.1.6.0811 Ground insulation, XPS, t = 100 mm	1035 1035	164 298	169740 1233720	169740 616860	169740 1233720	169740 616860
	Vapour barrier 0.2 mm	02.3.2.1.1210 Vapour barrier, t = 0.15 mm	1035	80	82800	82800	82800	82800
SH_BW_ 400 Sykehjem_ Basement wall 400 mm	XPS insulation 350 (PH) - 150 (TEK) mm	02.3.1.7.0150 Foundation wall insulation, XPS, t = 50 mm 02.1.7.0160 Foundation wall insulation, XPS, t = 100 mm	241.9 241.9	375 526	90712.5 508957.6	90712.5 254478.8	90712.5 508957.6	90712.5 254478.8
SH_BW_ 500 Sykehjem_ Basement wall 500 mm	XPS insulation 350 (PH) – 150 (TEK) mm	02.3.1.7.0150 Foundation wall insulation, XPS, t = 50 mm 02.1.7.0160 Foundation wall insulation, XPS, t = 100 mm	126.7 126.7	375 526	47512.5 199932.6	47512.5 66644.2	47512.5 199932.6	47512.5 66644.2
SH_EW_ 400 Sykehjem_ External wall 400 mm	Wooden cladding 20 mm	02.3.5.3.0108 Wood cladding	466.9	563	262864.7	262864.7	262864.7	262864.7
	Double wood battens 70 mm	02.3.5.3.0110 Wood battens for vertical wood cladding	28	124	3472	3472	3472	3472
	Wind barrier	02.3.2.1.1330 Wind barrier	466.9	148	69101.2	69101.2	69101.2	69101.2
	Wood fibre insulation 350 (PH) – 150 (TEK) mm	Nativo wood fibre insulation, t = 50 mm Nativo wood fibre insulation, t = 100 mm	466.9 466.9	161 238	75170.9 333366.6	75170.9 111122.2	0 0	0 0
	Mineral wool insulation 350 (PH) – 150 (TEK) mm	02.3.2.1.0620 Mineral wool insulation, t=50 mm 02.3.2.1.0620 Mineral wool insulation, t=100 mm	466.9 466.9	110 163	0 0	0 0	51359 228314.1	51359 76104.7
	Vapour barrier	02.3.2.1.1210 Vapour barrier, t = 0.15 mm	466.9	80	45840	45840	45840	45840
SH_EW_ 500 Sykehjem_ External Wall 500 mm	*Wooden cladding 20 mm	02.3.5.3.0108 Wood cladding	573	563	322599	322599	322599	322599
	Double wood battens 70 mm	02.3.5.3.0110 Wood battens for vertical wood cladding	34.4	124	4265.6	4265.6	4265.6	4265.6
	Wind barrier	02.3.2.1.1330 Wind barrier	573	148	84804	84804	84804	84804
	Wood fibre insulation 350 (PH) – 150 (TEK) mm	Nativo wood fibre insulation, t = 50 mm Nativo wood fibre insulation, t = 100 mm	573 573	161 238	92253 409122	92253 136374	0 0	0 0
	Mineral wool insulation 350 (PH) – 150 (TEK) mm	02.3.2.1.0620 Mineral wool insulation, t=50 mm 02.3.2.1.0620 Mineral wool insulation, t=100 mm	573 573	110 163	0 0	0 0	63030 280197	63030 93399
	Vapour barrier	02.3.2.1.1210 Vapour barrier, t = 0.15 mm	573	80	45840	45840	45840	45840
SH_R_ 350 Sykehjem_ Roof 350 mm	Wood cement board + paint 15 mm	02.5.6.3.0504 Wood cement board + paint	1567.1	505	791385.5	791385.5	791385.5	791385.5
	Wood fibre insulation 450 (PH) – 250 (TEK) mm	Nativo wood fibre insulation, t = 50 mm Nativo wood fibre insulation, t = 100 mm	1567.1 1567.1	161 238	252303.1 1491879.2	252303.1 745939.6	0 0	0 0
	Mineral wool insulation 450 (PH) – 250 (TEK) mm	02.3.2.1.0620 Mineral wool insulation, t=50 mm 02.3.2.1.0620 Mineral wool insulation, t=100 mm	1567.1 1567.1	110 163	0 0	0 0	172381 1021749.2	172381 510874.6
Labour TEK			4010.6	3906	0	15665404	0	15665404
Labour PH			4010.6	4092	16411375	0	16411375	0

Brick cladding

Compon.	Product	Element	Q (m²)	NOK /m²	S1.SH.BC. WF.PH (NOK)	S1.SH.BC. WF.TEK (NOK)	S1.SH.BC. MW.PH (NOK)	S1.SH.BC. MW.TEK (NOK)
SH_GF_ 370 Sykehjem_ Ground floor 370 mm	Linoleum 3 mm	02.5.G.004 Linoleum, t = 2.5 mm	1035	586	606510	8606510	606510	606510
	Vapour barrier 0.2 mm	02.3.2.1.1210 Vapour barrier, t = 0.15 mm	1035	80	82800	82800	82800	82800
	XPS insulation 450 (PH) – 250 (TEK) mm	02.1.6.0800 Ground insulation, XPS, t = 50 mm 02.1.6.0811 Ground insulation, XPS, t = 100 mm	1035 1035	164 298	169740 1233720	169740 616860	169740 1233720	169740 616860
	Vapour barrier 0.2 mm	02.3.2.1.1210 Vapour barrier, t = 0.15 mm	1035	80	82800	82800	82800	82800
SH_BW_ 400 Sykehjem_ Basement wall 400 mm	XPS insulation 350 (PH) - 150 (TEK) mm	02.3.1.7.0150 Foundation wall insulation, XPS, t = 50 mm 02.1.7.0160 Foundation wall insulation, XPS, t = 100 mm	241.9 241.9	375 526	90712.5 508957.6	90712.5 254478.8	90712.5 508957.6	90712.5 254478.8
SH_BW_ 500 Sykehjem_ Basement wall 500 mm	XPS insulation 350 (PH) – 150 (TEK) mm	02.3.1.7.0150 Foundation wall insulation, XPS, t = 50 mm 02.1.7.0160 Foundation wall insulation, XPS, t = 100 mm	126.7 126.7	375 526	47512.5 199932.6	47512.5 66644.2	47512.5 199932.6	47512.5 66644.2
SH_EW_ 400 Sykehjem_ External wall 400 mm	Brick cladding 120 mm - Reused	02.3.5.1.0300 Reuse of brick cladding	466.9	2259	1054727.1	1054727.1	1054727.1	1054727.1
	Wood fibre insulation 350 (PH) – 150 (TEK) mm	Nativo wood fibre insulation, t = 50 mm Nativo wood fibre insulation, t = 100 mm	466.9 466.9	161 238	75170.9 333366.6	75170.9 111122.2	0 0	0 0
	Mineral wool insulation 350 (PH) – 150 (TEK) mm	02.3.2.1.0620 Mineral wool insulation, t=50 mm 02.3.2.1.0620 Mineral wool insulation, t=100 mm	466.9 466.9	110 163	0 0	0 0	51359 228314.1	51359 76104.7
SH_EW_ 500 Sykehjem_ External Wall 500 mm	Brick cladding 120 mm - Reused	02.3.5.1.0300 Reuse of brick cladding	573	2259	1294407	1294407	1294407	1294407
	Wood fibre insulation 350 (PH) – 150 (TEK) mm	Nativo wood fibre insulation, t = 50 mm Nativo wood fibre insulation, t = 100 mm	573 573	161 238	92253 409122	92253 136374	0 0	0 0
	Mineral wool insulation 350 (PH) – 150 (TEK) mm	02.3.2.1.0620 Mineral wool insulation, t=50 mm 02.3.2.1.0620 Mineral wool insulation, t=100 mm	573 573	110 163	0 0	0 0	63030 280197	63030 93399
SH_R_ 350 Sykehjem_ Roof 350 mm	Wood cement board + paint 15 mm	02.5.6.3.0504 Wood cement board + paint	1567.1	505	791385.5	791385.5	791385.5	791385.5
	Wood fibre insulation 450 (PH) – 250 (TEK) mm	Nativo wood fibre insulation, t = 50 mm Nativo wood fibre insulation, t = 100 mm	1567.1 1567.1	161 238	252303.1 1491879.2	252303.1 745939.6	0 0	0 0
	Mineral wool insulation 450 (PH) – 250 (TEK) mm	02.3.2.1.0620 Mineral wool insulation, t=50 mm 02.3.2.1.0620 Mineral wool insulation, t=100 mm	1567.1 1567.1	110 163	0 0	0 0	172381 1021749.2	172381 510874.6
Labour TEK			4010.6	3906	0	15665404	0	15665404
Labour PH			4010.6	4092	16411375	0	16411375	0

Scenario 2: Internal insulation

Plasterboard

Compon.	Product	Element	Q (m²)	NOK /m²	S2.DW.PB.WF.PH (NOK)	S2.DW.PB.WF.TEK (NOK)	S2.W.PB.MW.PH (NOK)	S1.DW.PB.MW.TEK (NOK)
DW_GF Dementia wing_ Ground floors	Linoleum 3 mm	02.5.G.004 Linoleum, t = 2.5 mm	658	586	385588	385588	385588	385588
	Vapour barrier 0.2 mm	02.3.2.1.1210 Vapour barrier, t = 0.15 mm	658	80	52640	52640	52640	52640
	XPS insulation 450 (PH) – 250 (TEK) mm	02.1.6.0800 Ground insulation, XPS, t = 50 mm	658	164	107912	107912	107912	107912
		02.1.6.0811 Ground insulation, XPS, t = 100 mm	658	298	784336	392168	784336	392168
	Vapour barrier 0.2 mm	02.3.2.1.1210 Vapour barrier, t = 0.15 mm	658	80	52640	52640	52640	52640
DW_EW_ Dementia wings_ External walls	Wood fibre insulation 350 (PH) – 250 (LEB) – 150 (TEK) mm	Nativo wood fibre insulation, t = 50 mm	1635.8	161	263363.8	263363.8	0	0
		Nativo wood fibre insulation, t = 100 mm	1635.8	238	1167961.2	389320.4	0	0
	Mineral wool insulation 350 (PH) – 250 (LEB) – 150 (TEK) mm	02.3.2.1.0620 Mineral wool insulation, t=50 mm	1635.8	110	0	0	179938	179938
		02.3.2.1.0620 Mineral wool insulation, t=100 mm	1635.8	163	0	0	799906.2	266635.4
	Wood studs 50x50 mm	02.3.2.1.0180 Wood studs 48x40 mm	229	369	84501	84501	84501	84501
	Plasterboard 15 mm	02.3.6.3.0100 Plasterboard, t = 13 mm	1635.8	213	348425.4	348425.4	348425.4	348425.4
DW_R_ 350 Dementia wings_ Roof 350 mm	Wood cement board + paint 15 mm	02.5.6.3.0504 Wood cement board + paint	911.5	505	460307.5	460307.5	460307.5	460307.5
	Wood fibre insulation 450 (PH) – 350 (LEB) – 250 (TEK) mm	Nativo wood fibre insulation, t = 50 mm	911.5	161	146751.5	146751.5	0	0
		Nativo wood fibre insulation, t = 100 mm	911.5	238	867748	433874	0	0
	Mineral wool insulation 450 (PH) – 350 (LEB) – 250 (TEK) mm	02.3.2.1.0620 Mineral wool insulation, t=50 mm	911.5	110	0	0	100265	100265
		02.3.2.1.0620 Mineral wool insulation, t=100 mm	911.5	163	0	0	594298	297149
Labour TEK			3205.3	3906	0	12519902	0	12519902
Labour PH			3205.3	4092	13116088	0	13116088	0

Clay board

Compon.	Product	Element	Q (m²)	NOK /m²	S2.DW.CB.WF.PH (NOK)	S2.DW.CB.WF.TEK (NOK)	S2.W.CB.MW.PH (NOK)	S1.DW.CB.MW.TEK (NOK)
DW_GF Dementia wing_ Ground floors	Linoleum 3 mm	02.5.G.004 Linoleum, t = 2.5 mm	658	586	385588	385588	385588	385588
	Vapour barrier 0.2 mm	02.3.2.1.1210 Vapour barrier, t = 0.15 mm	658	80	52640	52640	52640	52640
	XPS insulation 450 (PH) – 250 (TEK) mm	02.1.6.0800 Ground insulation, XPS, t = 50 mm	658	164	107912	107912	107912	107912
		02.1.6.0811 Ground insulation, XPS, t = 100 mm	658	298	784336	392168	784336	392168
	Vapour barrier 0.2 mm	02.3.2.1.1210 Vapour barrier, t = 0.15 mm	658	80	52640	52640	52640	52640
DW_EW_ Dementia wings_ External walls	Wood fibre insulation 350 (PH) – 250 (LEB) – 150 (TEK) mm	Nativo wood fibre insulation, t = 50 mm	1635.8	161	263363.8	263363.8	0	0
		Nativo wood fibre insulation, t = 100 mm	1635.8	238	1167961.2	389320.4	0	0
	Mineral wool insulation 350 (PH) – 250 (LEB) – 150 (TEK) mm	02.3.2.1.0620 Mineral wool insulation, t=50 mm	1635.8	110	0	0	179938	179938
		02.3.2.1.0620 Mineral wool insulation, t=100 mm	1635.8	163	0	0	799906.2	266635.4
	Wood studs 50x50 mm	02.3.2.1.0180 Wood studs 48x40 mm	229	369	84501	84501	84501	84501
	Clay board 20 mm	Clay board	1635.8	410	670678	670678	670678	670678
DW_R_ 350 Dementia wings_ Roof 350 mm	Wood cement board + paint 15 mm	02.5.6.3.0504 Wood cement board + paint	911.5	505	460307.5	460307.5	460307.5	460307.5
	Wood fibre insulation 450 (PH) – 350 (LEB) – 250 (TEK) mm	Nativo wood fibre insulation, t = 50 mm	911.5	161	146751.5	146751.5	0	0
		Nativo wood fibre insulation, t = 100 mm	911.5	238	867748	433874	0	0
	Mineral wool insulation 450 (PH) – 350 (LEB) – 250 (TEK) mm	02.3.2.1.0620 Mineral wool insulation, t=50 mm	911.5	110	0	0	100265	100265
		02.3.2.1.0620 Mineral wool insulation, t=100 mm	911.5	163	0	0	594298	297149
Labour TEK			3205.3	3906	0	12519902	0	12519902
Labour PH			3205.3	4092	13116088	0	13116088	0

Scenario 3: Changing windows

Component	Product	Element	Q (m²)	NOK /m²	S3.SH (NOK)	S3.DW (NOK)
SH_W_B Sykehjem_Windows_ Balcony	Window 2100x 500 mm	02.0.4.0120 Dismantling of windows, outer wall 02.3.K.001 Window, wood, u-value < 1.2 02.3.K.002 Window, wood, u-value = 0.7	83.7 83.7 83.7	351 4415 5272	29378.7 0 441266.4	29378.7 369535.5 0
SH_W_2900 Sykhjem_Windows 2900 mm	Window 2900x 1500 mm	02.0.4.0120 Dismantling of windows, outer wall 02.3.K.001 Window, wood, u-value < 1.2 02.3.K.002 Window, wood, u-value = 0.7	1611.5 1611.5 1611.5	351 4415 5272	565636.5 0 8495828	565636.5 7114772.5 0
SH_W_2000 Sykehjem_Windows 2000 mm	Window 2000x 1500 mm	02.0.4.0120 Dismantling of windows, outer wall 02.3.K.001 Window, wood, u-value < 1.2 02.3.K.002 Window, wood, u-value = 0.7	106 106 106	351 4415 5272	37206 0 558832	37206 467990.0 0
SH_W_S Sykehjem_Windows _Stairs	Window 1200x 900 mm	02.0.4.0120 Dismantling of windows, outer wall 02.3.K.001 Window, wood, u-value < 1.2 02.3.K.002 Window, wood, u-value = 0.7	18.4 18.4 18.4	351 4415 5272	6458.4 0 97004.8	6458.4 81236.0 0
SH_W_2000-1000 Sykehjem_Windows 2000-1000 mm	Window 2000x 1000 mm	02.0.4.0120 Dismantling of windows, outer wall 02.3.K.001 Window, wood, u-value < 1.2 02.3.K.002 Window, wood, u-value = 0.7	25.5 25.5 25.5	351 4415 5272	8950.5 0 134436	8950.5 112582.5 0
SH_W_2000-1200 Sykehjem_Windows 2000-1200 mm	Window 2000x 1200 mm	02.0.4.0120 Dismantling of windows, outer wall 02.3.K.001 Window, wood, u-value < 1.2 02.3.K.002 Window, wood, u-value = 0.7	29.4 29.4 29.4	351 4415 5272	10319.4 0 154996.8	10319.4 129801.0 0
SH_W_2800 Sykehjem_Windows 2800 mm	Window 2800x1200 mm	02.0.4.0120 Dismantling of windows, outer wall 02.3.K.001 Window, wood, u-value < 1.2 02.3.K.002 Window, wood, u-value = 0.7	39.6 39.6 39.6	351 4415 5272	13899.6 0 208771.2	13899.6 174834.0 0
SH_CW_NB Sykehjem_Curtain wall_New balcony	Curtain wall	02.0.4.0120 Dismantling of windows, outer wall 02.3.J.005 Glass façade, u-value <1.2 02.3.J.006 Glass façade, u-value <0.8	82.2 82.2 82.2	351 5072 5812	28852.2 0 477746.4	28852.2 416918.4 0
SH_CW_B Sykehjem_Curtain wall_Balcony	Curtain wall	02.0.4.0120 Dismantling of windows, outer wall 02.3.J.005 Glass façade, u-value <1.2 02.3.J.006 Glass façade, u-value <0.8	137 137 137	351 5072 5812	48087 0 796244	48087 694864.0 0
NW_W_900 North wing_Windows 900 mm	Window 900x 900 mm	02.0.4.0120 Dismantling of windows, outer wall 02.3.K.001 Window, wood, u-value < 1.2 02.3.K.002 Window, wood, u-value = 0.7	23.9 23.9 23.9	351 4415 5272	8388.9 0 126000.8	8388.9 105518.5 0
EW_W_900 North wing_Windows 900 mm	Window 1100x 900 mm	02.0.4.0120 Dismantling of windows, outer wall 02.3.K.001 Window, wood, u-value < 1.2 02.3.K.002 Window, wood, u-value = 0.7	16 16 16	351 4415 5272	5616 0 84352	5616 70640.0 0
WW_W_900 West wing_Windows 900 mm	Window 1100x 900 mm	02.0.4.0120 Dismantling of windows, outer wall 02.3.K.001 Window, wood, u-value < 1.2 02.3.K.002 Window, wood, u-value = 0.7	16.8 16.8 16.8	351 4415 5272	5896.8 0 88569.6	5896.8 74172.0 0
WW_W_1800 West wing_Windows 1800 mm	Window 1100x1800 mm	02.0.4.0120 Dismantling of windows, outer wall 02.3.K.001 Window, wood, u-value < 1.2 02.3.K.002 Window, wood, u-value = 0.7	329 329 329	351 4415 5272	115479 0 1734488	115479 1452535.0 0
EW_W_1400 North wing_Windows 1400 mm	Window 1100x1400 mm	02.0.4.0120 Dismantling of windows, outer wall 02.3.K.001 Window, wood, u-value < 1.2 02.3.K.002 Window, wood, u-value = 0.7	156 156 156	351 4415 5272	54756 0 822432	54756 688740.0 0
NW_W_1600 North wing_Windows 1600 mm	Window 1100x1600 mm	02.0.4.0120 Dismantling of windows, outer wall 02.3.K.001 Window, wood, u-value < 1.2 02.3.K.002 Window, wood, u-value = 0.7	263 263 263	351 4415 5272	114777 0 1723944	114777.0 1443705.0 0
NW_W_1400 North wing_Windows 1400 mm	Window 1100x1400 mm	02.0.4.0120 Dismantling of windows, outer wall 02.3.K.001 Window, wood, u-value < 1.2 02.3.K.002 Window, wood, u-value = 0.7	327 327 327	351 4415 5272	114777 0 1723944	114777 1443705.0 0
NW_CW_V North wing_Curtain wall_Veranda	Curtain wall	02.0.4.0120 Dismantling of windows, outer wall 02.3.K.001 Window, wood, u-value < 1.2 02.3.K.002 Window, wood, u-value = 0.7	120 120 120	351 5072 5812	42120 632640	42120 529800.0
NW_CW_B North wing_Curtain wall_Balcony	Curtain wall	02.0.4.0120 Dismantling of windows, outer wall 02.3.J.005 Glass façade, u-value <1.2 02.3.J.006 Glass façade, u-value <0.8	72 72 72	351 5072 5812	25272 365184.0	 365184.0
Labour TEK (SH)			2133.3	1922		4100202.6
Labour PH (SH)			2133.3	2046	4364731.8	
Labour TEK (DW)			1327.7	1922		2544151.4
Labour PH (DW)			1327.7	2046	2708290.2	

Scenario 4: Dementia-friendly environment

Component	Product	Element	Q (m²)	NOK /m²	S4.PH (NOK)	S4.TEK (NOK)
SH_W_WO Sykehjem_Windows_Workers offices	Window 1100x2000 mm	02.0.4.0120 Dismantling of windows, outer wall 02.3.K.001 Window, wood, u-value < 1.2 02.3.K.002 Window, wood, u-value = 0.7	115 115 115	351 4415 5272	40365 0 606280	40365 507725 0
SH_D_850 Sykehjem_Doors 850 mm	Door wood cladding 15 mm	02.4.6.3.0500 Wood clading 14 mm	17.9	413	7393	7393
SH_D_RD Sykehjem_Doors_Room door	Door painting	02.4.J.007 Treatment on paneled interior walls	383	128	49024	49024
SH_D_850 Sykehjem_Doors 850 mm	Wooden single door 2100x850	02.4.H.002 Interior door, wood, 8x21	23	4115	94645	94645
SH_D_FD 2200 Sykehjem_Doors_Fire door 2200 mm	Double wooden door 2100x2200	02.4.H.046 Double leaf door EI60 21x21	3	30205	90615	90615
SH_D_950 Sykehjem_Doors 950 mm	Wooden single door 2100x950	02.4.H.003 Interior door, wood, 9x21	19	4369	83011	83011
	Door wood cladding 15 mm	02.4.6.3.0500 Wood cladding 14 mm	168	413	69384	69384
SH_D_SD 100 Sykehjem_Doors_Sliding door 100 mm	Door wood cladding 15 mm	02.4.6.3.0500 Wood cladding 14 mm	111	413	45843	45843
SH_IW_200 Sykehjem_Internal wall 200 mm	CLT wall 180 mm	02.4.1.5.0160 Solid wooden inner wall, t = 185 mm	171	2672	456912	456912
	Plaster and paint 20 mm	02.4.6.3.0110 Plasterboard 2 layers	171	390	66690	66690
SH_IW_100 Sykehjem_Internal wall 100 mm	Steel frame with mineral wool insulation 70 mm	02.4.2.1.0110 Steel frame, t = 100 mm	93.4	328	30635	30635
		02.4.5.0400 Mineral wool insulation, t = 70 mm	93.4	160	14944	14944
	Gypsum board and paint 30 mm	02.4.6.3.0110 Plasterboard 2 layers	93.4	390	36426	36426
SH_WC_20 Sykehjem_Wood cladding 20 mm	Interior wood cladding 15 mm	02.4.6.3.0500 Wood cladding 14 mm	1035	413	427290	427290
SH_C_W Sykehjem_Ceiling_Wood	Wood batten 15x35 mm	02.5.H.024 Wood ceiling	238	886	210868	210868
SH_W_20 Sykehjem_Wardrobe 20 mm	Wood board 15 mm	02.4.6.3.0330 MDF Board, t = 16 mm	627	595	373065	373065
SH_CW_NB Sykehjem_Curtain wall_New balcony	Curtain wall	02.3.J.005 Glass façade, u-value <1.2	125	5072	0	634000
		02.3.J.006 Glass façade, u-value <0.8	125	5812	726500	0
DW_D_O Dementia wings_Doors_Office	Door wood cladding 15 mm	02.4.6.3.0500 Wood cladding 14 mm	142	413	58646	58646
DW_D_BR Dementia wings_Doors_Bedrooms	Door painting	02.4.J.007 Treatment on paneled interior walls	120	128	15360	15360
DW_D_E Dementia wings_Doors_Exterior	Door wood cladding 15 mm	02.4.6.3.0500 Wood cladding 14 mm	74.5	413	30769	30769
DW_D_LR Dementia wings_Doors_Living rooms	Door painting	02.4.J.007 Treatment on paneled interior walls	98.6	128	12621	12621
DW_P_5 Dementia wings_Painting_5 mm	Wall painting	02.4.J.002 Paint on plastered interior walls	253	179	45287	45287
DW_WC_15 Dementia wings_Wood cladding 15 mm	Interior wood cladding 15 mm	02.4.6.3.0500 Wood cladding 14 mm	517	413	213521	213521
DW_C_W Dementia wing_Ceiling_Wood	Wood batten 15x35 mm	02.5.H.024 Wood ceiling	66	886	58476	58476
Labour TEK (SH)			3129	1922		6013746
Labour PH (SH)			3129	2046	6401729	
Labour TEK (DW)			1271	1922		2443054
Labour PH (DW)			1271	2046	2600671	

Appendix 6: EAT-HC questionnaire

Baseline scenario

Environmental Audit Tool-Higher Care (EAT-HC) scores of the dementia wings and the *sykehjem* unit in Trondhjems Hospital before the renovation.

Quest. Number	Item Description	Dementia wings			*Sykehjem*		
		Actual Score	Max. Score	RFI Score	Actual Score	Max. Score	RFI Score
	SUM	**7**	**18**	**11**	**11**	**18**	**7**
1.	***Unobtrusively reduce risks***						
1.1	The outside perimeter is secure	1	2	1	1	2	1
1.2	Outside, the gate can be secured	1	2	1	1	2	1
1.3	The front door can be secured	1	2	1	1	2	1
1.4	Outside, access is step free	0	1	1	0	2	1
1.5	Outside, floor surfaces are safe	0	1	1	0	1	1
1.6	Outside, path surfaces are even	1	1	0	1	1	0
1.7	Outside, paths are obstacle free	1	1	0	1	1	0
1.8	Outside, paths are the appropriate width	0	1	1	1	1	0
1.9	Outside, ramps are wheelchair accessible	0	1	1	1	1	0
1.10	The resident kitchen can be secured	1	2	1	1	2	1
1.11	The resident's kitchen has safe appliances	N/A	N/A	N/A	N/A	N/A	N/A
1.12	The residents' kitchen has a master switch	N/A	N/A	N/A	N/A	N/A	N/A
1.13	Inside, floor surfaces are safe	1	1	0	1	1	0
1.14	Inside, contrast between floor surfaces is avoided	0	1	1	0	1	1
1.15	Inside, ramps are wheelchair accessible	0	1	1	1	1	0
1.16	Bed/ensuite transfer is easy	0	1	1	1	1	0

2.	***Provide a human scale***						
	SUM	**3**	**4**	**1**	**2**	**4**	**2**
2.1	Number of people in the unit	2	3	1	2	3	1
2.2	Common areas are comfortable in scale	1	1	0	0	1	1

3.	***Allow people to see and be seen***						
	SUM	**6**	**16**	**10**	**5**	**16**	**11**
3.1	The lounge room is seen from the bedrooms	1	3	2	1	3	2
3.2	Bedrooms are seen from the lounge room	1	3	2	1	3	2
3.3	The dining room is seen from the bedrooms	1	3	2	1	3	2
3.4	The garden/outside area exit is seen from the lounge/dining room	1	1	0	1	1	0
3.5	The dining room is seen from the lounge room	0	1	1	1	1	0
3.6	The toilet is seen from the lounge room	0	1	1	0	1	1
3.7	The toilet is seen from the dining room	0	1	1	0	1	1
3.8	The lounge room is seen by the staff	1	1	0	0	1	1
3.9	The dining room is seen by the staff	0	1	1	0	1	1
3.10	Outside, the residents' area is seen by staff	1	1	0	0	1	1

4.	***Manage levels of stimulation - Reduce unhelpful stimulation***						
	SUM	**4**	**6**	**2**	**5**	**6**	**1**
4.1	Doors to dangerous areas are seen	0	1	1	1	1	0
4.2	Wardrobes are cluttered	1	1	0	1	1	0
4.3	Public address/paging/call system is intrusive	0	1	1	0	1	1
4.4	Doors, when closing, are noisy	1	1	0	1	1	0
4.5	Visual clutter is absent	1	1	0	1	1	0
4.6	Inside, glare is avoided	1	1	0	1	1	0

5.	***Manage levels of stimulation - Optimise helpful stimulation***						
	SUM	**14**	**23**	**9**	**10**	**23**	**13**
5.1	Rooms are easily identifiable	1	1	0	1	1	0
5.2	The dining room is clearly recognisable	1	1	0	1	1	0
5.3	The pathway is defined from the bedroom to the dining room	1	3	2	0	3	3
5.4	The lounge room is clearly recognisable	1	1	0	1	1	0
5.5	Corridors are clearly identifiable	0	1	1	0	1	1
5.6	Bedrooms are individually identified	1	1	0	0	1	1
5.7	Shared bathrooms/toilets are clearly identified	N/A	N/A	N/A	N/A	N/A	N/A
5.8	The toilet pan can be seen from the bed	1	1	0	0	1	1
5.9	Toilet seats contrast with the background	2	2	0	2	2	0
5.10	The window view is attractive from the bed	3	3	0	2	3	1
5.11	Inside, contrast aids the visibility of surfaces/objects	1	1	0	1	1	0
5.12	Inside, olfactory cues are used	0	1	1	0	1	1
5.13	Inside, tactile cues are used	0	1	1	0	1	1

5.14	Inside, auditory cues are used	0	1	1	0	1	1
5.15	Outside, contrast aids the visibility of surfaces/objects	0	1	1	0	1	1
5.16	Outside, materials/ finishes are varied	1	1	0	1	1	0
5.17	Outside, olfactory cues are used	0	1	1	0	1	1
5.18	Outside, auditory cues are used	0	1	1	0	1	1
5.19	The outside view from the dining/lounge is attractive	1	1	0	1	1	0
6.	***Support movement and engagement***						
	SUM	**8**	**9**	**1**	**7**	**9**	**2**
6.1	The inside/outside path clearly returns residents to the starting point	0	1	1	1	1	0
6.2	Outside, the path passes participation opportunities	1	1	0	1	1	0
6.3	Outside, activity choices are available	1	1	0	1	1	0
6.4	Outside, seating is available	1	1	0	1	1	0
6.5	Outside, sunny and shady areas are available	1	1	0	1	1	0
6.6	Outside, passive activities are available	1	1	0	1	1	0
6.7	Outside, verandahs and shaded seating are available	1	1	0	1	1	0
6.8	Inside, the path passes participation opportunities	1	1	0	0	1	1
6.9	Inside, the path passes conversation/rest areas	1	1	0	0	1	1
7.	***Create a familiar place***						
	SUM	**6**	**8**	**2**	**8**	**8**	**0**
7.1	Lounge furniture is familiar	2	2	0	2	2	0
7.2	Bedroom f urniture is familiar	2	2	0	2	2	0
7.3	Bedrooms have residents' own ornaments/photos	1	2	1	2	2	0
7.4	Bedrooms have residents' own furniture	1	2	1	2	2	0
8.	***Provide a variety of places to be alone or with others - In the unit***						
	SUM	**9**	**10**	**1**	**7**	**10**	**3**
8.1	Inside, small group areas are available	2	2	0	1	2	1
8.2	Inside, private conversation areas are available	3	3	0	2	3	1
8.3	Inside, a variety of different areas are available	1	2	1	1	2	1
8.4	The dining room allows for dining alone	1	1	0	1	1	0
8.5	The lounge room includes private conversation areas	1	1	0	1	1	0
8.6	Outside, private conversation areas are available	1	1	0	1	1	0
9.	***Provide a variety of places to be alone or with others - In the community***						
	SUM	**3**	**3**	**0**	**3**	**3**	**0**
9.1	Community interaction areas are accessible	1	1	0	1	1	0
9.2	Family/dining area is available in the facility	1	1	0	1	1	0
9.3	Visitors' break area is available	1	1	0	1	1	0
10.	***Design in response to vision for a way of life***						
	SUM	**6**	**6**	**0**	**4**	**6**	**2**
10.1	This unit has a vision/purpose for residents' way of life	1	1	0	1	1	0
10.2	The environment enables this unit's vision/purpose	5	5	0	3	5	2

Summary scenario: Sustainable renovation

Environmental Audit Tool-Higher Care (EAT-HC) scores of the dementia wings and the *sykehjem* unit in Trondhjems Hospital after the renovation.

Quest. Number	Item Description	Dementia wings			*Sykehjem*		
		Actual Score	Max. Score	RFI Score	Actual Score	Max. Score	RFI Score
	SUM	8	18	10	13	18	5
1.	***Unobtrusively reduce risks***						
1.1	The outside perimeter is secure	1	2	1	1	2	1
1.2	Outside, the gate can be secured	1	2	1	1	2	1
1.3	The front door can be secured	1	2	1	1	2	1
1.4	Outside, access is step free	0	1	1	0	2	1
1.5	Outside, floor surfaces are safe	0	1	1	0	1	1
1.6	Outside, path surfaces are even	1	1	0	1	1	0
1.7	Outside, paths are obstacle free	1	1	0	1	1	0
1.8	Outside, paths are the appropriate width	0	1	1	1	1	0
1.9	Outside, ramps are wheelchair accessible	0	1	1	1	1	0
1.10	The resident kitchen can be secured	1	2	1	1	2	1
1.11	The resident's kitchen has safe appliances	N/A	N/A	N/A	N/A	N/A	N/A
1.12	The residents' kitchen has a master switch	N/A	N/A	N/A	N/A	N/A	N/A
1.13	Inside, floor surfaces are safe	1	1	0	1	1	0
1.14	Inside, contrast between floor surfaces is avoided	0	1	1	0	1	1
1.15	Inside, ramps are wheelchair accessible	0	1	1	1	1	0
1.16	Bed/ensuite transfer is easy	0	1	1	1	1	0

2.	***Provide a human scale***						
	SUM	**3**	**4**	**1**	**3**	**4**	**2**
2.1	Number of people in the unit	2	3	1	2	3	1
2.2	Common areas are comfortable in scale	1	1	0	1	1	1

3.	***Allow people to see and be seen***						
	SUM	**6**	**16**	**10**	**11**	**16**	**5**
3.1	The lounge room is seen from the bedrooms	1	3	2	2	3	1
3.2	Bedrooms are seen from the lounge room	1	3	2	2	3	1
3.3	The dining room is seen from the bedrooms	1	3	2	2	3	1
3.4	The garden/outside area exit is seen from the lounge/dining room	1	1	0	1	1	0
3.5	The dining room is seen from the lounge room	0	1	1	1	1	0
3.6	The toilet is seen from the lounge room	0	1	1	1	1	0
3.7	The toilet is seen from the dining room	0	1	1	1	1	0
3.8	The lounge room is seen by the staff	1	1	0	1	1	0
3.9	The dining room is seen by the staff	0	1	1	0	1	1
3.10	Outside, the residents' area is seen by staff	1	1	0	0	1	1

4.	***Manage levels of stimulation - Reduce unhelpful stimulation***						
	SUM	**5**	**6**	**1**	**5**	**6**	**1**
4.1	Doors to dangerous areas are seen	1	1	0	1	1	0
4.2	Wardrobes are cluttered	1	1	0	1	1	0
4.3	Public address/paging/call system is intrusive	0	1	1	0	1	1
4.4	Doors, when closing, are noisy	1	1	0	1	1	0
4.5	Visual clutter is absent	1	1	0	1	1	0
4.6	Inside, glare is avoided	1	1	0	1	1	0

5.	***Manage levels of stimulation - Optimise helpful stimulation***						
	SUM	**19**	**23**	**4**	**19**	**23**	**4**
5.1	Rooms are easily identifiable	1	1	0	1	1	0
5.2	The dining room is clearly recognisable	1	1	0	1	1	0
5.3	The pathway is defined from the bedroom to the dining room	2	3	1	3	3	0
5.4	The lounge room is clearly recognisable	1	1	0	1	1	0
5.5	Corridors are clearly identifiable	1	1	0	1	1	0
5.6	Bedrooms are individually identified	1	1	0	1	1	0
5.7	Shared bathrooms/toilets are clearly identified	N/A	N/A	N/A	N/A	N/A	N/A
5.8	The toilet pan can be seen from the bed	1	1	0	1	1	0
5.9	Toilet seats contrast with the background	2	2	0	2	2	0
5.10	The window view is attractive from the bed	3	3	0	2	3	1
5.11	Inside, contrast aids the visibility of surfaces/objects	1	1	0	1	1	0
5.12	Inside, olfactory cues are used	1	1	0	1	1	0
5.13	Inside, tactile cues are used	1	1	0	1	1	0
5.14	Inside, auditory cues are used	1	1	0	1	1	0
5.15	Outside, contrast aids the visibility of surfaces/objects	0	1	1	0	1	1
5.16	Outside, materials/ finishes are varied	1	1	0	1	1	0
5.17	Outside, olfactory cues are used	0	1	1	0	1	1
5.18	Outside, auditory cues are used	0	1	1	0	1	1
5.19	The outside view from the dining/lounge is attractive	1	1	0	1	1	0

6.	***Support movement and engagement***						
	SUM	**8**	**9**	**1**	**9**	**9**	**0**
6.1	The inside/outside path clearly returns residents to the starting point	0	1	1	1	1	0
6.2	Outside, the path passes participation opportunities	1	1	0	1	1	0
6.3	Outside, activity choices are available	1	1	0	1	1	0
6.4	Outside, seating is available	1	1	0	1	1	0
6.5	Outside, sunny and shady areas are available	1	1	0	1	1	0
6.6	Outside, passive activities are available	1	1	0	1	1	0
6.7	Outside, verandahs and shaded seating are available	1	1	0	1	1	0
6.8	Inside, the path passes participation opportunities	1	1	0	1	1	0
6.9	Inside, the path passes conversation/rest areas	1	1	0	1	1	0

7.	***Create a familiar place***						
	SUM	**8**	**8**	**0**	**8**	**8**	**0**
7.1	Lounge furniture is familiar	2	2	0	2	2	0
7.2	Bedroom f urniture is familiar	2	2	0	2	2	0
7.3	Bedrooms have residents' own ornaments/photos	2	2	0	2	2	0
7.4	Bedrooms have residents' own furniture	2	2	0	2	2	0

8.	***Provide a variety of places to be alone or with others - In the unit***						
	SUM	**9**	**10**	**1**	**10**	**10**	**0**
8.1	Inside, small group areas are available	2	2	0	2	2	0
8.2	Inside, private conversation areas are available	3	3	0	2	3	0
8.3	Inside, a variety of different areas are available	1	2	1	2	2	0
8.4	The dining room allows for dining alone	1	1	0	1	1	0
8.5	The lounge room includes private conversation areas	1	1	0	1	1	0
8.6	Outside, private conversation areas are available	1	1	0	1	1	0

9.	***Provide a variety of places to be alone or with others - In the community***						
	SUM	**3**	**3**	**0**	**3**	**3**	**0**
9.1	Community interaction areas are accessible	1	1	0	1	1	0
9.2	Family/dining area is available in the facility	1	1	0	1	1	0
9.3	Visitors' break area is available	1	1	0	1	1	0

10.	***Design in response to vision for a way of life***						
	SUM	**6**	**6**	**0**	**6**	**6**	**0**
10.1	This unit has a vision/purpose for residents' way of life	1	1	0	1	1	0
10.2	The environment enables this unit's vision/purpose	5	5	0	5	5	0

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