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Simulation Assisted Target Setting for Building Life-cycle Energy Usage in the Predesign Phase

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Abstract

The construction, heating, and electricity consumption of buildings contribute to over 30% of the greenhouse gas emissions of Finland, with buildings accounting for nearly 40% of total energy consumption. Given these figures, the construction sector holds significant potential for emission reduction. Maximizing this potential is essential to meet the goals of the Paris Agreement and mitigating the global average temperature increase within the acceptable limits.

In light of the pressing need, the thesis embarked on developing an index for assessing the energy consumption of buildings, enabling users to establish energy efficiency targets prior to the planning phase. By integrating energy efficiency as a primary goal from the beginning, rather than as an outcome of subsequent choices and planning, users gain the ability to actively shape the energy performance. As a result, the immediate consequences of energy efficiency targets, such as the impact on building cost and carbon footprint, become evident. Consequently, users can assess the feasibility and impact of their chosen energy efficiency objectives.

The research began with a literature review encompassing the key environmental certifications like LEED, BREEAM, and RTS environmental classification, as well as relevant European and Finnish legislation and building regulations. Subsequently, expert interviews were conducted. Utilizing insights from both the literature review and interviews, the Energy Usage Index was developed. Following this, a case-study was conducted to assess the applicability of Haahtela's Realaizer building simulation model to meet the requirements of the Energy Usage Index.

The case-study revealed that the implementation of the Energy Usage Index led to a notably 35% reduction in energy consumption for the simulated office building. However, the study identified limitations in the compatibility of the Realaizer simulation model with the Energy Usage Index requirements. Consequently, the thesis outlined development areas and improvement proposals to address these shortcomings.

Keywords Building energy usage, energy efficient building, energy usage index

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Tiivistelmä

Rakentaminen, rakennusten lämmittäminen, sekä niiden sähkön kulutus aiheuttavat yli 30 % Suomen kasvihuonepäästöistä, ja rakennukset käyttävät lähes 40 % kokonaisenergian kulutuksesta. Rakennussektorilla on suuri päästövähennyspotentiaali, jota tulee hyödyntää, jotta saavutetaan Pariisin ilmastosopimuksen tavoitteet, ja pidetään maapallon keskilämpötilan nousu sallituissa rajoissa.

Edellä mainituiden syiden takia diplomityön tarkoituksena on kehittää rakennusten energiankäytön indeksi, jonka avulla käyttäjät voivat asettaa energiatehokkuustavoitteen rakennuksellensa jo ennen suunnitteluvaihetta. Tällöin energiatehokkuus on alusta alkaen mukana rakennusta määrittävänä tavoitteena, sen sijaan, että se olisi valintojen ja suunnittelun lopputulos, jolloin siihen ei käytännössä voi vaikuttaa. Näin energiatehokkuustavoitteen seuraukset tulevat myös heti ilmi, esimerkiksi rakennuksen hinnassa ja hiilijalanjäljessä, ja käyttäjä näkee, kannattaako asetettua energiatehokkuustavoitetta tavoitella.

Tutkimus aloitettiin kirjallisuuskatsauksella, jossa tutustuttiin yleisimpiin ympäristösertifikaatteihin kuten LEED, BREEAM, ja RTS ympäristöluokitus, sekä Euroopan ja Suomen lainsäädäntöön ja rakentamismääräyksiin. Kerättyyn tietoon perustuen suoritettiin asiantuntijahaastattelut. Haastatteluiden sekä kirjallisuuskatsauksen perusteella luotiin Energiankäyttöindeksi. Energiankäyttöindeksiä käyttäen suoritettiin tapaustutkimus, jossa tutkittiin, kuinka hyvin Haahtelan Realaizer- simulaatiomalli pystyy vastaamaan Energiankäyttöindeksin tarpeisiin.

Tapaustutkimuksessa simuloidun toimistorakennuksen energiankulutusta pystyttiin Energiankäyttöindeksin avulla pienentämään 35 % lähtötasoon verrattuna. Tutkimuksessa huomattiin, ettei Realaizer- simulaatiomalli vastaa täysin Energiankäyttöindeksin tarpeisiin, ja kehityskohdat ja parannusehdotukset esitettiin diplomityössä.

Avainsanat Rakennusten energiankäyttö, energiatehokas rakennus, energiankäyttöindeksi

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Preface and acknowledgements

This thesis has been conducted in collaboration with Haahtela-kehitys Oy, and I am grateful to them for giving me this opportunity. I extend special thanks to my advisors Saku Metsärinne and Daniel Böhling for their invaluable guidance, assistance, and willingness to address all my questions. I also appreciate the contributions of my supervisor, Risto Kosonen, for his valuable corrections and comments.

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Otaniemi, 17 May 2024
Suvi Kallio

Abbreviations

ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Methodology
COP	Coefficient of performance
EPBD	Energy Performance of Buildings Directive
g-value	Total solar energy transmittance
ISO	International Organization for Standardization
LEED	Leadership in Energy and Environmental Design
NZEB	Nearly zero energy building
PV	Photo voltaic
SPF	Seasonal performance factor
U-value	Heat transmission coefficient
USGBC	U.S. Green Building Council
VVVF	Variable-voltage and variable-frequency

1 Introduction

1.1 Background

The building sector plays a significant role in achieving the environmental targets established by the climate policy of European Union (EU), which derives from the United Nations Framework Convention on Climate Change, the Paris Agreement, and the Kyoto Protocol. In Finland, buildings account for a third of greenhouse gas emissions, and consume approximately 40% of the total energy utilized (Green Building Council Finland, n.d.). Hence, the sustainability and energy efficiency of the building stock are crucial in achieving the environmental targets. Implementing building energy efficiency technologies and policies is not only cost-effective for enhancing energy security and productivity, but also offers benefits like improved health and well-being, reduced local air pollution, climate change adaptation, and job creation (Ürge-Vorsatz et al., 2020; Dean et al., 2016).

As emerging economies experience population and purchasing power growth, the demand for energy in the building sector is also growing. Dean et al. (2016) estimates that the energy demand could increase by 50%, and global building area is expected to double by 2050, compared to 2016 levels. The role of building sector is well recognized as a pivotal element in achieving the goal of the Paris Agreement of limiting global warming to well-below 2°C (Dean et al., 2016). According to the 2050 low-carbon economy roadmap by the European Commission, a reduction of 80% to 95% in greenhouse gas emissions within the built environment relative to the 1990 levels, is necessary to keep the global temperature within the 2°C limit (European Commission, 2011).

The carbon footprint of building life cycle encompasses various factors, including the manufacturing of building materials, transportation, site operations, maintenance and repair, building product changes, energy and water consumption, as well as demolition and material processing. Currently, the largest contributor to the carbon footprint of a building is energy usage during the operational phase. However, Bionova (2017) states that extensive research indicates that construction materials play a significant role in lifetime emissions. As energy production emissions decrease and building efficiency improves, the proportion of emissions associated with construction materials increases. Emission control for buildings would also encourage the product and method development of the industry to devise better solutions (Bionova, 2017).

The energy consumed by a building consists of heating, potential cooling, and the energy used by electrical equipment and lighting. As stated by Dean et al. (2016), space heating and cooling demand in buildings is a priority area for energy efficiency action in the building sector. Space heating accounts for more than one-third of global energy consumption in buildings and will maintain its significance as a major energy-consuming factor even in 2050. In contrast, space cooling has a significantly smaller share of 5% of global energy demand in buildings but is the fastest-growing end use and could increase by tenfold by 2050 in some warm-climate and rapidly emerging regions. This growth, while promising in terms of comfort and lifestyle enhancements, carries the risk of straining power sector infrastructure already operating at-capacity, particularly in aging systems. To address this challenge, it is needed to improve the building envelope efficiencies, ramp up energy performances of cooling equipment, and reduce the growing global demand for mechanical conditioned thermal comfort, for example through natural cooling solutions (Dean et al., 2016).

Motiva (2022) noted that targets for energy consumption should be established for electricity, heat, water, and any alternative cooling methods. To track these targets effectively, buildings should be equipped with system specific energy metrics. Moreover, these measurements should be integrated with a robust reporting system, allowing for hourly monitoring of the consumption of diverse systems (Motiva, 2022).

Ürge-Vorsatz et al. (2020) discussed in their article, that in recent decades, the concepts of nearly zero energy buildings, and zero energy buildings have gained prominence as potential solutions to the increasing energy consumption and CO_2 emissions from the building sector. In the literature, the definitions for nearly zero energy buildings, and zero energy buildings vary. Nearly zero energy buildings are either designed to minimize operational energy usage, utilize renewable energy generation and energy saving measures, or demand less operating and life-cycle energy compared to conventional ones (Ürge-Vorsatz et al., 2020). The Energy Performance of Buildings Directive mandated that by the end of 2020, all new buildings in EU countries must be nearly zero energy buildings (European Commission, n.d.a).

Zero energy buildings, also known as net zero energy buildings, elevate the sustainability benchmark. According to European Commission (n.d.a), these structures integrate energy efficiency with renewable energy generation, ensuring the buildings consume only what they can produce on-site through renewable sources within a given timeframe. Notably, they produce no on-site carbon emissions from fossil fuels. The zero energy building requirement should apply as of 1 January 2030 for all new buildings in all EU countries (European Commission, n.d.a).

1.2 Objectives and the research questions

Rather than treating the energy efficiency of the building as an outcome emerging from choices and planning, it should be integrated as a foundational target right from the beginning in the predesign phase. The impacts of this target become evident immediately and can be reflected to for example the price of the building or its carbon footprint, allowing for a prompt assessment of whether pursuing the target is justified.

Realaizer building simulation model by Haahtela is an advanced building simulation software that provides users with the ability to model detailed data on construction, life cycle costs, and environmental impact prior to initiating the design process. In addition to computing the annual energy consumption of simulated buildings, the modelling ensures compliance with energy efficiency regulations. However, users seeking for enhanced energy efficiency beyond regulatory standards must modify the initial building data by themselves.

The primary goal of the thesis is to develop an Energy Usage Index which enables users to establish an energy efficiency target for buildings easily and quickly. The index will be utilized in the predesign phase to guide the development of buildings and achieve the sustainability goals. In developing the Energy Usage Index, the key performance indicators are derived from energy usage standards and legislation, existing literature, and interviews with industry professionals.

The primary research question of the thesis is: how can Haahtela's Realaizer simulation model be utilized to establish a life-cycle energy usage target for a building during the predesign phase? The related subordinate questions of the research question are:

1. What are the key performance indicators of life-cycle energy usage and how are they measured?
2. How can the Realaizer simulation model be utilized to achieve the targets defined in the indicators of the Energy Usage Index?
3. What criteria must the building meet to reach the desired targets set in the Energy Usage Index?

1.3 Research methodology

Determining the life-cycle energy usage target for a building requires a comprehensive analysis of relevant resources related to building energy consumption. This includes scholarly articles, building code and classification, and insights gathered from interviews with experienced industry professionals. Drawing from literature review and interview findings, an Energy Usage Index was constructed and simulated using Realaizer simulation model from Haahtela.

1.4 Scope and limits

The research scope of the thesis is limited to new buildings located in Finland, and their energy usage during the operational phase. The thesis only considers the energy usage of the building, not its carbon footprint. The thesis does not take a stance on endorsing measures like monitoring energy consumption. This limitation of the index arises from the understanding that energy monitoring primarily measures energy consumption rather than actively reduces it. These limits are intentionally set to maintain a manageable research scope and ensure the attainability of the research objectives.

1.5 Thesis structure

The thesis is structured into six chapters. Chapter 2 presents a comprehensive literature review focusing on prevalent environmental certificates, and European and Finnish legislation related to building energy usage. Chapter 3 delves into the interviews conducted as part of the research. Chapter 4 focuses on developing the Energy Usage Index and its associated indicators, based on the literature review and interviews. The chapter also includes a case-study carried out using Realaizer simulation model from Haahtela. Chapter 4 also discusses the potential enhancements to Realaizer, aiming to influence all aspects of the Energy Usage Index. Chapter 5 provides discussion of the results, while Chapter 6 offers key conclusions drawn from the research.

2 Energy usage of buildings

2.1 Energy usage and environmental classification methods

2.1.1 BREEAM

Building Research Establishment Environmental Assessment Methodology (BREEAM) is a science-based collection of validation and certification systems for built environment (McPartland, 2016). It was launched by the Building Research Establishment (BRE) in 1990, and is utilized to masterplan projects, infrastructure, and buildings. BREEAM sets targets for the environmental performance of buildings through the design, specification, construction, and operation phases, and can be applied to new and renovated buildings. It evaluates the procurement, design, construction, and operation of a building against a selection of targets which are based on performance benchmarks (McPartland, 2016).

According to the article by McPartland (2016), BREEAM focuses on sustainable value across a variety of categories, which include energy, land use and ecology, water, health and wellbeing, pollution, transport, materials, waste, and management. Each category focusses on the most significant factors, including decreased carbon emissions, low impact design, ecological value, adaption to climate change, and biodiversity protection. A total of 100 credits can be attained from the aforementioned categories. Furthermore, an additional innovation category offers the opportunity to secure an extra 10 credits. Notably, there is no requirement to target the innovation category, and receiving 0 points in the category does not impact the overall BREEAM rating of the building. Certified buildings are classified into Unclassified (< 30%), Pass (> 30%), Good (> 45%), Very Good (> 55%), Excellent (> 70%), and Outstanding (> 85%) The percentages represent the proportion of the full 100 credits (McPartland, 2016).

BREEAM is based on common European standards, for example national and international building codes, International Organization for Standardization (ISO) standards and energy performance standards and is therefore one of the leading environmental classification systems for construction in Europe, according to Green Building Council Finland (n.d.). The classification metrics can be applied to Finnish best practices to simplify the implementation of project requirements (Green Building Council Finland, n.d.).

McPartland (2016) states that in the UK, the BREEAM rating benchmark levels allow a client to compare the performance of an individual building with other BREEAM rated buildings of similar function. At present, it is estimated that there are almost 550 000 BREEAM certified developments, and more than 2 250 000 buildings are going to be assessed. Demand from outside of the UK has encouraged BRE to expand BREEAM versions to international projects. At present, BREEAM has been applied in over 70 countries and it enjoys around 80% market share in Europe (McPartland, 2016).

2.1.2 LEED

Leadership in Energy and Environmental Design (LEED) is the most used building environmental classification system in the world, launched in 1998 by the U.S. Green Building Council (USGBC), states Kirvan (2023). Its strengths are a uniform set of criteria and comparability around the world. LEED is used in more than 167 countries and territories (Kirvan, 2023).

LEED certification is a globally recognized symbol of sustainability achievement and leadership, states European Commission (n.d.a). The certification provides a framework for highly efficient, healthy, and cost-saving green buildings. Many of the requirements are based on American practices, but it is possible to apply European and Finnish practices to some of them (European Commission, n.d.a). According to Kirvan (2023), LEED certification aims to improve building and construction project performance across different areas of environmental and human health. The areas are use of integrative process, location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation, and regional priority (Kirvan, 2023).

According to Kirvan (2023), LEED certification is available for new buildings, construction, and existing buildings. It has four levels, which are based on the number of points earned in an examination. With a maximum of 110 points attainable, the certification levels include Certified (40-49 points), Silver (50-59 points), Gold (60-79 points), and Platinum (80+ points) (Kirvan, 2023).

Of all the credits, 35% relate to climate change, 20% affect human health, 15% impact water resources, 10% affect biodiversity, 10% relate to the green economy, and 5% impact community and natural resources respectively (Kirvan, 2023). LEED is not just a point system; it provides a framework for the project team to identify and implement green building solutions through the building lifetime.

2.1.3 Level(s)

Level(s) is a voluntary framework which building specialists in Europe can utilize to measure, report, and share the environmental performance of their buildings (One Click LCA, n.d.). It was developed by European Commission to improve the sustainability of buildings (Dodd et al., 2021). Level(s) is a common EU framework of core indicators for assessing the sustainability of residential and office buildings. It can be applied from the earliest stages of conceptual design through to the projected end of life of the building. The focus of Level(s) is environmental performance, but it also assesses health and comfort, life cycle cost, and potential future risks to performance (Dodd et al., 2021).

Level(s) consists of six macro-objectives which are greenhouse gas emissions along a building's life cycle, resource efficient and circular material life cycles, efficient use of water resources, healthy and comfortable spaces, adaptation to climate change, and optimized life cycle cost and value. There is also a set of 16 indicators, which can be used to measure the performance of buildings and their contribution to the six macro-objectives (One Click LCA, n.d.).

2.1.4 Finnish Environmental classification of building information

Environmental classification of building information, formerly known as RTS environmental classification, is an environmental classification for construction and property maintenance, developed by the Building Information Foundation (Rakennustietosäätiö) (Green Building Council Finland, n.d.). The classification has been developed for Finnish conditions and considers Finnish legislation, conditions, and the versatility of the real estate stock. The classification is based on European Standards (CEN TC 350 standards) and the common practices of the industry in Finland, such as Classification of Indoor Environment (Sisäilmastoluokitus), M1-emission classification (M1-emissioluokitus), building life cycle indicators, Kuivaketju 10- model and the Green Factor Method (Green Building Council Finland, n.d.).

According to Rakennustieto (2022), the environmental classification of building information is suitable for new construction and renovation projects, as well as for changes in the purpose of use. It can be employed across projects of varying sizes and types, such as educational and kindergarten facilities, residential buildings, office and commercial buildings, and accommodation buildings (Rakennustieto, 2022).

The environmental classification (Rakennustieto, 2022) encompasses five primary categories that embrace the triad of sustainable development: economic, ecological, and social sustainability. Additionally, it includes the process category, which assesses the construction process, and innovations category which considers new innovations and development ideas. RTS environmental classification includes 28 evaluation criteria, with a maximum score of 100 points. Furthermore, it provides an opportunity to earn an additional 10 points from the innovations category (Rakennustieto, 2022).

RTS environmental classification (Rakennustieto, 2022) utilizes a five-step star rating system to indicate the grade achieved, which is determined by the number of points attained. The different ratings are; no rating (< 25 points), one star (meeting the usual level of environmental quality, ≥ 25 points), two stars (exceeding the usual level of environmental quality, ≥ 40 points), three stars (reflecting a good level of environmental quality, ≥ 55 points), four stars (high level of environmental quality, ≥ 70 points), and five stars (signifying an excellent level of environmental quality, ≥ 85 points). In addition, certain levels are associated with mandatory minimum requirements that must be fulfilled (Rakennustieto, 2022).

2.1.5 Finnish Energy class

Energy class is the calculated reference number of energy efficiency of the building, as outlined in the guide from the Ministry of the Environment (2018a). It is an important part of the energy certificate of a building. There are seven different energy efficiency classes ranging from A to G, with class A representing the highest level of efficiency and class G indicating the lowest level. New buildings are obligated to satisfy the minimum level of energy efficiency according to the Finnish Energy Efficiency Regulation (1010/2017). Typically, new buildings that meet the regulated level are categorized under the energy efficiency class B. The energy efficiency requirement sets a minimum level for the energy efficiency of the building, ensuring that a certain standard is met (Ministry of the Environment, 2018a).

According to the Ministry of Environment (2018a), the calculation begins with determining the purchase energy consumption, which is based on the standard usage of the building. The calculation involves weighing the purchase energy consumption according to coefficients of different energy forms (Ministry of the Environment, 2018a). For district heating the coefficient is 0.5, for electricity 1.2, for fossil fuels 1.0, for renewable fuels 0.5, and for district cooling 0.28 (Ministry of the Environment, 2018b). The total result is reported per heated net area of the building per year, and the unit of the Energy class is kilowatt-hour per heated net area per year (kWh_e/m^2a) (Ministry of the Environment, 2018a).

2.1.6 Energy certificate

Energy certificate is an official document describing the energy efficiency of a building, states the Ministry of the Environment (2018a). In Finland, it has been in use since 2008. Energy certificate is a mandatory requirement for buildings over 50 m^2 that are under construction, as well as for buildings that are being rented out or sold (Ministry of the Environment, 2018a). Motiva (2022) discusses that energy certificate enables the comparison of different buildings by assessing the characteristics of the buildings, and the energy consumption resulting from them. This comparison focuses solely on the building itself and its technical systems (Motiva, 2022).

In the guide from the Ministry of the Environment (2018a) it is stated that energy certificate is a standardized eight-page document that applies uniformly to all types of buildings. It consists of the calculated Energy class of the building and calculated purchased energy consumption. In addition, if information on purchased energy is available, it must be included in the certificate. Energy certificates aim to enhance target setting and comparison of the energy efficiency of buildings. The certificates also aim to promote energy efficiency practices and encourage the utilization of renewable energy sources (Ministry of the Environment, 2018a).

2.1.7 Method comparison

This chapter presents a comparison of BREEAM, LEED, RTS environmental classification, Level(s), Energy certificate, and Energy class, and their different criteria.

As previously noted, BREEAM, is originated as a British certificate, and is tailored to comply with British and European Construction legislation, as well as incorporating British best practices. In contrast, LEED is tailored specifically for U.S. buildings, with guidance drawn from the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) standards. Conversely, RTS environmental classification, Energy class and Energy certificate are tailored to comply with Finnish and European legislation, taking into consideration the Finnish climate conditions.

LEED, RTS environmental classification, Energy class, and Energy Certificate base their thresholds on percentages whereas BREEAM relies on quantitative standards. Also, LEED, RTS environmental classification, Energy class and Energy Certificate are relatively more straightforward to comprehend compared to the complexity of BREEAM.

Level(s) is specifically designed for residential and office buildings, offering no scored criteria or distinct certification levels for the buildings. Instead, it functions as a reference framework, allowing member countries to develop their individual sustainability assessment methods. Consequently, due to its design, Level(s) is not utilized in the thesis.

While LEED, BREEAM and RTS environmental classification deal with the environmental sustainability of buildings, the significant difference between them is how the rating is awarded. BREEAM employs licensed assessors who evaluate the provided evidence against the credit criteria. In contrast to BREEAM, LEED does not rely on assessors to gather evidence for certification. Instead, the design team of the building compiles data and submits it to the USGBC. Following a throughout review, LEED certification is awarded if the building satisfies the requirements. Like in BREEAM, in the RTS environmental classification, an auditor separate from the project is responsible for the classification of the building. Following the audit, a panel of expert evaluators then assigns the building its classification.

Environmental certificates generally align on core criteria related to building energy efficiency, but subtle distinctions set them apart. For example, the weighting of the energy use criterion varies, it is 8/110 in RTS, 13/110 in BREEAM, and 18 (20 for healthcare)/110 in LEED. Notable, the criterion for using renewable energy is present in BREEAM and LEED, but not in RTS.

BREEAM stands out by introducing criteria to assess the energy efficiency of laboratories, and elevators and escalators, aspects not covered by RTS or LEED. Another differentiating factor lies in how efficient water fixtures are addressed. While all certificates consider this, RTS utilizes a binary pass/no pass system, whereas BREEAM and LEED adopt a nuanced approach with multiple levels, assigning credits based on the efficiency of water fixtures. The variance in water consumption restrictions among certifications can be attributed to the diverse countries of origin. In Finland, where there is an abundance of fresh water, shortages are not a concern. Consequently, the necessity for stringent limitations on water usage is less evident compared to other certificates.

In addition to the classification systems discussed in this chapter, several national real estate certification systems have been developed, such as DGNB

(Germany), Miljöbyggnad (Sweden), Green Globes (USA and Canada), HQE (France), and the Nordic Swan Ecolabel (Nordic countries). It is worth noting that, except for the Nordic Swan Ecolabel, these systems typically have limited usage within their respective countries.

2.2 Energy usage legislation

2.2.1 EU perspective

Climate change and environmental degradation pose existential threats not only to Europe but also to the entire world. To overcome these challenges, the European Climate Law was made, to write into law the goals set out in the European Green Deal. All 27 EU Member States committed to turning EU into the first climate neutral continent by 2050.

According to European Commission (n.d.b), climate neutrality means achieving net zero greenhouse gas emissions for all EU countries, by cutting emissions, protecting the natural environment, and investing in green technologies. As an interim goal, by 2030 all EU countries pledged to reduce emissions by at least 55% compared to 1990 levels (European Commission, n.d.b). To boost the energy performance of buildings, the EU has established a legislative framework that includes the Energy Performance of Buildings Directive, and the Energy Efficiency Directive.

Energy Performance of Buildings Directive

The Energy Performance of Buildings Directive (EPBD) is one of the key EU laws addressing building energy efficiency. It was initially adopted in 2002 and has undergone revisions since then (European Commission, 2021), with the latest revision approved in March 2024 (One Klick LCA, 2024). The directive aims to improve the energy performance of buildings across the EU to reduce greenhouse gas emissions and enhance efficiency (European Commission, 2021).

The primary objectives are to ensure that by 2030, all new buildings are zero-emission, to enhance efforts against climate change, to reduce energy bills, and to establish support measures for vulnerable households (European Commission, n.d.a). The directive is a strong political signal of the commitment of EU to modernize the building sector considering technological improvements and to increase building renovations.

Energy Efficiency Directive

The Energy Efficiency Directive, which came into force on December 4, 2014, was amended on December 24, 2018 (Ministry of Economic Affairs and Employment of Finland, n.d.). As part of the so-called fit for 55 package, the European Commission proposed modifications to the directive. After successful tripartite negotiations, the amended directive received approval through votes in both the Council and the Parliament in July 2023. It officially came into force on October 10, 2023. National implementation takes 24 months, which means that the legislation required for implementation must be in force in October 2025 (Ministry of Economic Affairs and Employment of Finland, n.d.).

Energy Efficiency Directive sets rules and obligations for achieving the ambitious energy efficiency targets of the EU, states European Commission (n.d.c). One of the key policy instruments of the directive is that EU countries must achieve an annual saving of 1.3% of final energy consumption by 2024, rising to 1.9% by 2028, up from the 2023 level of 0.8%. It is an important instrument to drive energy savings in end-use sectors such as buildings, transport, and industry (European Commission, n.d.c).

2.2.2 Finnish legislation

Building energy efficiency in Finland is primarily governed by national legislation, although influenced and complemented by European Union laws and directives. The foundation of this national legislation is the Land Use and Building Act, which sets the general framework for planning, constructing, and maintaining buildings in Finland. The specificities and details of energy efficiency requirements for new constructions are encapsulated within the Decree of the Ministry of Environment of the Energy Efficiency of New Buildings.

Land Use and Building Act

As stated in the report from Kangas et al. (2019), the development of the low-carbon construction roadmap began in 2017, and since then the Ministry of Environment has been preparing the regulatory guidance for low-carbon assessment of the life cycle of buildings. The Ministry of the Environment has set an ambitious target to control the greenhouse gas emissions of the entire life cycle of buildings with the new Building Act by the year 2025 (Kangas et al., 2019). The primary goal of the current Land Use and Building Act is to effectively regulate the utilization and development of areas, in such a way that it creates the conditions for a good living environment and promotes ecologically, economically, socially, and culturally sustainable development (Ministry of the Environment, 2000).

The new Building Act was approved by Finnish Parliament on 1.3.2023, and it enters into force on 1.1.2025, as detailed in the announcement from the Ministry of the Environment (2023). The most significant change to the current Land Use and Building Act is the inclusion of climate change mitigation into construction legislation. The law steers to build with low carbon, ensuring that the climate-related drawbacks and benefits that emerge over the entire life cycle of the building are taken into careful account. In practice, this takes place under the new law with regulations concerning the climate assessment, material declaration, and carbon footprint limits for buildings (Ministry of the Environment, 2023).

The building act states, based on EU taxonomy, that new buildings must be designed and built as nearly zero energy buildings (NZEB). Essentially, NZEB is characterized by its outstanding energy efficiency, with the minimal energy demand primarily fulfilled through renewable sources. This ensures that the small amount of energy required is largely derived from sustainable sources (Ministry of the Environment, 2000).

Decree of the Ministry of the Environment on the Energy Efficiency of New Buildings (1010/2017)

The Energy Efficiency of New Buildings decree applies to the design and construction of new buildings consisting of covered wall structure that utilizes energy to maintain the indoor climate (Ministry of the Environment, 2017). The decree was revised in 2017 by the Ministry of the Environment.

As outlined by the Ministry of the Environment (2017), the decree establishes minimum energy efficiency requirements for buildings based on their specific purpose of use. The requirements for the buildings are:

1. In terms of energy efficiency, buildings must either have a calculated Energy class lower than the specified limit value or meet the requirements for structural energy efficiency.
2. Establishing conditions that minimize thermal efficiencies, thereby mitigating heat loss and effectively reducing the overall energy demand of buildings.
3. Being energy efficient in terms of the calculated summertime room temperature, energy consumption measurements, heating, and electricity requirements, and if applicable, the specific electrical power of the mechanical ventilation system (Ministry of the Environment, 2017).

The Energy Efficiency of New Buildings decree defines various requirements for different calculation methods, including the calculation of energy efficiency of the building and its Energy class and heat loss. The decree states that the building must have measuring devices that enable the measurement of energy use, or the energy monitoring must be easily feasible (Ministry of the Environment, 2017).

2.3 Haahtela simulation model

Realaizer by Haahtela is the first building simulation model in the world, delivering timely and accurate information to decision-makers (Haahtela-kehitys Oy, 2021). It was born out of the necessity to establish a result-oriented approach for the construction and property industry. Within the Realaizer framework, the entire building is algorithmically pre-designed before the actual design phase. This ensures that the project remains consistent with its goals from planning through completion.

Realaizer consists of four key transformations: functional dimensioning, formation of spaces and space features, geometry model of the building, and building element estimation (Haahtela-kehitys Oy, 2021). Space dimensioning converts the functional requirements of the user, such as size of the building and user count, into spaces and space groups. Spaces-module transforms operational requirements like room air temperature, ventilation, and imposed loads into required properties of the building, including dimensions and shape, and load-bearing capacity. The design solution modelling converts spaces, space groups, and their properties into building and technical systems, which in turn define the construction tasks. The construction task modelling calculates costs associated with project management, planning, and on-site activities, derived from the properties and geometry of the building. All the previously mentioned transformations can be specified when the user determines the location of the building, its desired building specifications, and functional requirements, including aspects like size and user count (Haahtela-kehitys Oy, 2021).

In Realaizer, users have the flexibility to select one or more functional sectors, also known as building types, tailored to their planned building. These sectors encompass various industries such as accommodation, churches and chapels, offices, multi-storey car parks, as well as dental clinics, among others. Once the user has identified the functional sectors for the building, the building can be dimensioned either based on the building area, or through the utilization of sizing tools, including possible secondary sizing tools.

Various sizing tools and secondary sizing tools are employed across different sectors. For instance, for healthcare clinics the sizing tool is the number of annual visits, for residential buildings it is the number of apartments in the building, for high schools it is the number of students, and for hotels it is the number of hotel rooms. Healthcare clinics do not have a secondary sizing tool, but for residential buildings it is the average surface area per apartment, for high schools it is the number of students per teaching group, and for hotels it is the quality level of the rooms, ranging from 1 to 5.

Realaizer then efficiently generates models that incorporate functions, space groups and spaces to serve the needs of the users (tree chart shown in Figure 1). Examples of functions include cold storage, apartments, customer service, and sauna section, just to name a few. Examples of space groups include for example cooking, education (grades 1-2), entrance, and meeting. Spaces include different types of spaces, such as art classroom, dining area, library hall, and office room. To complete the space program, Realaizer automatically models common functions such as stairwells and technical spaces to serve the needs of the building itself.

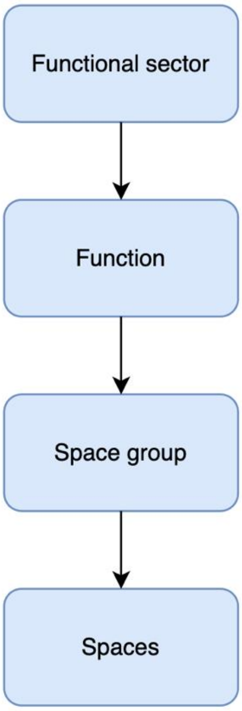


Figure 1. Tree chart of how the functional sectors, functions, space groups, and spaces are linked together in Realaizer.

After establishing the initial simulation model of the building, users have the flexibility to make extensive modifications. They can add other functional sectors, individual spaces, or space groups. Additionally, users can adjust various properties of the building, including its frame solution and heating method. Moreover, users have the capability to refine the characteristics of the building, such as its position, altering the number of floors, adjusting floor areas, refining the massing of the building, and enhancing the quality of materials and details.

Realaizer offers insights that steer the design and construction process of buildings, ensuring they achieve their intended targets. With the simulation model it is possible to evaluate the feasibility of the building project. By simulating multiple scenarios during the development stage stakeholders can assess the impacts of different choices. Examples of these choices include chancing the U-values, building frame solution and heat generation method. The changes affect the costs and emissions, both for the construction and the entire lifecycle of the building. Users can then determine whether to proceed, revise plans, or even abandon the project entirely.

3 Interviews

The objective of the interviews was to construct a comprehensive overview of the current status of energy efficiency and usage in buildings. The focus was to gain insight into the perspectives of customers, understand their defined targets and how these are outlined in projects, and identifying the language users employ when setting targets. Additionally, the interviews aimed to pinpoint the targets that clients consider particularly significant.

Four specialists from diverse backgrounds contributed to this project, including two construction economics graduates, a graduate engineer in environmental engineering and a construction foreman, and an architect. These individuals were chosen for their in-depth knowledge of building energy efficiency and energy utilization. Importantly, the interviewees came from diverse educational and professional backgrounds, contributing to a multifaceted examination of the subject, encompassing various viewpoints and perspectives.

3.1 Interview methods

The interviews were conducted through a semi-structured interview approach. This qualitative survey method established an open reference framework that facilitated purposeful, interactive, and bidirectional communication between the interviewer and the interviewees. The objective of these interviews was to construct a comprehensive understanding of the features and significance associated with building energy efficiency and energy consumption.

The interview questions remained largely consistent across all interviews. However, in the subsequent interviews, these questions were refined to enhance their format, eliminating unnecessary redundance. The semi-structured interview approach allowed for the inclusion of varied supplementary questions tailored to the specific interviews. These interviews were carried out in both remote and in-person settings during the autumn of 2023, with each session lasting between half an hour to one hour. The interview questions in Finnish can be found from the Appendix A1.

All the interviewees are employed by Haahtela, but they represented different diverse professional backgrounds. By harnessing the collective expertise of professionals spanning these various disciplines, it was possible to construct a more comprehensive understanding of building energy efficiency and energy consumption.

The interviews centered around strategies to enhance the energy efficiency of new buildings and minimize energy consumption, with particular emphasis on:

- During the predesign phase, what specific energy efficiency and energy usage goals have customers established for their new buildings?
    - What is the role of environmental certificates in determining energy goals?
    - What motivates customers to establish energy goals?
- How does defining energy efficiency and energy usage goals in the predesign phase impact new buildings in terms of:
    - cost implications,
    - carbon footprint,
    - construction timeline?
- What decisions made during the predesign phase regarding energy efficiency and energy usage
    - have the most significant impact on reducing the energy consumption of new buildings?
    - are the easiest ways to decrease the energy usage of new buildings?
    - are the most cost-effective to implement in terms of construction costs?
    - are proven to be the most financially profitable in the long run?
    - are the most commonly adopted?

4 Results

This chapter will first delve into the conducted interviews, and after that the Energy Usage Index developed in the thesis is presented, outlining its objectives and applications. The index, along with its five different indicators is thoroughly discussed. Subsequently, Realaizer simulation model from Haahtela is utilized to simulate the different energy usage levels for a specific building. This enables an observation of how the objectives outlined by the index can be achieved through the simulation model. Simultaneously, the consequences of varying energy usage levels are observed in both cost and energy consumption. Following the simulation, the potential enhancements to incorporate into Realaizer are being reviewed, as well as identifying any aspects of the index that cannot be integrated into Realaizer.

4.1 Performed interviews

4.1.1 Interviewee 1: Project manager

Construction economics graduate engineer Tiina Luhtanen has worked at Haahtela for over 30 years and is a highly respected expert in her field. She works as a project manager in project development, working on tasks such as design steering, needs assessment, and cost estimation. The interview with Luhtanen took place on-site on September 28, 2023.

Energy efficiency and consumption targets

In the projects in which Luhtanen (2023) has participated, there are no directly set targets for energy efficiency that surpass the Finnish regulatory standards. Energy efficiency and energy use are actively discussed, but there has not been a recognized imperative to set higher goals than the regulatory standards. However, certain entities, for example the city of Helsinki and Senate Properties, do insists on higher energy efficiency standards for their projects (Luhtanen, 2023).

According to Luhtanen (2023), each project investigates the viability of adopting renewable energy production methods, such as geothermal heat or solar panels. When examining the feasibility of geothermal energy, the process begins with a technical evaluation to determine its practicality and its ability to provide comprehensive energy coverage. Following this, an economic assessment is carried out to gauge the financial viability of incorporating geothermal energy (Luhtanen, 2023).

Luhtanen (2023) has had projects that have explored the potential of solar power, geothermal heat, sea heat, and energy recycling. Notably, Luhtanen highlighted the Lyyra project, in which Haahtela has participated, as a prime example of energy recycling. Lyyra includes an office building, a hotel, and a residential complex. Within the Lyyra project, an energy recycling system was implemented to efficiently capture waste heat from various sources. The office building generates condensate heat from the refrigeration equipment of the adjacent grocery store, while the hotel portion recovers heat from wastewater. Additionally, waste heat is collected from electrical facilities and server rooms. The energy harnessed through condensate heat pumps is primarily utilized for preheating domestic water and heating networks (Luhtanen, 2023).

According to Luhtanen (2023), customers tend to consider both the commercial and financial aspects when pursuing their energy goals. Investors, when strategizing and committing to an investment, aim to enhance their chances of selling the property in the future, a goal that becomes more achievable when the property boosts energy efficiency. Additionally, conforming to the targets outlined in the EU taxonomy can open doors to securing green financing. The creation of an energy-efficient building not only contributes to energy conservation but also results in simultaneous cost savings (Luhtanen, 2023).

When discussing the relationship between different energy targets, Luhtanen (2023) underscores the pivotal role of financial considerations in shaping the implementation of energy efficiency improvements in projects. To illustrate this point, she highlights the instance of regulating the heat energy entering through windows. Low emission coated windows serve to insulate against thermal energy, with their efficiency often directly tied to their cost. According to Luhtanen, a comprehensive assessment of all potential options is conducted, with a dedicated focus on prioritizing practical alternatives (Luhtanen, 2023).

The impact of achieved targets

Luhtanen (2023) asserts that meeting energy targets typically leads to an increased cost in building projects. To illustrate this, she references the Lyyra project, which involved a comparison between the costs of conventional concrete and environmentally friendly “green” concrete in construction. Within this project, thorough calculations were conducted to determine the cost savings associated with reducing carbon emissions in various solutions. These calculations guided the allocation of budget resources towards low-carbon practices where the most significant and efficient reductions in carbon emissions were achievable (Luhtanen, 2023).

The majority of enhancements in energy efficiency and energy utilization tend to prolong the construction duration of projects. Luhtanen (2023) attributes this extension to the implementation of separate systems. Additionally, she notes that when substituting green concrete for conventional concrete, the longer drying time of green concrete can further impact the construction schedule. Nonetheless, exceptions do exist where project timelines remain unaffected. For instance, improvements in the U-values of windows or the installation of photo voltaic (PV) panels on the roof are changes that can be made without extending construction times (Luhtanen, 2023).

The most significant factors for improving energy efficiency and reducing energy consumption

Luhtanen (2023) says that the biggest effect on improving the energy efficiency and consumption of a building is to build only for the need, in other words, good spatial dimensioning. The easiest and most prevalent ways, on the other hand, to implement energy efficiency and consumption methods, are to improve U-values of windows and implement measures to restrict thermal energy ingress with low emission coated windows and adding solar panels. Other improvements are basically separate systems that require more planning and construction (Luhtanen, 2023).

When inquired Luhtanen’s (2023) perspective on the most cost-effective method for improving energy efficiency and reducing energy consumption, she responded that there is no universal solution. Instead, the approach should be tailored to each individual project, with costs being assessed on a case-by-case basis. As an example, when evaluating the potential use of geothermal heat in a project, it is necessary to dimension it on every occasion. Additionally, in conjunction with geothermal heat, a backup system is usually also required. It is pivotal to determine the extent to which geothermal heat can meet the heating requirements, in other words, the energy coverage provided by geothermal heat. A larger investment is likely to yield a greater energy savings, but there may come a point where the investment is no longer financially viable (Luhtanen, 2023).

4.1.2 Interviewee 2: Cost estimation expert

Maria Tepponen is a graduate engineer in environmental engineering, complemented by a degree as a construction foreman, and she is currently pursuing her path to becoming a construction engineer. Her expertise lies in environmentally sustainable construction practises, and she excels in the field of cost estimation. At Haahtela, she focuses on cost estimations within project development. The interview with Tepponen was conducted remotely on October 4, 2023.

Energy efficiency and consumption targets

Recent project involvements of Tepponen (2023) have encompassed varying objectives related to energy efficiency and energy consumption. For instance, one project aimed to achieve a specific Energy class for an office building in alignment with the 4-star rating of the RTS environmental classification. The regulatory Energy class requirement stands at 135, but in this project, the target Energy class was set at 99. In another project, the objective was to reduce the primary energy demand of the building by ten percent compared to the established threshold, adhering to the criteria of the EU taxonomy. The EU taxonomy aims to streamline sustainable investment opportunities (Tepponen, 2023).

Tepponen (2023) has been in various projects targeting specific environmental certification criteria. For instance, one project aimed to achieve an 80% score in the Y2.1 Energy efficiency criterion of the RTS environmental classification. To meet this target, the Energy class of the office building had to reach 73. Another project focused on achieving a -35% improvement in energy efficiency, aligning with the Optimize energy performance- criterion in the LEED environmental classification. A third example involved striving for a 40% reduction in energy use and carbon emissions, following the Ene01 Reduction of energy use and carbon emissions- criterion within the BREEAM environmental certification, utilizing the Ene01 tool from BREEAM (Tepponen, 2023).

According to Tepponen (2023), most projects are steered by Energy class and energy efficiency targets. These energy targets may originate from municipal authorities, like the city of Helsinki, or be based on environmental certifications. Additionally, customers have the option to establish their own energy efficiency targets. Notable, the influence of the EU taxonomy on these targets is relatively modest, as the taxonomy is generally in harmony with the targets of the projects (Tepponen, 2023).

Tepponen (2023) states that nowadays rarely any customers try to meet only the minimum requirements, for example the minimum requirement for a building permit is so modest, on the worse side of the middle of a B energy class building, while it is possible to achieve an A energy class with almost basic construction. Responsible construction is also a market advantage and an image advantage, and possibly guarantees a better rental income in the long run (Tepponen, 2023).

When discussing the relationship between different solutions, Tepponen (2023) points out that when aiming to improve the U-value of walls by adding insulation, there is a minor increase in carbon dioxide (CO2) emissions. However, at present, the more significant focus is on reducing the energy consumption during use. Tepponen also highlights that the current emissions associated with solar panels are quite substantial, approximately 220 kg CO2e per panel, which makes it unlikely for them to completely offset the emissions generated during their manufacturing through energy savings (Tepponen, 2023).

The impact of achieved targets

According to Tepponen (2023), project targets are actively tracked throughout its execution, and a legal update for the Energy Certificate is required upon project completion. Successfully meeting these energy objectives is projected to result in an increase in the price of the building, typically ranging from 5% to 10% above the original estimate. Tepponen also underscores the need for active involvement in various aspects of construction and procurement, including the adoption of eco-friendly materials such as green concrete, to achieve energy efficiency and energy consumption targets (Tepponen, 2023).

It is important to note that these energy objectives are not anticipated to have a significant impact on project timelines, states Tepponen (2023). While there might be a potential increase in planning time if solutions are reevaluated and plans are adjusted, the overall construction schedule is expected to remain largely unaffected by these targets (Tepponen, 2023).

The most significant factors for improving energy efficiency and reducing energy consumption

Tepponen (2023) asserts that the most significant factor in enhancing energy efficiency and reducing energy consumption lies in optimizing the ventilation system. This optimization involves assessing the necessity for ventilation and enhancing heat recovery processes. In standard construction practices, the structures are already quite well-established, making further enhancements challenging. Accurate dimensioning of ventilation, heat recovery, control mechanisms, adjustments, and overall functionality is vital for effectively managing energy consumption and ensuring control over indoor climate conditions (Tepponen, 2023).

Tepponen (2023) identifies presence-control and demand-based lighting as the most straightforward means of enhancing energy efficiency and reducing energy consumption. This also constitutes a readily attainable point in numerous environmental certifications. Nonetheless, it is worth noting that the impact of lighting on energy savings remains relatively modest. Moreover, Tepponen points out that one of the most prevalent methods for improving energy efficiency is investing in the U-values and air leak number of the structures (Tepponen, 2023).

4.1.3 Interviewee 3: Project developer

Heli Pennanen, a construction economics graduate engineer, is an integral member of Haahtela's project development team. With a long-standing career at the company, she has been actively engaged in projects that place a strong emphasis on energy efficiency and effective energy consumption. The interview with Pennanen was conducted at Haahtela's office on October 10, 2023.

Energy efficiency and consumption targets

According to Pennanen, the city of Helsinki is driving progress in the construction industry, partly due to their utilization of the funds of taxpayers. The city has set ambitious energy and life cycle sustainability goals for its projects, closely aligned with the Carbon-Neutral Helsinki 2030 program (Pennanen, 2023).

Recently, Pennanen (2023) has been actively engaged in two projects aimed at enhancing energy efficiency and reducing energy consumption. Both of the projects are school buildings, and both of them are supported by a public actor.

Within the framework of the first project, a precise Energy class target was established with a strict limit that could not be exceeded. According to Pennanen (2023), this target proved to be an effective guideline for designers. In addition to the Energy class, energy targets were also influenced by the RTS environmental classification. The public actor behind the project has made a commitment to prioritize geothermal energy, with the goal of covering 90% of the energy needs with it, alongside a requirement that solar panels should contribute a minimum on 10% to the annual electricity consumption of the building. In situations where geothermal heating is not a viable option, the public actor has contingency plans in place for alternative heating sources (Pennanen, 2023).

The second school project is presently in progress with a primary objective of transitioning to geothermal heating and cutting down on maintenance expenses, states Pennanen (2023). Essentially, both school projects share almost identical goals since the same public actor serves as the funder of the projects. Pennanen notes that it is uncommon for clients to provide such specific energy and life cycle objectives, along with clear instructions regarding their preferences. Drawing insights from these projects, Pennanen has had the opportunity to inquire about similar energy targets in other projects (Pennanen, 2023).

In the previously mentioned projects, the objectives have been explicitly set by the public actor. When a customer seeks green financing, the energy goals are determined by the EU taxonomy and the energy efficiency directive (Pennanen, 2023).

Pennanen (2023) suggests that it would be beneficial for energy efficiency consults to provide customers with clear, well-defined energy goals and minimum energy consumption requirements. Up to this point, most customer goals have lacked specificity, typically focusing on a desire for highly energy-efficient or carbon neutral buildings without clearly outlined targets. Pennanen asserts that customers would greatly benefit from having precise goals, including metrics like Energy class, and other numerical targets, to guide their sustainability objectives (Pennanen, 2023).

The impact of achieved targets

According to Pennanen (2023), setting energy targets can lead to increased project costs. Take, for example, the case of the first school project. Initially, the public actor imposed more stringent U-value standards for the building envelope than the prevailing regulations required. However, during the execution of the project, these standards were relaxed, justified by the argument that the additional funds required to meet the stricter U-values criteria were not justifiably proportionate to the overall budget. As another example, Pennanen highlighted investments in geothermal energy. The investment in geothermal heating pays for itself over approximately 15 years. However, as an investment, geothermal heating is expensive, and, for instance, in the same project, district heating was also introduced alongside it, resulting in the presence of two different systems during the investment phase (Pennanen, 2023).

Pennanen (2023) underscores the profound impact of setting energy targets on carbon footprint of the building. Take, for example the first school project. When comparing a scenario where no improvements are made to one where investments are solely directed toward renewable energy sources, like geothermal energy, there is a remarkable reduction of approximately 30% in the carbon footprint. By combining energy efficiency enhancements with renewable energy integration, one can effectively meet the criteria outlined in RTS and other environmental certifications. It becomes notably challenging to attain these objectives without the adoption of renewable energy, necessitating significant efforts in areas such as energy recycling (Pennanen, 2023).

The most significant factors for improving energy efficiency and reducing energy consumption

Pennanen (2023), like Luhtanen, states that the most crucial factor in enhancing the energy efficiency and reducing energy consumption lies in how much is constructed. Also, when a building is designed to minimize its exterior surface area, it results in a more energy-efficient structure. Pennanen mentions that many environmental certifications often overlook the fact that their targets are established on a per square meter basis. Prior to establishing these values, critical decisions must be made regarding whether new construction is necessary or if it is feasible to repurpose existing buildings through reconfiguration (Pennanen, 2023).

To achieve energy efficiency and energy usage goals, Pennanen (2023) suggest a variety of solutions. The most cost-effective approach for construction is to add insulation to the façade, improve the energy efficiency of the envelope, install solar panels, and enhance the U-values of windows. However, when focusing on the most prevalent method to enhance energy performance of buildings, it is most prudent to invest in renewable energy sources and curtail the consumption of purchased energy (Pennanen, 2023).

During the interview with Pennanen (2023), it was emphasized that the most financially beneficial strategies for achieving long-term energy efficiency and minimizing energy consumption involve opting for durable systems with life cycles that do not necessitate frequent replacements over the lifetime of the building. It is also essential to consider the impact of energy efficiency measures on the wellbeing and performance of buildings. For instance, if improvements in energy efficiency led to deterioration of moisture-related performance and require the reconstruction of the façade due to a lack of consideration for structural integrity, it would ultimately prove to be an unprofitable undertaking (Pennanen, 2023).

4.1.4 Interviewee 4: Architect

Architect Markus Mikkola works as a senior project development specialist in Haahtela. He is a professional in real estate development and facilities strategies, specialized in project planning and design management, feasibility studies, and real estate development and facilities strategies. The interview with Mikkola took place at the office on October 13, 2023.

Energy efficiency and consumption targets

Mikkola (2023) has been actively engaged in complex office space projects, primarily situated in the capital region. These projects consistently aim to meet demanding energy consumption targets, guided by environmental certifications. The most recent project of Mikkola was a cultural project, with the goal of surpassing the requirements for achieving an A class energy rating (Mikkola, 2023).

Mikkola (2023) emphasizes that energy targets within commercial projects align with the demands of investment market. When considering property resale, it becomes crucial for the building to achieve a certification, preferably at a high standard. Mikkola points out that the Finnish RTS environmental classification excels in terms of energy efficiency and reducing carbon emissions, compared to other environmental certifications. However, it does fall short in certain categories, such as water consumption measurement. This discrepancy can be attributed to the abundance of fresh water in Finland, where water consumption is not as pressing an issue as it is in other regions, and this characteristic is also reflected in the RTS certificate (Mikkola, 2023).

Mikkola (2023) discussed that in Finland, projects situated outside the capital region typically prioritize energy efficiency through investment strategies. For instance, they explore the viability of utilizing geothermal heating as a cost-effective heating option for the project. In certain instances, energy assessments are conducted during the development phase of the project, to assess the potential energy-saving measures that can be implemented, such as achieving an A energy class rating. Following this, the economic impact of these measures is evaluated, and the energy consumption target of the project is established based on the findings of the report (Mikkola, 2023).

The impact of achieved targets

According to Mikkola (2023), energy targets have a notable impact on building costs, generally causing an increase. These energy goals typically contribute to a reduction in the carbon footprint of the building, although exceptions can be observed, particularly in cases involving the installation of solar panels, where the impact is less straightforward. Moreover, energy targets often lead to extended construction timelines, particularly in projects integrating complex technical systems. This extension results from the longer planning phase and the additional time required for system testing (Mikkola, 2023).

The most significant factors for improving energy efficiency and reducing energy consumption

During his interview, Mikkola (2023) emphasized the importance of distinguishing between two key aspects of energy consumption in buildings: specific energy consumption and absolute consumption driven by operational activities. When addressing absolute consumption, the primary factor impacting its reduction is the size and mass of the building. Additionally, space properties, such as indoor temperature requirements, the heat load generated by operation, the efficiency of energy-consuming devices, and the surface area of windows, play significant roles in minimizing absolute consumption. It is worth noting that these factors also have a partial influence on specific energy consumption (Mikkola, 2023).

Mikkola (2023) pointed out that when seeking advice from an energy consultant to enhance energy efficiency and minimize energy consumption, common recommendations include improving ventilation heat recovery, achieving a higher Seasonal Performance Factor (SPF) for ventilation, enhancing the air tightness of the building envelope, and upgrading the thermal insulation of outer walls (Mikkola, 2023).

Once the energy consumption has been reduced, the next step, as outlined by Mikkola (2023), is to explore various possibilities for localized energy production. This includes investigating the potential for generating electrical power utilizing solar panels, harnessing thermal energy from geothermal sources, or producing free cooling through a combination of geothermal systems or heat pump solutions. For projects involving substantial condensation heat, such as a combination of an ice rink and swimming pool, an in-depth examination of energy recycling opportunities is made. In later stage, the impact of a necessary ventilation system can be examined (Mikkola, 2023).

Exploring the potential for a geothermal solution is a commonly adopted approach, states Mikkola (2023). It is essential to include budget considerations at an early stage when contemplating investments in solar panels and geothermal energy. While geothermal energy has previously been a reliable source of profit, the current context, marked by increasing electricity prices, does not guarantee consistent profitability for geothermal energy implementation (Mikkola, 2023).

4.2 Summary of the interviews

Within this chapter, the emphasis lies on summarizing the conducted interviews. It specifically explores the points of consensus and divergence among the interviewees.

According to the interviewees, energy efficiency targets are established based on environmental certifications like LEED, BREEAM, and RTS. Notably, Pennanen expressed the view that project energy efficiency goals should be more explicitly defined, potentially utilizing the Energy class for assistance. The interviews further highlighted that in Finland, the city of Helsinki and Senate Properties are leading the way in establishing energy efficiency targets.

Each interviewee emphasized the crucial role of financial incentives in promoting energy efficiency in buildings. They pointed out that properties with environmental certifications tend to fetch higher prices upon resale, attract better rental income, and qualify for green financing during construction. Furthermore, financial considerations dictate that energy efficiency improvements prioritize the implementation of measures that offer the greatest energy savings relative to their costs.

All interviewees emphasized that pursuing energy efficiency targets can drive up the overall cost of building projects. For instance, investments in technologies like geothermal heating, though effective, often require significant upfront investments and additional heating system. According to the insights from the interviews, establishing such targets can extend either the planning or construction phase, primarily due to intricate design, and installation of complex systems. However, the interviewees acknowledged that certain energy efficiency improvements, such as upgrading window U-values and installing solar panels, can be implemented without affecting project timelines. Nevertheless, both Tepponen and Mikkola cautioned that studies suggest solar panels may not fully offset the carbon footprint they generate.

Three out of four interviewees highlighted the importance of building only as per actual need as the primary solution for reducing energy usage. Pennanen particularly advocated for thorough exploration of the potential for repurposing existing buildings whenever feasible. Additionally, Tepponen and Mikkola stressed the critical importance of optimizing ventilation systems. Both Pennanen and Mikkola criticized the per square meter approach of environmental certificates, arguing that it fails to accurately depict the impact of improvements of the overall energy consumption of the building. In terms of practical enhancements, Luhtanen suggested prioritizing the improvement of the U-values of windows, while Tepponen recommended the installation of presence lighting.

4.3 Definition of the Energy Usage Index

The primary objective of the thesis is to define the Energy Usage Index for buildings. The purpose of the Energy Usage Index is to provide constructors, construction developers, customers, and other simulation model users with a straightforward and user-friendly method to define an energy efficiency goal for their projects.

The index consists of different indicators that affect the building energy usage. The indicators have been determined according to environmental certifications, Finnish and European legislation and regulation, and insights gathered from expert interviews.

There are six different levels (shown in Table 1) in the Energy Usage Index, with the first level aligning with regulatory standards. Subsequent levels are named as follows: Average energy usage, Above-average energy usage, Good energy usage, High-quality energy usage, and Excellent energy usage. Transitioning between these Energy Usage Index levels enables users to promptly observe how reduced energy consumption affects both cost and carbon footprint. This functionality simplifies comparisons, and for example allows users to assess the significance of different heating solutions in relation to overall energy.

Table 1. Six different energy usage levels and their comparability with environmental certificate ratings.

Energy usage level	Comparability with environmental certificate ratings
Regulatory standards	RTS, LEED, BREEAM: Unclassified
Average	RTS: One star LEED: Unclassified BREEAM: Pass
Above average:	RTS: Two stars LEED: Certified BREEAM: Good
Good:	RTS: Three stars LEED: Silver BREEAM: Very good
High-quality	RTS: Four stars LEED: Gold BREEAM: Excellent
Excellent	RTS: Five stars LEED: Platinum BREEAM: Outstanding

Table 1 illustrates how the different levels of the Energy Usage Index correspond to the classification levels of RTS, LEED, and BREEAM. The Energy Usage Index diverges from the mentioned environmental certificates, it is not a duplication, amalgamation, or truncation of the certificates. The Energy Usage Index is driven by a distinct goal, concentrating solely on energy consumption, and the comparison in the table is limited to the scope of energy use. Table 1 is designed to simplify the understanding of the different levels of the index, and their relationship with environmental certificates. However, the indicator is comparable and consolidates the energy consumption categories from environmental certificates into a single unified metric.

This chapter provides an overview of the Energy Usage Index and the five indicators and outlines the various levels of requirements associated with each.

4.4 Energy Usage Index

The Energy Usage Index consists of five distinct indicators that influence the energy consumption of the building. These indicators are Energy Efficiency, Renewable Energy Production, System Efficiency, Energy Efficient Transport Systems, and Efficient Water Equipment.

A total of 19 credits can be achieved through the five indicators. Table 2 provides a comprehensive overview of all indicators along with their respective maximum credits. In cases where certain facilities, for example commercial kitchens are not present in the building, the corresponding indicator, or a part of it can be excluded when calculating the total credits.

Table 2. Maximum number of credits from different indicators.

Indicator	**Max. credits**
Energy Efficiency	10
Renewable Energy Production	3
System Efficiency	2
Energy Efficient Transport Systems	2
Efficient Water Equipment	2
Total	**19**

Similar to RTS, BREEAM, and LEED, the Energy Usage Index classifies its levels by determining the percentage of credits earned out of the maximum achievable score. Table 3 presents the specified percentages required for each of the six levels within the Energy Usage Index.

Table 3. Minimum percentages out of maximum achievable credits for different energy usage levels

Energy usage level	**Minimum percentage out of maximum credits**
Regulatory standards	0 %
Average	20 %
Above-average	35 %
Good	50 %
High-quality	65 %
Excellent	80 %

4.4.1 Energy Efficiency

This metric incorporates elements from various sustainability criteria, including the Energy Efficiency criterion from RTS environmental classification, the Reduction of Energy Use and carbon emissions criterion from BREEAM, and the Optimize Energy Performance criterion from LEED. The purpose of this indicator is to enhance energy performance levels beyond the required standard to reduce environmental and economic impacts associated with excessive energy use.

A maximum of 10 credits can be obtained through this indicator, depending on the percentage reduction in energy usage of the building calculated during the predesign phase, compared to the regulated energy usage of the building which serves as a reference baseline. Table 4 outlines the credits achievable at different improvement percentages. Haahtela’s Realaizer simulation model aligns building simulations with Finnish regulations, making it possible to utilize Realaizer to simulate the reference baseline of energy usage of the building.

Table 4. Credits for percentage improvement in the total purchase energy consumption of a building.

Credits	**Percentage improvement**					
	Office buildings	**Commercial buildings**	**Accommodation**	**Educational buildings**	**Physical exercise buildings**	**Healthcare**
1	4	7	9	2	2	5
2	11	13	18	11	11	11
3	15	20	26	16	16	16
4	20	27	35	18	18	21
5	24	33	44	20	20	27
6	27	38	48	26	26	32
7	30	41	51	30	30	37
8	35	46	54	32	32	43
9	40	50	58	35	35	48
10	44	53	61	37	37	53

The minimum requirements corresponding to different energy usage levels are detailed in Table 5. Buildings that meet only the regulatory standards or achieve an Average energy usage level do not have minimum requirements in this indicator. The credits obtained through the indicator and the percentage improvements in comparison to the reference baseline level are determined based on the Energy Efficiency criterion from RTS and Optimize Energy Performance criterion from LEED.

Table 5. Minimum requirements for different energy usage levels.

Level	**Minimum requirement**
Regulatory standards	-
Average	-
Above average	2 credits
Good	3 credits
High-quality	4 credits
Excellent	7 credits

In contrast to RTS, this criterion does not focus on reducing the Energy class value of the new building but on minimizing the overall energy consumption of the new building. Insights gathered from expert interviews emphasized that the Energy class may not always be the most suitable reference value. The Energy class is computed by multiplying the consumption of purchased energy by the specific coefficient assigned to each energy form. For example, a comparison between district heating and geothermal heat reveals the coefficient for district heating is 0.5, whereas the coefficient for geothermal heat (electricity) is 1.2. Thus, the methodology for this indicator mirrors LEED, prioritizing scoring based on percentage improvement rather than the Energy class.

There are many ways to reduce the purchase energy consumption of a new building. The reduction can be achieved by either decreasing overall energy usage or incorporating sustainable energy production techniques to generate a portion of the required energy. For instance, converting from district heating to geothermal heat can substantially lower the overall energy usage of a building. Similarly, the dependence on purchased energy can be decreased through the incorporation of solar power systems.

The majority of energy consumption of buildings is allocated to heating. Lylykangas et al. (2015) states that while architectural design plays a crucial role, the heating demand of a building is significantly influenced by factors like thermal insulation, heat recovery from ventilation, and the insulation and airtightness of the outer envelope of the building. Improving the aforementioned factors not only reduces the purchased energy consumption of the building, but also earns credits through this Energy efficiency indicator. These aforementioned factors are illustrated in Figure 2, generated by the German Passive House Institute (Passive House Institute, 2015).

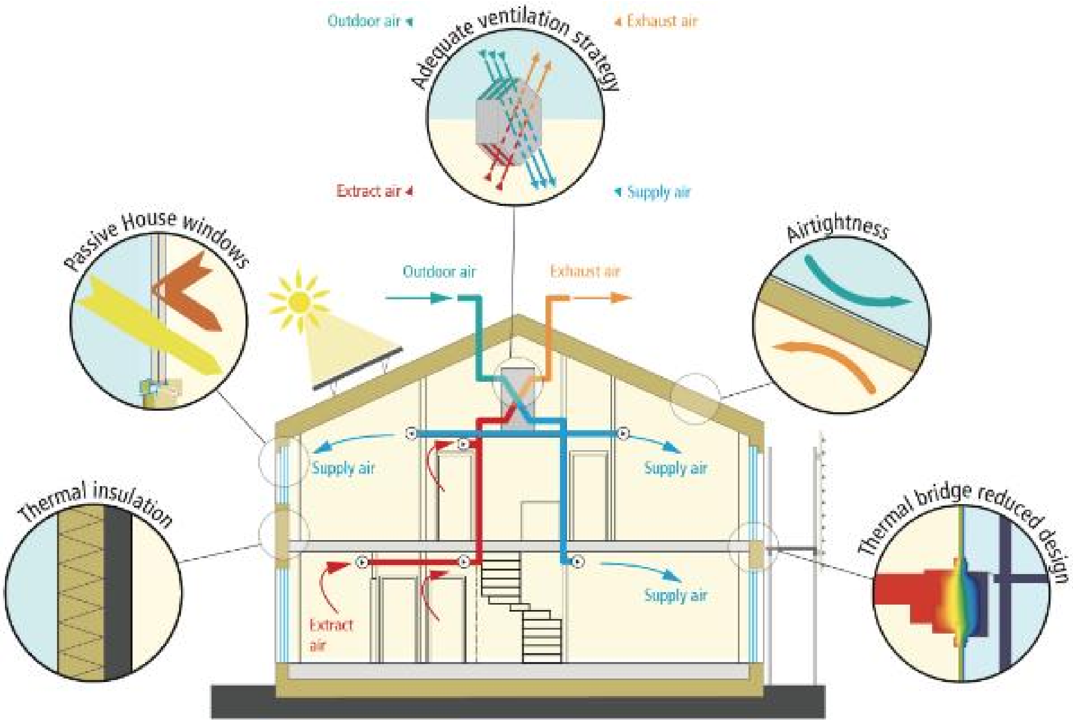


Figure 2. Five basic principles to energy efficient building (Passive House Institute, 2015).

Additionally, the energy utilized for heating is shaped by elements such as the heat transmission coefficient (U-value) of windows, their total solar energy transmittance (g-value), and solar protection features. Strategies like mitigating cold bridges through methods such as cold bridge breaks or integrating windows into thermal insulation can effectively reduce heating energy needs of a building. However, it is important to note that the occurrence of cold bridges cannot be completely avoided (Lylykangas et al., 2015).

The Land Use and Building Act (2017) establishes specific reference values for the U-values of buildings. The permissible heat loss from the building must not exceed the reference heat loss, which is determined based on these specific values. The reference U-value for the outer wall is set at 0.17 W/(m^{2}K) for the roof ceiling joist and the base floor exposed to outside air it is 0.09 W/(m^{2}K), for the base floor limited to the crawl space it is 0.17 W/(m^{2}K), and for windows and doors it is 1.0 W/(m^{2}K) (Ministry of the Environment, 2017). Enhancing U-values offers the potential to decrease the heating energy requirements of the building.

According to Motiva (2018), demand-controlled ventilation is a key strategy for enhancing energy efficiency, offering the potential to reduce both fan power, and heating and cooling energy requirements. This approach is most effective in buildings where internal loads vary significantly during use periods (Motiva, 2018).

When selecting ventilation equipment, it is essential to consider both heat recovery efficiency and the SFP value. Heat recovery involves transferring heat energy from exhaust air to supply air, thereby minimizing the need for additional heating energy. SFP value represents the specific electrical power consumption of the fan, indicating the power required to move one cubic meter of air through the building per second. Optimal energy efficiency in ventilation systems is achieved when heat recovery efficiency is high, and the SFP value is low. Minimizing ventilation energy consumption significantly impacts the overall energy usage of the building, and thereby results in earning credits in this indicator.

4.4.2 Renewable Energy Production

The basis for the Renewable Energy Production- indicator lies in both the LEED criterion with the same name and the Low Carbon Design criterion from BREEAM. It aims to mitigate environmental and economic impacts linked to fossil fuel usage. The objective is to enhance self-sufficiency through the integration of renewable energy sources (U.S. Green Building Council, 2019). Utilizing renewable energy also reduces the energy costs of buildings.

The indicator is scored by determining the percentage of the contribution of renewable energy to the total annual energy consumption of the building, as outlined in Formula 1:

$$\%\, re = \frac{C_{re}}{C_{total}} \tag{1}$$

Where C_{re} is the equivalent cost of usable energy produced by the renewable energy system, and C_{total} is the total building annual energy cost.

The denominator for the calculation is the total annual energy expenditure. The numerator considers contributions from solar gardens or community renewable energy systems. To qualify, the project must either own the system outright or have committed to a lease agreement spanning a minimum of 10 years. Additionally, the systems must be situated within the utility service area corresponding to the facility making the claim. Credit is determined based on the percentage of ownership or usage outlined in the lease agreement. Points for this indicator are awarded according to Table 6.

Table 6. Points for renewable energy production.

Percentage renewable energy	Credits
1 %	1
5 %	2
10 %	3

4.4.3 System Efficiency

The System Efficiency indicator is derived from the corresponding indicator in the RTS environmental classification, while the outdoor lighting component is also addressed in the External Lighting indicator in BREEAM. This indicator is designed to monitor the energy efficiency of crucial energy-utilizing systems and to ensure that their environmental impacts are appropriately considered (Rakennustieto, 2022).

According to Rakennustieto (2022), the following systems are identified as significant energy consumers:

- Outdoor lighting exceeding 1 kW
- All façade and accent lighting
- Semi-warm or warm garages with ventilation dimensions exceeding 1 m^3/s
- Room cooling refrigeration equipment with a cooling capacity surpassing 30 kW
- District heating defrosts and electric defrosts over 5 kW (approximately 60 m^2) for area defrosts, excluding gutter, downspout, or roof outlet defrosts
- Kitchens with a daily capacity surpassing 500 portions (Rakennustieto, 2022).

The indicator considers only the equipment that belongs to the property, excluding special tenant facilities like refrigerators in grocery stores.

Outdoor and façade lighting must meet certain standards to ensure compliance. This involves for outdoor lighting to maintain an average luminous flux output of at least 50 lumens per watt of input power, with the upward luminous flux limited to no more than 5%. For façade lighting the luminous efficacy of the lamps must exceed 70 lumens per watt. Additionally, effective control mechanisms, such as brightness, motion, and luminosity sensors, should be implemented to regulate the outdoor and façade lighting. Furthermore, incorporating a timed program ensures the lighting can be deactivated during scheduled periods.

Garage ventilation should be regulated according to indoor air quality, with additional consideration given to heat recovery, when the indoor temperature exceeds 15 °C.

For cooling systems, the Coefficient of Performance (COP) for cold production must exceed 3.0, considering compressors, condensate pumps, and condensers. If the cooling system serves both ventilation and space cooling, pumps should either be equipped with dual pumps or have sufficient adjustment capacity for partial power usage during the winter season. The system should feature variable temperature control for cold production to avoid unnecessary production of liquid below 12°C during the winter. If the location has a space cooling network, the system must incorporate free cooling, with a commissioning limit set above +7 °C.

Each designated melting area should be set up as a separate control zone, enabling the establishment of tailored control parameters within the automation framework. Beyond considering external temperatures, the control and regulation should respond to surface temperatures, rain detection, or other relevant variables specific to each zone. Additionally, in line with the outlined melting control criteria, a weather forecast-driven control system must be incorporated for all control larger than 500 m^2.

Kitchen appliances should be designed to be flexible and adjustable according to the specific needs of the kitchen. According to the Energy-efficient professional kitchen guideline by Reisbacka et al. (2009), the calculated energy usage per portion includes both cold storage and cooking processes. To provide a reference point, the recommended energy consumption per serving is detailed for various kitchen types: 0.53 kWh/serving for hospital kitchens, 0.31 kWh/serving for school cafeterias, 0.61 kWh/serving for student cafeterias, 0.84 kWh/serving for staff cafeterias, and 1.49 kWh/serving for restaurants (Reisbacka et al., 2009).

Attaining a full score of two credits in the indicator requires meeting the defined criteria for all essential energy-consuming systems in the building. If over 50% but less than 100% of these systems meet their criteria, it results in a score of one, as shown in Table 7. However, if less than 50% of these systems meet their designated criteria, it results in a score of zero.

Table 7. Credits for system efficiency.

Percentage of systems meeting their criteria	Credits
< 50 %	0
< 100%	1
100 %	2

4.4.4 Energy Efficient Transport Systems

The Energy Efficient Transport Systems indicator is derived from the corresponding indicator found in BREEAM with the same name. The fundamental idea of this indicator is to acknowledge and incentivize the use of energy-efficient transport systems. Credits within the indicator can be acquired according to Table 8.

Table 8. Credits for energy efficient transport systems.

Percentage of lifts, escalators or moving walkways meeting their criteria	Credits
0 %	0
100 %	2

If the building has no lifts, escalators, or moving walkways, this indicator can be excluded. In situations where only one of the transportation systems is in place, both credits can be awarded if that singular system meets the relevant criteria.

For lifts, the credits can be obtained by adhering to the following three energy-efficient features for each lift:

1. The lifts are designed to operate in a standby condition during off-peak periods. This involves the automatic shutdown of the power side of the lift controller and auxiliary equipment (such as lighting, user displays, and ventilation fans) when the lift remains inactive for a specified duration.
2. The lighting systems within the lift car and display areas must achieve an average lamp efficacy exceeding 70 lumens per watt.
3. The lift should be equipped with a drive controller capable of variable speed, variable-voltage, and variable-frequency (VVVF) control for the drive motor.

Furthermore, the use of regenerative drives should be considered, but only when they produce an energy saving greater than the additional standby energy used to support the drives. These drives are generally well-suited for elevators with significant travel and frequent use. However, where it can be demonstrated that the investment is not financially viable, considering payback considerations over the service life of the installation, then this option can be discounted.

Escalators and moving walkways are required to meet at least one of the following criteria:

1. Is fitted with a load sensing device that synchronizes motor output with passenger demand through a variable speed drive.
2. Is equipped with a passenger sensing device for automated operation, allowing the escalator to shift into standby mode when there is no demand from passengers.

This indicator applies to any lifting device with a rated speed greater than 0.15 m/s. This means that lifts in single dwellings, or in other low-rise buildings, specifically intended for individuals with impaired mobility, are generally not subject to this assessment. Evacuation lifts, which will be used during an emergence only, can be excluded from the indicator.

4.4.5 Efficient Water Equipment

The Efficient Water Equipment indicator is derived from the Low-consumption water fixtures component of the Water Use Efficiency indicator from RTS. The aim of the indicator is to reduce the consumption of potable water for sanitary purposes by integrating water-efficient components. RTS was specifically selected among the different environmental certifications due to its optimal alignment with the environmental conditions in Finland, being a Finnish environmental certification.

Attaining 2 credits from the indicator is possible when all water consuming components listed in Table 9 within the building meet the specified requirements. One credit is awarded when over 50% but less than 100% of the components meet their criteria, and zero credits are awarded if less than 50% of the components meet the criteria, as shown in Table 10.

Table 9. Performance levels of water-consuming components.

Water-consuming component	Perfomance level	Unit
WC, double flush	6/3	dm^3/flush
WC, single flush	4.5	dm^3/flush
Urinal, automatic control	2	l/flush
Washbasin tap	5	dm^3/min
Shower	8	dm^3/min

Table 10. Credits for Efficient Water Equipment.

Percentage of components meeting their criteria	Credits
< 50 %	0
< 100 %	1
100 %	2

4.5 Simulating the Energy Usage Index with Realaizer

The objective of the simulation is to perform a case-study to assess the compatibility between the indicators of the Energy Usage Index and Realaizer. The aim of the simulation is to address the second subordinate question: How can Realaizer simulation model be utilized to achieve the targets defined in the indicators of the Energy Usage Index? In other words, the current simulation model of Realaizer is used to evaluate how well the requirements of the Energy Usage Index indicators can be influenced.

4.5.1 Case-study

The case-study simulation began by defining the target of analysis: an office building located in Torpparinmäki, Helsinki. The office was assigned for 130 workstations, with 50% being office rooms. Additionally, the simulation included a parking garage with a capacity for 40 parking spaces.

During the case-study, it was noticed that when utilizing Realaizer for building simulations, the only indicator that can be adjusted within the Energy Usage Index is Energy Efficiency. It can be tailored within the simulation by adjusting U-values for the exterior wall, roof structure, base floor, and exterior windows and doors. Realaizer also offers flexibility in modifying the heat generation method of the building, providing district heating, oil central heating, ground-source heat pump (borehole), and electric hydronic heating system. Furthermore, Realaizer provides the capability to influence ventilation within the building, along with determining the seasonal performance factor for heat recovery. In addition, simple changes, such as shifting from non-adjustable lighting to presence detector and constant light control, also have a reducing effect on the energy consumption of the building.

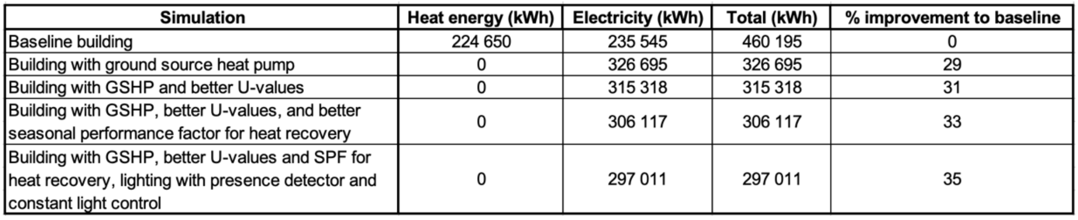
In Realaizer, the adjustment of window surface area is a possibility. However, when considering a decrease in the number of windows, careful attention must be paid to not only to align with Finnish building code, but also to ensure the comfort of the occupants of the building, and the overall architectural aesthetics. In this simulation, the decision was made to refrain from reducing the number of windows, taking into consideration the factors mentioned earlier.

To initiate the simulations, an unaltered office building modeled in Realaizer is utilized, complete with an attached parking garage. The building utilizes district heating as its heat production method, with specific U-values: 0.17 $\frac{W}{m^2K}$ for the exterior wall, 0.09 $\frac{W}{m^2K}$ for the roof structure, 0.16 $\frac{W}{m^2K}$ for the base floor, and 1.0 $\frac{W}{m^2K}$ for the exterior windows and doors. The seasonal performance factor of heat recovery stands at 73%. In this simulation, the annual energy consumption of the building comprises of 224 650 kWh of heat energy, and 235 550 kWh of electricity, summing up to 460 200 kWh.

Transitioning to a ground-source heat pump for the building heating system has the potential to decrease energy consumption to 326 700 kWh per year – a notable 29% reduction compared to the baseline energy consumption.

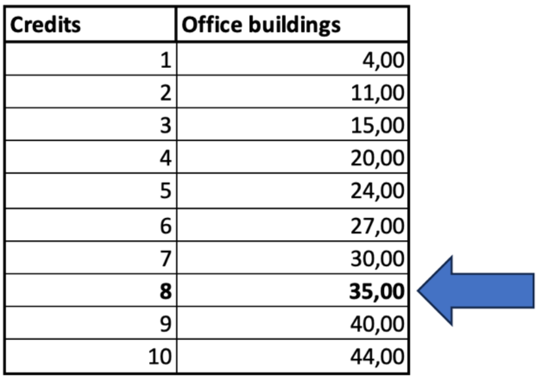
By refining not only the heating method but also the U-values of the building – setting the U-values for the exterior wall at 0.08 $\frac{W}{m^2K}$, for the roof structure at 0.07 $\frac{W}{m^2K}$, for the base floor at 0.1 $\frac{W}{m^2K}$, and for the exterior windows and doors at 0.58 $\frac{W}{m^2K}$ – combined with enhancing the seasonal performance of heat recovery to 80%, and transitioning lighting in the office from non-adjustable to presence detector lighting with constant light control, a further reduction in energy consumption is achievable. Subsequent to these modifications, the annual energy consumption of the building is 297 010 kWh. This represents a significant 35% improvement compared to the building simulation that has not undergone any energy efficiency enhancements. Table 11 presents the outcomes of different energy efficiency enhancements.

Table 11. Effects of energy efficiency improvements on the total energy consumption of the building.



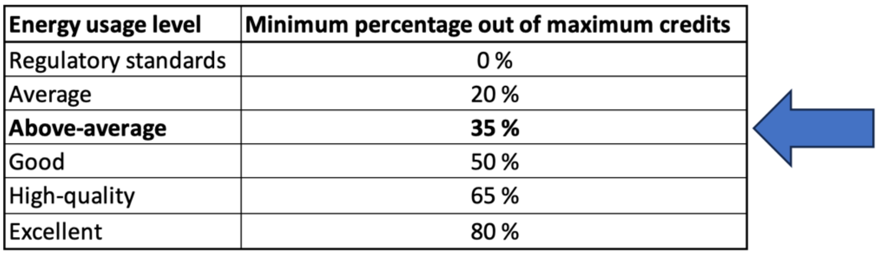
Simulation	Heat energy (kWh)	Electricity (kWh)	Total (kWh)	% improvement to baseline
Baseline building	224 650	235 545	460 195	0
Building with ground source heat pump	0	326 695	326 695	29
Building with GSHP and better U-values	0	315 318	315 318	31
Building with GSHP, better U-values, and better seasonal performance factor for heat recovery	0	306 117	306 117	33
Building with GSHP, better U-values and SPF for heat recovery, lighting with presence detector and constant light control	0	297 011	297 011	35

Implementing these four energy efficiency enhancements resulted in a remarkable 35% reduction in the energy consumption for the simulated office compared to the baseline. This accomplishment is reflected in the scoring of the office, achieving a score of 8 out of 10 in the Energy Efficiency indicator, shown in Figure 3. Consequently, the office qualifies for the Above average- energy usage category of the Energy Usage Index, as illustrated in Figure 4, attaining a 42% of the maximum score, solely from the points earned in the Energy efficiency- indicator.



Credits	Office buildings
1	4,00
2	11,00
3	15,00
4	20,00
5	24,00
6	27,00
7	30,00
8	**35,00**
9	40,00
10	44,00

Figure 3. Number of credits achieved with the energy efficiency improvements.



Energy usage level	Minimum percentage out of maximum credits
Regulatory standards	0 %
Average	20 %
Above-average	**35 %**
Good	50 %
High-quality	65 %
Excellent	80 %

Figure 4. Energy usage level achieved through the energy efficiency improvements.

4.5.2 Potential improvements to Realaizer

The case-study revealed that at present only the Energy Efficiency indicator can be modified in Realaizer. This chapter focuses on the improvements that must be made to Realaizer, so that it is possible to influence each indicator of the Energy Usage index. A detailed review is conducted for the indicators, outlining the necessary developments in Realaizer for it to effectively impact the indicators of Energy Usage Index.

First, the potential enhancements related to the Energy efficiency indicator will be examined. Although the current simulation model aligns well with the requirements of the Energy efficiency indicator, there are specific areas where further improvements will be needed. For example, the simulation should incorporate the ability to add window shading, enabling the prevention of heat radiation through windows in the summer without reducing the amount of radiation during the winter heating season.

Furthermore, the simulation should also include the capability to modify the g-values of windows, determining how much solar radiation penetrates the windows to heat the room. Additionally, an option for coated window glasses, like low-emission coated windows, would further enhance the capabilities of the simulation model.

There is also a limitation in Realaizer in the inability to orient windows based on cardinal directions, as the modelling does not consider the placement of the building or its spaces on the plot. At present, window surface distribution remains uniformly spread across all four primary cardinal directions, with potential adjustments under consideration. Integrating the exact locations of spaces into the simulation model is achievable, and would enable improved window orientation, but would demand considerable effort and development work.

Enhancing the building simulation involves integrating the ability to modify the ventilation SFP number. Additionally, it would be beneficial to also introduce a selection feature focused on the cold bridges of the building. This feature would empower users to strategically influence the placements of cold bridges, consequently optimizing the overall energy efficiency of the building.

Concerning the Renewable energy production indicator, it is essential to incorporate the modelling of solar panels into the simulation. This enhancement enables users to assess the potential energy output and total cost of solar panels prior to the planning phase. By providing this information early on, users can make well-informed decisions about the feasibility and financial implications of incorporating solar energy solutions into their building projects.

In the future, there is a need to advance the System efficiency indicator for outdoor, façade and accent lighting, by incorporating a comprehensive model that considers three key factors: the carbon footprint, energy efficiency and pricing of the lighting. This same framework should also extend to room cooling refrigeration. As a result, when a user changes the energy usage level of a simulated building in Realaizer, the system automatically adjusts the presented choices based on the specific energy usage level.

For the successful implementation of the Energy efficient transport systems indicator in Realaizer, it is necessary to introduce two options, energy efficiency and price, for lifts, escalators, and moving walkways.

Simultaneously, there is a need for refining the modelling of energy consumption for these transport systems. These enhancements ensure the smooth integration of the indicator into Realaizer.

A needed addition to Realaizer is the incorporation of a water equipment related selection, which encompasses key considerations such as the carbon footprint, energy efficiency, and price of the water equipment. Currently, Realaizer features static table values for the water consumption of buildings, making the transition to low-consumption water equipment ineffective in reducing both the water and energy consumptions of the building. The proposed addition of a new selection, combined with an enhanced water usage modelling approach, would enable the seamless integration of the Efficient water equipment indicator into Realaizer.

5 Discussion

The primary research question of the thesis was: how can Haahtela's simulation model be utilized to establish a life-cycle energy usage target for a building during the predesign phase? During the simulation of the Energy Usage Index using Realaizer simulation model, it was observed that currently, only the parameters related to the Energy Efficiency indicator can be adjusted in Realaizer. However, by modifying these parameters, significant reductions in energy consumption were achieved. In the simulation of an office building with 130 workstations and a 40-space parking garage, the initial annual consumption of 460 200 kWh was reduced by 35%, resulting in an annual consumption of 297 010 kWh. This reduction was achieved through various adjustments, including switching from district heating to ground-source heat pump, enhancing the U-values of structures, improving the seasonal performance factor of heat recovery, and changing lighting from non-adjustable to presence detector and constant light control.

There are some challenges related to the indicators of the Energy Usage Index that cannot be implemented into Realaizer. These challenges arise either from the excessive specificity of the indicators, or the need for substantial modifications to the modelling of Realaizer to fully accommodate them.

When considering the System efficiency indicator, certain criteria cannot be incorporated into Realaizer. These include functionalities such as district heating defrosts and electric defrosts, which are not currently modeled in Realaizer. Additionally, calculating the energy consumption of kitchens per portion is not feasible at present, due to the existing method of calculating energy consumption based on power usage $(\frac{W}{m^2})$, and the area of kitchen equipment in the preparation kitchen. Although integrating a device selection feature for energy-efficient kitchen appliances could address this criterion, the extensive effort required outweighs the potential benefits. Consequently, this particular aspect of the indicator will not be incorporated into Realaizer.

The current simulation lacks a comprehensive assessment of the cost implications related to energy efficiency improvements of the Energy Usage indicator. The forward-looking strategy involves refining the pursuit of energy efficiency goals by calculating the cost per saved unit of energy for diverse energy efficiency targets. This systematic approach prioritizes the implementation of the most cost-effective improvements as the initial steps toward realizing the energy efficiency targets.

In the initial simulation of the office building, the total price of the building was 10 278 230 €, and implementation of energy efficiency improvements increased its price to 10 634 160 €. Notably, the lighting modification alone, saving only 9 100 kWh annually, incurred a cost of 206 680 €. Currently in Realaizer, the effect of lighting modification on the price of the building is the only correctly modelled price effect of the energy efficiency improvements.

During the simulation of the office building, certain limitations became apparent regarding the price changes of energy efficiency improvements related to changing energy production method and enhancing the U-values. When altering the energy production method of the building, for example from district heating to ground-source heat pump, the simulation should allow for the addition of a backup heating system. This addition would raise the overall construction costs of the building. However, this functionality is not currently feasible.

Additionally, enhancing the U-values of the structures of the building does not influence its structural solutions in Realaizer, thus leaving the total costs unaffected. The enhancements solely influence the energy consumption of the building and the sizing of its heating system. Therefore, the simulation model should be enhanced to ensure that improving the U-values also influences the structural configuration of the outer walls.

If a pricing model could be established for the amount of energy saved by each efficiency enhancement, it would enable the organization of these improvements from the most economical to the most expensive. This approach would greatly benefit the customers, as financial considerations often steer the project decisions. As a result, in the predesign phase, it would be clear which energy efficiency improvements are feasible with the budget.

Research is also required on investigating how different building types impact the selection and extent of the energy efficiency improvements. Building upon the research findings, initial matrices could be established to customize parameters influencing the indicators, with adjustments tailored to the selected Energy usage level. Subsequently, this concept could be refined further, potentially employing advanced methodologies such as neural networks.

By incorporating the Energy usage Index into Haahtela's Realaizer building simulation, it enables the capability to evaluate energy efficiency of the building prior to the design phase. Consequently, energy efficiency becomes an integral goal right from the beginning, rather than being an outcome emerging from choices and planning. This advancement holds significant promise for the construction industry, as it enables stakeholders to identify and address annual emissions prior to the planning phase, enabling adjustments before the construction begins.

By simulating various levels of the Energy Usage Index, users gain a clear understanding of the importance of energy efficiency improvements in terms of both building costs and energy consumption. Moreover, it simplifies the implementation of these enhancements for users, as they no longer need to search for ways to reduce the energy consumption of buildings by themselves. Instead, they can effortlessly compare the impacts of various Energy Usage Index levels on their buildings. As the industry moves towards zero-energy construction for new buildings, the Energy Usage Index and the research associated with it become increasingly crucial in facilitating this transition.

6 Conclusions

The building sector is a key contributor to GHG emissions. In Finland, buildings account for a third of the GHG emissions, and consume approximately 40% of the total utilized energy. Considering this, it is crucial to lower energy consumption in the building sector by enhancing building energy efficiency. The most straightforward and effective way to achieve this is by prioritizing energy efficiency before the design phase, as the decisions made during this stage greatly influence the overall energy performance of the building.

The objective of the thesis was to develop an index for assessing building energy usage. The goal of the index was to comprehensively consider all factors influencing building energy usage and to explore how Haahtela's Realaizer building simulation model could effectively influence these factors to decrease energy consumption of buildings.

The primary research question of the thesis was: how can Haahtela's Realaizer simulation model be utilized to establish a life-cycle energy usage target for a building during the predesign phase? Initiating the search for an answer to the research question involved examination of notable environmental certifications such as LEED, BREEAM, and RTS environmental classification, alongside a review of EU and Finnish legislation and regulations on building energy usage. The groundwork led to the creation of the Energy Usage Index, comprising five indicators: Energy Efficiency, Renewable Energy Production, System Efficiency, Energy-Efficient Transport Systems, and Efficient Water Equipment.

Once the index was established, it underwent examination through a case-study. Initially, an office building was simulated without any energy efficiency enhancements, followed by a simulation of the same building after modifications aligned with the Energy Usage Index indicators. Throughout the case-study, it became evident that only one indicator of the index, Energy Efficiency, could be influenced within Realaizer, thus limiting the scope of the simulation.

Utilizing solely the Energy Efficiency indicator, the energy consumption of the simulated office building decreased by 35%, bringing the annual energy consumption down from the baseline 460 200 kWh to 297 010 kWh. This enhancement resulted in 8 out of 10 score for the Energy Efficiency indicator, accounting for 42% of the total index score. As a result, the improved building was classified in the Above Average- energy usage level within the index. After conducting the case-study, an analysis was conducted to determine the necessary modifications to Realaizer in order to align with the requirements of the Energy Usage Index.

At present, there is no tool on the market designed to calculate and adjust the energy consumption of a building before the design phase. Such a tool would be of immense importance to the construction sector, playing a crucial role in reducing emissions.

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Appendix

A1. Suomenkielinen haastattelurunko

Johdanto haastatteluun

Tämä haastattelu on osa diplomityötäni, jota teen Haahtelalle. Diplomityöni tavoitteena on antaa Realaizerin käyttäjälle jo ennen suunnitteluvaihetta mahdollisuus vaikuttaa suunniteltavan uudisrakennuksen käytönaikaiseen energiatehokkuuteen ja energian kulutukseen. Tällöin rakennuksen energiatehokkuus olisi heti alusta alkaen mukana rakennusta määrittävänä tavoitteena, sen sijaan että energiatehokkuus on valintojen ja suunnittelun lopputulos, jolloin siihen ei voi käytännössä vaikuttaa. Tällöin myös energiatehokkuustavoitteen seuraukset tulevat heti ilmi, esimerkiksi rakennuksen hinnassa tai hiilijalanjäljessä, jolloin käyttäjä näkee suoraan kannattaako asetettua energiankäytön tavoitetta tavoitella.

Diplomityössäni aion kehittää energiatehokkuus-indeksin, joka koostuu erilaisista indikaattoreista. Indeksin avulla käyttäjä voi ennen suunnitteluvaihetta valita kuudesta eri tasosta, kuinka energiatehokkaan rakennuksen haluaa toteuttaa. Eri energiatehokkuustasot ovat: standardit täyttävä, keskiverto, keskivertoa parempi, hyvä, korkealaatuinen ja erinomainen. Tällöin käyttäjä voi myös vertailla eri energiatehokkuusluokkien vaikutuksia jo aikaisessa vaiheessa.

Olen kesän ja syksyn aikana lukenut paljon erilaisia ympäristösertifikaatteja, kuten BREEAM, LEED ja RTS- ympäristöluokitus, sekä Suomen ja EU:n lainsäädäntöä asiaan liittyen. Lukemani perusteella tulen määrittelemään eri indikaattoreita, jotka otetaan huomioon energiatehokkuusindeksissä. Energiatehokkuusindeksin indikaattorit jakautuvat rakennuksen lämmitykseen, jäähdytykseen, vedenkulutukseen, rakennuksen vaippaan, sekä sähkölaitteisiin ja valaistukseen.

Haastattelun tarkoitus

Tämän haastattelun tarkoituksena on selkeyttää mitkä indikaattorit tulevat olemaan indeksin kannalta tärkeitä, ja onko minulta mahdollisesti jäänyt jotain kriittistä huomaamatta.

Materiaalin käyttö

Haastatteluiden avulla saatuja tietoja käytetään taustamateriaalina diplomityössä. Haastattelut äänitetään, jos haastateltava antaa luvan. Äänitteitä ei säilytetä diplomityön valmistumisen jälkeen, eikä niitä käytetä muihin tarkoituksiin. Haastattelupohja on luotu haastatteluiden kysymysrungoksi, mutta haastatteluiden ei tarvitse seurata suunnitelmaa.

Kysymykset

Perustiedot

Tiedot esittelytekstejä, sekä viitteitä varten.

- Haastateltavan nimi, koulutus, sekä työnkuva Haahtelalla ja titteli

1. Tavoitteiden asettaminen hankkeissa

a) Minkälaisia tavoitteita rakennuksen energiatehokkuuden ja energiankäytön suhteen on asetettu niissä hankkeissa (uudisrakennukset), joissa olet ollut mukana? Vai onko tavoitteita asetettu ollenkaan?
  - Esimerkiksi: E-luku/energiatehokkuusluokka, ekologiset vesikalusteet/valaistus, sähköautojen latauspaikat, pyörävarastot, tilamitoitus & muunneltavuus, aurinkopaneelit, maalämpö, kulutusjousto & älykkäät ohjausjärjestelmät, energiankäytön mittaus, ilmanvaihto
  - 5 %/10 %/15 % jne. keskiarvoa pienempi energiankulutus tms. Millä ohjelmalla/tavalla tulos on laskettu?

b) Minkä perusteella tavoitteet on määritetty?
  - I. Perustuvatko ne sertifikaatteihin kuten BREEAM, LEED tai RTS?
  - II. Onko tavoitteena täyttää vain minimivaatimukset?
  - III. Kuka päättää mitä tavoitteet ovat?

c) Miksi tavoitteet on määritetty:
  - I. Markkinointisyistä?
  - II. Huoli ilmastonmuutoksesta?
  - III. Pakko täyttää minimivaatimukset?
  - IV. Kaupallinen/taloudellinen näkökulma (vihreä ”edullisempi” raha, saa myytyä eteenpäin helpommin)?
  - V. Joku muu, mikä?

d) Oletko huomannut korrelaatiota eri energiatehokkuuden tai energian käytön parannusten välillä? Jos jotain parantaa, onko mahdollista, että se sulkee toisen mahdollisen parannuksen pois? Esimerkiksi:
  - I. Rakenteet, materiaalit
  - II. Uusiutuva energiantuotanto
  - III. Joku muu, mikä?

2. Asetettujen tavoitteiden saavuttaminen

Onko etukäteen määritettyjä energiatehokkuus ja energian käytön tavoitteita saavutettu ja onko hankkeissa jälkiseurantaa?

a) Mitä tavoitteet olivat?

b) Vaikuttiko tavoitteiden asettaminen/saavuttaminen rakennuksen:
   I. Hintaan
   II. Hiilijalanjälkeen
   III. Rakennusaikaan

   ja oliko vaikutus positiivinen vai negatiivinen?

3. Merkittävimmät energiatehokkuuden parannuskeinot

Mitkä tekijät koet itse merkittävimmiksi, joilla voi vaikuttaa rakennuksen energiatehokkuuteen ja energiankäyttöön, ja millä on:

a) Suurin vaikutus?

b) Helpoin toteuttaa?

c) Rakentamiskustannuksiltaan edullisin toteuttaa?

d) Pitkällä tähtäimellä kannattavin?

e) Yleisin?