Development of the framework and the methodologies towards nZEBs in Finland

Sadaf Alam
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Sadaf Alam

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Abstract

The emerging trends for deep-retrofit of existing buildings in Europe require the formulation of strategies for nearly zero-energy buildings (nZEBs) and achieving benchmarks as outlined in the Energy Performance of Buildings Directive (EPBD) recast. The fundamental process of retrofitting to an explicit high performance necessitates the development of robust and diverse methodologies to be used during the early stages of planning in retrofit projects. The construction sector lacks the extensive use of such methods for early decision-making that are essential to accelerate building renovation in Europe. Perhaps literature suggests that there is a huge mismatch between the predicted and measured performance is referred to as the "Performance Gap". The most prominent causes of this uncertainty of energy performance savings identified in the literature are; specification uncertainty in building modeling, poor practice in operation, lack of proper knowledge and skills in the construction industry, facility managers, etc.

Low carbon building energy technologies for low carbon generation are diverse. People's adoption of low carbon buildings increases the use of different types of renewables, and each technology utilises various natural resources in a variety of ways and the economic, social, and environmental impacts. Thus, it is important to evaluate the social acceptance of low carbon buildings to understand the social perceptions of the people in terms of usage of low carbon buildings and climate challenges.

The role of key stakeholders in the industry becomes highly responsible for achieving the energy performance targets. Thus, this research presents the application of combined i) research techniques and ii) building simulation and optimization strategies that shall support the decision-making in retrofitting buildings to low-energy, Nearly zero energy, and comfortable buildings. The findings of this research can provide classical knowledge in many ways. For example, (1) they provide us with a new approach to know how and what kind of steps have already been taken to create awareness about low carbon building energy technology and climate change so far in Finland, and (2) they help us to analyse public perceptions towards low carbon building applicability and to acquire knowledge about what different kinds of low carbon building energy technologies they (participants) are aware of. 3) Attitudes and approaches of the stakeholders towards nearly zero energy buildings (nZEBs).

Societal acceptance study contributes to the sustainable development of low-carbon buildings meeting current and future-oriented societal needs. It will provide specific observations concerning the impact of low carbon buildings on society. This study will empower construction industry stakeholders to address the barriers, gaps, and challenges identified in retrofit projects, as well as inform the formulation of policies aimed at promoting retrofit uptake.

Keywords Energy Efficiency, Social acceptability, Nearly Zero energy buildings, Low carbon buildings, Renewable Energy, Building simulation
Tekijä
Sadaf Alam

Väittöskirjan nimi
Viitekehys ja metodologiat lähes nZEB-rakennusten edistämiseksi Suomessa

Julkaisija
Insinööritieteiden korkeakoulu

Yksikkö
Insinööritieteiden korkeakoulu

Sarja
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Tiivistelmä

Rakennusten korjaurakentamisen trendi Euroopassa on uusia energiajärjestelmiä perustelluilla. Tämä edellyttää strategiaa lähes nollaenergirakennuksille (nZEB) jotta uudet rakennusten energiatehokkuutta koskevan direktiivin (EPBD) mukaiset suoritusarvot saavutetaan. Korkeiden suoritusarvojen saavuttaminen edellyttää robustien ja monipuolisten menetelmien kehitämistä suunnittelun alkuvaiheita varten. Rakennusallalla ei ole laajalti käytössä sellaisia varhaisen päätöksenteon menetelmiä, jotka ovat välttämättömiä rakennusten korjaurakentamisen

Käsittelemiseksi. Kirjallisuus viittaa siihen, että ennustetun ja mitatun suorituskyvyn välillä on suuri epäsuhtaa, "Performance Gap". Selkeimmät syyt tunnistettuun energiatehokkuuden

parametrien epävirrupteeseen ovat rakennusmallinmuutoksen määräteylän epävarmuus, huonot

käytännöt, sekä rakennusalan asiantuntijien ja taitojen puute. Vähähömillä rakennuksilla on erilaisia energiateknologioidensa. Vähähöillä rakennusten lisääntyminen lisää erityyppisten uusiutuvien energialähteiden käyttöä, ja eri teknologioidensa on

myös erilaisia taloudellisia, sosiaalisia ja ympäristövaikutuksia. Siksi on tärkeää arvioida

vähähöillä rakennusten yhteiskunnallista hyväksyttävyyttä ja ymmärtää ihmisten käsityksiä

vähähöillä rakennusten toiminnaasta ja ilmastohaasteista.

Alan keskeisillä sidosryhmillä on erittäin vastuullinen rooli energiatehokkuustavoitteiden

saavuttamisessa. Tässä tutkimuksessa esitellään yhdistettyä tutkimusmenetelmiä ja

rakennusmuutostavoitteista erottavien suorittamista tutkemana päätökseenteko

rakennusten korjaurakentamisessa piiriin maataloenergia- tai nollaenergirakennus

Tämä tutkimuksen tulokset on monen tyypistä tietoa. Ensinnäkin tutkimus tarjoaa uuden

lähestymistavan tietää mitä toimenpiteitä on jo Suomessa tehty lisäämään tietoisuutta
ergiateknologioidensa ja ilmanmuutoksesta. Toiseksi tutkimus auttaa analysoimaan yleisin

käsityksiä vähähöilisen rakentamisen soveltuvuudesta ja mistä erilaisista energiateknologioidensa

osallistujat) ovat tietoisia. Kolmanneksi tutkimuksessa on selvitetyt sidosryhmien asenteet

lähestymistavat lähes nollaenergirakennukseni (nZEB).

Yhteiskunnallinen hyväksyntätekijä on yhtenäinen rakennusten kehitystä, joka

vastaan nykyisiä ja tulevussa suuntautuneita yhteiskunnallisia tarpeita. Se tarjoaa konkreettisia

havainnoja vähähöillisten rakennusten vaikutuksista yhteiskuntaan. Tämä tutkimus antaa

rakennusalan sidosryhmille mahdollisuuden puuttua julkaisensuunnistusten havahtuihin

esteisiin, puutteisiin ja haasteisiin sekä antaa tietoa politiikkojen muotoilusta, joilla pyritään

edistämään julkaisenkunnan käyttöönottoa.

Avainsanat
Energiatehokkuus, Sosiaalinen hyväksyttävyys, Lähes nollaenergirakennuks, Vähähöilliset rakennukset, Uusiutuva energia, Rakennusmuutostavoite

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My journey as a doctoral researcher has, perhaps, resembled a winding roller-coaster road, and I sort of ‘hung around’ for several years. I would probably say that during those years, I experienced different flavors of life. Nevertheless, despite the mountains of challenges, there was always a flicker of certainty deep within me, whispering that I could complete my doctoral studies sooner or later.

First and foremost, I want to thank my supervisor, Professor Risto Lahdelma, for giving me the opportunity to enter the doors of Aalto University and start my PhD. Looking back to those turbulent times when you agreed to be my supervisor, I still feel the sparks in my eyes. I have immense gratitude for Dr. Risto Lahdelma’s unwavering support, who believed in me when I needed it the most. I am forever in debt.

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Besides all the lovely people at work, I am lucky to have an amazing family who always believed in me no matter what, no matter if I had changed my plans from Finland and come to Ireland to further explore my career and my life. Special thanks go to my mother, Ms. Saleema Khatoon, and Father, Dr. Sharf Alam, for their unconditional support, which I can always count on, and for giving me an example of lifelong learning. Thanks for giving me the wings to fly in this world out there. I am privileged and blessed to have parents like you who always stood for me; you people are the epitome of my motivation in my life and have been the driving force behind my academic journey. Your love, sacrifice, and guidance have given me the strength and confidence to pursue my dreams and achieve my goals. Needlessly, I am proud to say that I have a father who has always believed in me, even when I doubted myself. To my lovely siblings, Iram Alam and Ashraf Alam, blessed to have you by my side. You guys means world to me.

Finally, Asad, my husband, you are a jewel. I am blessed to have you. Times were hard with us, but in the end, we sailed through. Thank you for your love and your patience. Cheers to us!

I purely dedicate this dissertation to my dearest father Dr. Sharf Alam.

Ireland, 21 January 2023
Sadaf Alam
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Appendix A: Publication III
Appendix B Publication IV
List of Publications

This doctoral dissertation consists of a summary of the following publications;


Author’s Contribution

**Publication 1:** Both authors have equal contributions. The co-author Sadaf Alam initiated and contributed to the literature review, and modelling of the studied houses examined the fulfilment of the ASHRAE standard 55 for the studied houses and contributed to the writing of the article. The main author participated in the literature review, model development, assessment of the thermal comfort, development of the control algorithms, and responding to comments of the editors and reviewers. The 3rd co-author helped to develop the control algorithm. The 4th co-author analyzed the consumption profiles of the Finnish houses. The 5th and 6th co-authors contributed to the development of the research idea, and selection of the research methodology, and provided supervision and revision for this research article.

**Publication 2:** The author was the first and the main author of the publication. The article was written edited and reviewed by the author. The whole work and the analysis of the results were done solely by the author of the publication. The author responded to the comments of the editors and the reviewers and was responsible for all the revisions. The 2nd author commented and reviewed the paper. The 3rd author reviewed the final draft of the paper.

**Publication 3:** The author was the first and the main author of the publication. All the work done for publication was performed, led, and managed by the author. The article was written, edited, and reviewed by the author. Analysis of the results was done solely by the main author of the publication. The 2nd author reviewed the final draft of the paper.

**Publication 4:** The author was the first and the main author of the publication. All the work done for publication was performed, led, and managed by the author. The idea, methodology, and the whole manuscript were developed by the author only. The article was written edited and reviewed by the author. A review response was carried out by the author. The 2nd and the 3rd authors provided comments and reviewed the final draft of the article.
List of abbreviations

ACH: Air Change per Hour
CHG: greenhouse gas
DR: Demand Response
EED: Energy Efficiency Directives
EPBD: Energy Performance of Building Directive
ESCOs: Energy Service Companies
EPC: Energy Performance Contracting
HVAC: heating, ventilation and air conditioning
IDP: integrated design process
LCB: Low Carbon Buildings
NBCF: National Building Code of Finland
nZEBs: Nearly Zero Energy Buildings
PMV: Predicted Mean Vote
PPD: Predicted Percentage of Dissatisfaction
RETs: renewable energy technologies
SDGs: Sustainable Development goals
WWR: window-to-wall ratio
1. Introduction

Building stock is among the biggest cause of greenhouse gases [1][2]. The European Union (EU) has set an ambitious target to increase the number of ‘nearly Zero Energy Buildings’ (nZEBs) by 2020, which seems to be an unachievable target now. The existing ‘National Plan of Finland’ [3] aimed to expand the amount of nZEBs, however, it has not yet established any detailed specifications.

Nonetheless, definitions of nearly zero-energy construction and associated specifications are underway. The variations in building culture and climate throughout Europe make it a bit tough for the European Building Legislation (EPBD) to prescribe a uniform approach to nZEBs [4][5]. Perhaps, in certain countries, the building stock can contribute more than 40% of the total greenhouse gas emissions [6]. The transition to sustainable and environmentally friendly construction practices has become an imperative in contemporary society. Two key approaches in this regard are Low-Carbon Buildings (LCBs) and Nearly Zero Energy Buildings (nZEBs). Low-carbon building (LCB) is generally considered an effective solution for reducing energy consumption and carbon emissions in the construction industry [7]. Low-carbon building (LCBs) implementations are therefore essential [8]. There are numerous benefits associated with the implementation of LCB. These benefits are multi-facet. Apart from environmental benefits such as pollution reduction, low carbon buildings have social and economic implications [9][10][11]. For instance, tenants of low carbon building experience a higher level of satisfaction, wellbeing, and productivity [12]. However, the challenges remain mainly due to the comparatively higher up-front cost associated with the sustainable features [13][14].

Both LCBs and nZEBs are effective in reducing carbon emissions. LCBs focus on lowering emissions by improving energy efficiency, while nZEBs take it a step further by producing as much clean energy as they consume, thereby achieving a near-zero carbon footprint [15]. Perhaps, The European Union has provided regulatory support for nZEBs through directives, making them a prominent choice in Europe to meet sustainability goals. Nevertheless, Both LCBs and nZEBs benefit from advancements in construction technologies. However, nZEBs often incorporate cutting-edge technologies, making them a frontrunner in terms of innovation [16].
1.1 Low-carbon project practices

The growth of (LCB) can be seen in the improvement of theories and project applications[17]. The research not only established the key factor in the performance of low carbon buildings and their connection. The various critical factors for low carbon building development were highlighted.

In this context, international cooperation, macro-level management, low carbon theories and technologies growth, carbon knowledge and training, economic advantages, low carbon facilities, and the structure of building energy use should be given the highest focus [17]. An admirable project plays a crucial role in fostering systemic transition in the building sector towards low-carbon sustainable growth[13]. Low carbon initiatives have been carried out worldwide. For example, by integrating process and input-output analysis, the integrated energy usage in buildings can be estimated by a hybrid approach, based on a case study done on ETown in Beijing [18]. In the same manner, successful policy mechanisms for reducing greenhouse gas (CHG) emissions are being formed in a direction to achieve low carbon development [19]. Such include the laws, carbon tax, and other financial incentives.

Furthermore, Beliz Ozorhon found that corporate policy has influenced the implementation of energy-efficient technology on low-carbon projects through a series of case studies [20]. Such project activities provide useful knowledge for low carbon building and research on relevant hypotheses.

Low carbon building energy technologies for low carbon generation are diverse. People’s adoption of low carbon buildings increases the use of different types of renewables, and each technology utilises various natural resources in a variety of ways, and the economic, social, and environmental impacts of each technology vary[21]. Thus, it is important to evaluate the social acceptance of low carbon buildings to understand the social perceptions of the people in terms of the usage of low carbon buildings and climate challenges [22][23].

1.2 nzEB buildings and attitudes of the stakeholders towards nzEB

The EU has set an ambitious target to increase the number of ‘nearly Zero Energy Buildings’ (nZEBs) by 2020, which seems to be an unfulfilling target now. The current ‘National Plan of Finland’ [3] also intends to increase the number of nZEBs but does not give detailed specifications. Nonetheless, definitions of nearly zero-energy construction and associated specifications are underway. The variations in building culture and climate throughout Europe make it a bit tough for the European Building Legislation (EPBD) to prescribe a uniform approach to nZEBs [4] [5]. Perhaps, in many countries, the building stock contributes to more than 40% of the total amount of greenhouse gas emissions [6].

Stakeholders [24][25][26] strongly influence project success, particularly for complex projects with heterogeneous stakeholders, and hence, understanding their influence is essential for project management and implementation. Stakeholder management largely accounts for the success of projects [27].
Stakeholders can be defined as an individual or a group of individuals, who are influenced by or able to influence a project [28]. The strong cooperation of stakeholders is necessary for project success since a project can be considered a temporary organization of stakeholders pursuing an aim together[29]. McElroy and Mills [27] indicated that the purpose of stakeholder management is to achieve project success through the continuing development of their interrelationships. Therefore, identifying how stakeholders influence[30] project success is an important and fundamental issue of stakeholder management.

1.3 Role of the stakeholders in the construction industry

In construction projects, numerous stakeholders are involved at each stage directly or indirectly. An integrated design process (IDP) involves all participants in the early design phase of the project. This means that all stakeholders collaborate throughout the initial design process from the setting of the project goals to the definition of measurable design parameters that represent these goals.

The different stakeholders [31][32] of the early design stage have been divided into three main groups (refer Figure 1). These groups are as follows: (a) society and citizens: local authorities, and citizens; (b) clients and users: end users, investors, initiators, developers, building owners, and facility managers and (c) construction sector: builders, designers, suppliers[33].

Traditionally the most powerful stakeholders have been (a) local authorities through the building regulations and (b) investors who have been overly concerned with project capital cost and have disregarded future savings through reduced life cycle costs. When life cycle environmental impact is considered all stakeholders are recognised and encouraged to collaborate, interact, and influence each other’s designs.

<table>
<thead>
<tr>
<th>Society and Citizens</th>
<th>Clients and Users</th>
<th>Construction Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local Authorities</td>
<td>End users, Investors</td>
<td>Builders, Designers,</td>
</tr>
<tr>
<td>Citizens</td>
<td>Initiators, Developers, Building owners, Facility managers</td>
<td>Contractors, Suppliers</td>
</tr>
</tbody>
</table>

1.3.1 Retrofit industry and construction professionals

Finland’s Integrated Energy and Climate Plan contains the national targets and the related policy measures to achieve the EU’s energy and climate targets. Concerning energy efficiency, under the EED, Finland’s indicative national energy efficiency target for 2020 is the absolute level of final energy consumption at 310 TWh. The energy efficiency target to contribute to the EU 2030 target in final energy consumption is 290 TWh. In 2017, Finland achieved a level of 294 TWh for final energy consumption, corresponding to 371 TWh of primary energy consumption.

Market development, adaptability, and filling the gaps in homeowner information are of vital importance and are governed by the growing construction industry. The provision of incentives supports the market penetration of nZEBs and a recent market report on Energy Service Companies (ESCOs) [33] in Europe notes that the Irish retrofit industry is growing rapidly due to such incentives [34]. The retrofit industry [35][36][37] is an important stakeholder for nZEB and key actors include professionals such as architects, engineers, small and medium businesses, contractors, and other construction professionals.

Retrofit businesses need consensus over processes, tools, and best practices to overcome the existing technical, social, economic, and environmental barriers as highlighted in this study. Cohesive interaction among industry stakeholders over project inception, development, and delivery standards can raise the quality of retrofits required along with the tools and techniques to achieve them [38]. Several studies have investigated the requirements of end users to assist in decision-making in retrofits using surveys [39][40][41]. However, very few studies have evaluated the requirements of construction industry stakeholders in Europe in achieving low energy buildings [42] [43][44]. They indicated that most countries require information and training to push market development forward. They also stated that there is a lack of trust and reliable information for the growth of ESCOs in Europe. Existing skills in the construction sector are of high quality, yet they are not sufficiently aligned with the approach of low-energy buildings. The ZEBRA 2020 project is trying to develop frameworks for monitoring the market uptake of nZEBs across Europe and its recommendations are awaited [45]; however, it does not include Finland in its consortium.

To address current technological, social, economic, and environmental hurdles, retrofitting companies need a greater agreement around processes, tools, and best practices, as discussed in this thesis. Coordinated engagement between industry stakeholders in the starting, production, and delivery of projects will improve the quality and technology necessary for retrofit [39]. Several studies have explored the criteria of end users to help retrofit decision-making using surveys [46] [41].

Therefore, an extensive stakeholder consultation process was undertaken in this study to identify the barriers, gaps, and challenges being faced by the retrofit industry in Finland.
1.4 Thermal comfort and energy efficiency

The rapid improvement in the standard of living requires more detailed and sophisticated methods of evaluating comfort conditions. Low-energy opportunities ensure that building occupants remain comfortable in a period of changing environmental conditions[47]. A study on thermal comfort by Yoshino et al. suggested that indoor thermal comfort is strongly affected by the outdoor climate in non-heating usage zones [48]. However, maintaining thermal comfort conditions in confined environments may require complex regulation procedures and the proper management of heating, ventilating and air conditioning (HVAC) systems[49]. This concern has led to several studies conducted worldwide to improve building energy efficiency: on the designs and construction of building envelopes (e.g. thermal insulation and reflective coatings [50][51][52][53][54], sensitivity and optimization [50][55][56], and life-cycle analysis [57]; technical and economic analysis of energy-efficient measures for the renovation of existing buildings [58] [59][60]; and the control of heating, ventilation and air conditioning (HVAC) installations and lighting systems[61]. In turn, the requirements for indoor thermal comfort do not necessarily coincide with those of energy saving purposes, which in the last years have become a crucial issue owing to the enactment of the European Energy Performance of Buildings Directive (EPBD)[62]. It is well known that the increasing demand for energy management in buildings prompts the development of control methodologies that could improve the energy efficiency of building-HVAC systems [63][64][65][66].

International Energy Agency (IEA)[67] states that control strategies[68][69] such as pricing regulation, technical standards of demand response, and environmental impacts by retailers or consumers form the main approach to relieve the global energy crisis.

1.4.1 Demand control actions and thermal comfort

Demand Response (DR) relates to any program that communicates with the end customer about price changes in the market and their energy use and encourages them to reduce or shift their energy consumption demand. DR actions also include load shifting and dynamic pricing control [70]. DR changes the electricity consumption patterns of end consumers to reduce instantaneous demand in times of high electricity prices [71].

Residential DR is used and developed, in interesting ways, to improve systems' energy efficiency, as shown in[72], [73], and [74]. Also, the same authors present a scheme for optimal performance of major household loads under a smart grid context to get the benefits of the availability of variable tariffs and renewables. Avci et al.[75] proposed a practical cost- and energy-efficient model for a predictive HVAC load control strategy for buildings with dynamic real-time electricity pricing.
1.5 Research questions

To assess the performance of the Low carbon Building, nZEB from the user’s and stakeholder’s perspective, we aim to answer the following research questions:

1) What could be energy-efficient solutions towards nZEB maintaining the thermal comfort of the occupants?
2) What is the social acceptance and the level of awareness of using Low Carbon Buildings and climate change in the Finnish Society?
3) What are the attitudes and approaches of Finnish retrofit industry stakeholders towards achieving nearly zero-energy buildings?

1.6 Framework of the dissertation

This dissertation is a compendium of four peer-reviewed journal publications as illustrated in Figure 2.

1.7 Methodologies and the outcome

<table>
<thead>
<tr>
<th>Publication</th>
<th>Research Question</th>
<th>Research Methodology</th>
<th>outcome</th>
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<tbody>
<tr>
<td>Paper I</td>
<td>RQ1: What could be energy-efficient solutions towards nZEB maintaining the thermal comfort</td>
<td>Dynamic simulation of the 9 types of detached houses.</td>
<td>An acceptable range of indoor air temperature for 9 different types of detached houses.</td>
</tr>
<tr>
<td>Paper II</td>
<td>RQ2: Chapter 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper III</td>
<td>RQ3: Chapter 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper IV</td>
<td>RQ1, 4 Chapter 5</td>
<td></td>
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</tr>
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</table>

Figure 2. Connections of the publications and the research Questions

**RQ2:** What is the social acceptance and the level of awareness of using Low Carbon Buildings and climate change in the Finnish Society?

Web-based questionnaire and Intense systematic critical literature review

Perceptions and acceptability of the Low carbon Buildings in Finland.

Publication III: Towards net zero energy buildings: building performance optimization, simulation and analysis.

**RQ1:** What could be energy-efficient solutions towards nZEB?

Dynamic simulation

Presented guidelines for office building facade design from the perspective of energy-efficiency and daylighting to architects, engineers, real-estate developers, etc.

Publication IV: Attitudes and approaches of Finnish retrofit industry stakeholders towards achieving nearly zero-energy buildings.

**RQ4:** What are the attitudes and approaches of Finnish retrofit industry stakeholders towards achieving nearly zero-energy buildings?

Web-based questionnaire, Literature review, and stakeholders’ interviews

The outcome was the assessment of the attitudes and approaches of the stakeholders towards the nZEB. Further, it will enable construction industry stakeholders to make provisions for overcoming the barriers, gaps, and challenges identified in the practices of the retrofit projects. It will also inform the formulation of policies that drive retrofit uptake.

1.8 Novelty of the dissertation

This section summarizes the novelty value of this dissertation based on the author’s original publications, which were conducted during the author’s doctoral study period. The novelty of original publication I, is to find out the acceptable range of indoor air and operative temperatures complying with the recommended thermal comfort categories in accordance with the EN 15251 standard in detached residential houses (1960, 2010, and passive) in a cold climate. There was a lack of studies that considered all the factors such as air velocity,
metabolic rate, and clothing factor while assessing the thermal comfort in different types of detached houses.

The novelty of the original publication II is to identify the level of awareness of using Low Carbon Buildings and climate change in Finnish Society. In addition, this paper also addressed how the acceptability rate of using low carbon buildings energy technology varies especially for participant’s own use in their buildings or near the environment. In this paper, we focused on public awareness and knowledge about the cost of low carbon building energy applications, willingness to pay for green energy, and low carbon building acceptability.

The novelty of the original publication III is to define the heating, cooling, and electricity demand of a residential building in a cold climate region towards nZEB. The façade parameters were optimized for the best possible energy performance, to be used as design guidelines for facades in low and nearly zero-energy buildings for architects and engineers. The purpose of the study is to give guidelines for office building facade design from the perspective of energy-efficiency and daylighting to architects, engineers, real-estate developers, etc.

The novelty of the original publication IV is to assess the approaches and the attitudes of the stakeholders in the Finnish construction industry. The results will support policymakers, technology providers, stakeholders in the energy and building sector, and building engineers to enable the development and adoption of RETs for residential buildings, including nZEBs, in urban centers of Finland. This study will enable construction industry stakeholders to make provisions for overcoming the barriers, gaps, and challenges identified in the practices of the retrofit projects. It will also inform the formulation of policies that drive retrofit uptake.
2. Literature Review

The review highlights the critical need to balance energy efficiency measures with occupant comfort and social acceptability while addressing the challenges and complexities faced by stakeholders in the construction industry.

This literature review covers several key aspects related to building sustainability and energy efficiency, particularly focusing on thermal comfort, social acceptability of low carbon buildings, building performance optimization towards net-zero energy buildings (nZEB), and stakeholder attitudes towards nZEB.

2.1 Influence of demand response on energy efficiency and thermal comfort

On a wider side in the EU residential sector, 22% of electricity consumption is through electric heating, 9% through hot water heating, and 1% through air conditioning [76]. Due to the cold climate in Finland, the heating in residential buildings accounts for 22% of the total primary energy consumption [77]. Moreover, detached houses comprise 89% of Finnish residential buildings [78] and 31% of the heating energy is electricity [77].

To reduce and control the electricity consumption of buildings, better demand side management and optimal control of Heating, Ventilation and Air Conditioning (HVAC) systems can reduce electricity demand and shift peak loads during shortage times. International Energy Agency (IEA) [67] states that control strategies such as pricing regulation, technical standards of demand response, and environmental impacts by retailers or consumer is the main approach to relieve the global energy crisis. Callaway et al. showed [79] that smart grid investments are demonstrating the potential for buildings to become grid-interactive resources that are just as controllable as or even more controllable than electricity generators. The smart grid concept proposes an electricity network that integrates generation and consumption with real-time two-way communications [80]. Surles et al. [81] focused on utilizing a control analytic tool for evaluating the effectiveness of different demand response actions to shift and reduce energy consumption during peak pricing periods and lower energy costs.
for residential homes and utilities. Residential DR is being interestingly used and developed to improve the energy efficiency of systems [72][73][74]. Avci et al. [75] proposed a practical cost and energy-efficient model predictive HVAC load control strategy for buildings facing dynamic real-time electricity pricing. Klein et al. [82] presented and implemented a multi-agent comfort and energy system to model alternative management and three different controller strategies and occupants. Hazyuk et al. [83] proposed model predictive control (MPC) to embed in building energy management systems to compare with two PID control systems.

However, the technological breakthroughs [84] and [85]. Du and Lu [84] [85] in efficient construction, better demand side management, and optimal control of HVAC systems not only must be addressed to save energy but also to achieve thermal comfort for the occupants. Occupant’s comfort is the major factor to be considered for evaluating the performance of a building control system [86]. This research proposes to fill this gap by addressing the acceptable range of the operative and indoor air temperatures to maintain the thermal comfort of the occupants.

2.2 Social Acceptability of Low Carbon Buildings

The development of (LCB) is reflected in not only the advances of theories but also project practices. Showcase projects help to demonstrate the benefits of low-carbon building developments. An exemplary project plays a pivotal role in facilitating cultural change in the construction industry toward low carbon sustainable development [13].

However, besides the low energy solutions [18] [19] to achieve low carbon buildings, the social acceptability of such buildings shall also be studied, and is of high importance to know the social aspects.

The social acceptability of renewable technology in Finland in the communal context has been recently examined by[22]. Low carbon buildings energy technologies for low carbon generation are diverse. People’s adoption of low carbon buildings increases the use of different types of renewables, e.g., biomass-fuelled plants at scales from small combined heat and power plants; solar power; wind turbines of different scales, designs, and on offshore locations; waste plants. Each technology captures different natural resources in different ways, and the economic, social, and environmental impacts of each technology vary [21]. Thus, the need for assessing the societal acceptability of low carbon buildings is fundamental for understanding people’s social perspectives in terms of using low carbon buildings and climate issues [22].
2.3 Building performance and optimization towards nZEB

There has been growing interest in net-zero energy buildings in recent years. And has been applied in many different fields, from fossil fuel [87] and nuclear power to renewable energy [88]. In the building sector, net energy is often referred to as a balance between the energy consumption in a building and the energy produced by its renewable energy systems. The terms ‘ZEBs (zero energy buildings)’ and ‘NZEBs (net zero energy buildings)’ have both been adopted by different researchers. Detailed definitions and descriptions can be found by Marszal et al. [40] and Sartori et al.[89].

Several analyses have been made about facade design’s influence on buildings’ energy consumption. Poirazis et al. [90] Motuziene and Joudis [91] conducted office building energy simulations studying window-to-wall ratios (WWR) between 30% and 100%, different glazing, shading, and orientation options. The results showed that optimal WWR was 20–40%, however, it was noted that there will be problems fulfilling daylighting requirements. Supernova et al. [92] simulated office buildings in 7 different climates and concluded that in cold climates increasing WWR increases office buildings’ total energy consumption. Using energy simulations of an institutional building Tzempelikos et al. [93] came to the conclusion that substantial energy savings can be achieved using an optimum combination of glazing, shading devices, and controllable electric lighting systems. Johnson et al. [94] optimized daylighting use and studied the sensitivity of orientation, window area, glazing properties, window management strategy, lighting installed power, and control strategy. The results showed that saving can be significant with automatically controlled lighting, however, total energy consumption must be kept in mind as analyzed parameters influenced the energy use of HVAC greatly.

All the authors Boyano et al. [95] Franzetti et al. [21] Grynning et al. [97] mentioned previously, have done a thorough investigation of an office building facade, however, windows with U-values below 1.0 W/ (m² K) have been rarely studied.

The overall consequence of the [98] [4]. retrofit strategies would be an energy-efficient building with low greenhouse gas emissions that is both comfortable for occupants and cost-effective. Another important factor in studying nZEB is the climate of the region where retrofitting is performed. It’s generally accepted that buildings in colder climates use more energy for heating than those in warmer climates use for heating building space and air ventilation. So, it takes less energy to achieve indoor comfort in cooling-dominated climates as well and it’s easier to build an nZEB, indicating differences in approach towards nZEB in cold and warm climates. For example, while thick layers of insulation get most of the attention in cold climates, insulation needs less emphasis in warm climates [99].
2.4 Attitudes of stakeholders towards nZEB

The management of stakeholders is crucial for the performance of projects, especially in the case of a complex project [27]. For project success, strong collaboration among stakeholders is important as a project can be viewed as a temporary organization for stakeholders pursuing a goal together [29][30][31].

In all construction projects [33], numerous stakeholders are involved at each stage directly or indirectly. An integrated design process (IDP) involves all participants in the early design phase of the project. This indicates that all parties work together in the preliminary design process, from setting the project priorities to identifying measurable design criteria for these objectives.

The provision of incentives supports the market penetration of nZEBs, and a recent market report on Energy Service Companies (ESCOs) in Europe notes that the Irish retrofit industry is growing rapidly due to such incentives [34].

In the Irish context, conventional construction professions, such as carpenters, electricians, and manufacturers, directly interact with the owners, and it is important to establish the supply chain in value [35]. The Build-up skills roadmap is a key component of the Build 2020 plan formed by a coalition of governmental departments, state agencies, training centers, and construction workers to enhance skills for tradesmen and retrofit professionals [20].

To address current technological, social, economic, and environmental hurdles, retrofitting companies need a greater agreement around processes, tools, and best practices, as discussed in this study. The retrofit industry is an important stakeholder for nZEB, and key actors include professionals such as architects, engineers, small and medium businesses, contractors, and other construction professionals.

Coordinated engagement between industry stakeholders in the starting, production, and delivery of projects will improve the quality and technology necessary for retrofit [36]. Several studies have explored the criteria of end users to help retrofit decision-making using surveys [37,38].

Nevertheless, very few studies [40] have assessed the demands for low energy buildings by building industry stakeholders in Europe [39]. They suggested that most countries need knowledge and training to encourage potential business growth.

They also suggested that the growth of ESCOs in Europe lacks confidence and reliable information. Established skills in the building industry are quite high, but they are not enough matched to the low energy building approach. However, it does not include Finland in its consortium.

Therefore, a thorough stakeholder consultation process has been initiated in this study to recognize the barriers, gaps, and challenges to the retrofit industry in Finland.
3. Thermal Comfort and Energy Efficiency

The buildings in the European Union (EU) account for 40% of the total energy consumption, mainly in space heating and hot water [100][101]. Overall, residential and tertiary sectors in the EU account for 50% of the electricity consumption [101]: 22% of that consumption is for electric heating, 9% for hot water heating, and 1% for air conditioning [76]. In Finland, due to its cold climate, the heating in residential buildings accounts for 22% of the total primary energy consumption [77]. In 2012, detached houses comprised 89% of Finnish residential buildings [78] and 31% of their heating energy was obtained from electricity [77].

Better demand-side management and optimal control of HVAC systems can reduce electricity demand and shift peak loads during shortage times. International Energy Agency (IEA) [67] states that control strategies such as pricing regulation, technical standards of demand response, and environmental impacts by retailers or consumers form the main approach to relieve the global energy crisis. Callaway et al. [79] showed that smart grid investments can demonstrate the potential for buildings to become grid-interactive resources while being just as controllable as or even more controllable than electricity generators. However, the technological breakthroughs in efficient constructions, better demand side management, and optimal control of HVAC systems must not only address energy savings but also thermal comfort for the occupants. Occupants’ comfort is the major factor to be considered in evaluating the performance of a building control system [86][102].

This chapter discusses the acceptable range of indoor air and operative temperatures complying with the recommended thermal comfort categories in accordance with the EN 15251 standard; and minimizing the energy cost of electrically-heated detached houses utilizing the demand response (DR) control strategy, without sacrificing the thermal comfort of the occupants for residential detached houses.

3.1 Objectives

This study has two aims to investigate the energy demand response (DR) actions on thermal comfort and energy cost in detached residential houses (1960, 2010, and passive) in a cold climate. The first one is to find out the acceptable range
of indoor air and operative temperatures complying with the recommended thermal comfort categories in accordance with the EN 15251 standard. The second one is to minimize the energy cost of the electric heating system using the DR control strategy, without sacrificing the thermal comfort of the occupants.

3.2 Methodology

3.2.1 Assessment of thermal comfort

Thermal comfort describes a person’s psychological state of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation [86]. Thermal comfort has a great influence on the productivity and satisfaction of occupants in buildings [103]. This study uses the Fanger approach to predict the thermal comfort of the occupants in the buildings [86].

Fanger proposed a method by which the actual thermal sensation could be predicted. He assumed that the sensation experienced by a person is a function of the physiological strain imposed on him by the environment. He calculated this extra load for people involved in climate chamber experiments and plotted their comfort vote against that load. He developed a set of correlations giving the Predicted Mean Vote (PMV) as a function of six variables: 1) air temperature, 2) mean radiant temperature, 3) air velocity, 4) air humidity, 5) clothing resistance (Insulation, clo), and 6) activity level (metabolic rate, met). Table 1 shows the thermal sensation grades for thermal comfort, as quantified in the ASHRAE standard 55 [86]. It also shows the seven PMVs with values ranging from -3, indicating cold, through 0, indicating neutral, to +3, indicating hot.

<table>
<thead>
<tr>
<th>PMV</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3</td>
<td>Cold</td>
</tr>
<tr>
<td>-2</td>
<td>Cool</td>
</tr>
<tr>
<td>-1</td>
<td>Slightly cool</td>
</tr>
<tr>
<td>0</td>
<td>Neutral</td>
</tr>
<tr>
<td>1</td>
<td>Slightly warm</td>
</tr>
<tr>
<td>2</td>
<td>Warm</td>
</tr>
<tr>
<td>3</td>
<td>Hot</td>
</tr>
</tbody>
</table>

Fanger [104] realized that the predicted vote was only the mean value to be expected from a group of people, and he extended the PMV to predict the proportion of any population who will be dissatisfied with the environment. A
person's dissatisfaction was defined in terms of their comfort vote: that is, people whose vote falls outside the central three grading points of the thermal sensation scale (see Table 2) are termed as dissatisfied. The distribution of the Predicted Percentage of Dissatisfaction (PPD) is based on observations from climate chamber experiments and not from field measurements. The variation of the PPD index can be approximated by an analytic expression that corresponds to a curve, as follows:

$$PPD = 100 - 95 e^{-(0.03353 \cdot PMV^4 + 0.2179 \cdot PMV^2)}.$$  \(1\)

As equation 1 shows, the PPD curve is symmetric with respect to PMV=0; thus the number of complaints on the warm and cold sides are the same. Figure 3 shows that, due to individual differences between people, even for a situation that, on average, is considered by the population as thermal neutrality (PMV=0), the percentage of dissatisfied is 5%[86] and [104].

![Figure 3. Predicted percentage of dissatisfied (PPD) as a function of predicted mean vote (PMV)](image)

**Indoor thermal comfort according to related standard**

To conduct this research, two reference standards including EN 15251[105] and ASHRAE standard 55 [86] were considered. EN 15251, the European standard, specifies the indoor environmental parameters that have an impact on the energy performance of the buildings. Through energy simulation, a study and analysis have been carried out to satisfy the thermal conditions for different categories defined in that standard [105].

Table 1 and 2 show the four categories, describing the level of expectations for the occupants, and the comfort conditions for those categories of buildings respectively defined in this standard.

**Table 2. Description of the applicability of thermal comfort categories of the EN 15251 [105].**

<table>
<thead>
<tr>
<th>Category</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Moreover, the categories in Tables 2 and 3 are defined by means of PPD and PMV values, and the lower limits of PMV values were used to determine the minimum acceptable indoor air and operative temperatures during the heating season. The maximum PMV values were used to define the maximum acceptable indoor air and operative temperature during the heating season, even though the maximum PMV values had originally been defined for the cooling season.

**Table 3.** Thermal comfort categories for the design of mechanically heated and cooled buildings [105].

<table>
<thead>
<tr>
<th>Category</th>
<th>Thermal state of the body as a whole</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PPD %</td>
</tr>
<tr>
<td>I</td>
<td>&lt;6</td>
</tr>
<tr>
<td>II</td>
<td>&lt;10</td>
</tr>
<tr>
<td>III</td>
<td>&lt;15</td>
</tr>
<tr>
<td>IV</td>
<td>&gt;15</td>
</tr>
</tbody>
</table>

The EN 15251 standard [105] defines several methods for residential and non-residential buildings to evaluate the fulfillment of comfort indoor conditions. This study uses the percentage falling outside the limits of the acceptable range method. The method allows a slight time deviation from the acceptable range. A 5% deviation [105] is used in this study for temperatures above the criteria for, 24 minutes (during a working day), 2 hours (during a working week), 9 hours (during a working month), and 108 hours (during a year).

The ASHRAE 55 standard [86] defines the maximum operative temperature change allowed. The monotonic and non-cyclic changes in operative temperature are known as temperature drifts and ramps. Drifts and ramps refer to passive temperature changes in the enclosed space and actively controlled temperature changes, respectively. **Table 4** specifies the maximum allowed variation in operative temperature during a period of time. According to the ASHRAE 55 standard [86], for any time period, the variation of operative temperature cannot exceed the limits defined in **Table 4**. But, if the variations are created as a
result of control or adjustments by the occupant, higher variations may be acceptable

Table 4. Maximum allowed variation in operative temperature [86].

<table>
<thead>
<tr>
<th>Time period (h)</th>
<th>0.25</th>
<th>0.5</th>
<th>1</th>
<th>2</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum operative temperature change allowed (°C)</td>
<td>1.1</td>
<td>1.7</td>
<td>2.2</td>
<td>2.8</td>
<td>3.3</td>
</tr>
</tbody>
</table>

3.2.2 Building simulation IDA ICE

In this study, we have used IDA ICE building simulation software [106]. IDA Indoor Climate and Energy (IDA ICE) is a whole-year detailed and dynamic multi-zone simulation application for the study of indoor climate as well as energy. It is a befitting tool for building a simulation of energy consumption, indoor air quality, and thermal comfort. It undertakes a variety of other phenomena, such as the integrated airflow network and thermal models, CO2 and moisture calculation, and vertical temperature gradients. Different case studies have been validated IDA IC [107][108].

3.2.3 Weather Data and Location

This research used the Finnish test reference year (TRY2012) as weather data for dynamic simulations. The data consists of detailed hourly data of temperature, relative humidity, wind velocity, and solar direction and radiation describing the current climatic conditions of Southern Finland. The weather conditions data was accumulated and computed by recording 30 years (1980-2009) in the Helsinki region [109].

The Finnish climate is highly influenced by the country’s geographical position between the 60th and 70th northern parallels in the Eurasian continent’s coastal zone, which shows characteristics of both a maritime and a continental climate, depending on the direction of weather front. The annual average temperature for the Helsinki-Vantaa region is +5.4°C, bringing the region under climatic zone 1 [110]. The average number of degree days at an indoor temperature of 17°C is 3952 Kd.

3.2.4 Building description

In this paper, we have simulated a Finnish single-family detached house with three different types of thermal insulation and thermal mass having a heated area of 180 m² and air volume of 468 m³ the building has four occupied zones, Living room, Bedroom, bathroom, and hall. Nine different versions of the detached house design were simulated, these being determined based on differences in construction practice, building regulations, and guidance.
Three different types of buildings namely 1960, 2010, and Passive, each with three different types of structure namely Light weight, Medium weight, and Massive have been simulated and analyzed, to show how much indoor air temperature can be decreased while fulfilling the target values for thermal conditions (according to SFS – EN – 15251, ASHRAE– 55). Table 5 shows the different cases of structures with their U value and air tightness.

Table 5. Definition of different structures their U values and air tightness.

<table>
<thead>
<tr>
<th>Cases</th>
<th>Thermal insulation</th>
<th>U-values, W/m²K</th>
<th>Window properties</th>
<th>Air tightness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ext wall</td>
<td>Roof</td>
<td>Base floor</td>
</tr>
<tr>
<td>Lightweight</td>
<td>Typical 1960</td>
<td>0.81</td>
<td>0.47</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Standard 2010</td>
<td>0.17</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>Passive</td>
<td>0.08</td>
<td>0.07</td>
<td>0.08</td>
</tr>
<tr>
<td>Medium weight</td>
<td>Typical 1960</td>
<td>0.81</td>
<td>0.47</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Standard 2010</td>
<td>0.17</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>Passive</td>
<td>0.08</td>
<td>0.07</td>
<td>0.08</td>
</tr>
<tr>
<td>Massive</td>
<td>Typical 1960</td>
<td>0.81</td>
<td>0.47</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Standard 2010</td>
<td>0.17</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>Passive</td>
<td>0.08</td>
<td>0.07</td>
<td>0.08</td>
</tr>
</tbody>
</table>

U-values and air tightness of the 1960 cases are based on the default values of the statement of the Finnish Energy Certificate 2013.

We have considered daily moisture production of 2.7 kg/24 hr., Occupant according to the study by Vinha et al.[111], therefore the total moisture production from person and equipment is 10.8kg/24h and 5.4148 kg/24h (0.00006267kg/s) respectively [111].

We have taken the activity levels of 1 met (Seated and relaxed) and 1.2 met (Standing and relaxed) and clothing insulation levels of 0.96 clo (Trousers, long sleeved shirts plus suit jackets) and 1.14 clo (Trousers, long sleeved shirts plus suit jackets plus vest and T-shirt)[112].
3.2.5 Heating and ventilation systems

This research deals with the electric radiator heating system (ERHS) and electric floor heating system (EFHS), focusing on these two heat distribution systems and two controllers (on-off controller [113] and P-controller [114]) as the alternative systems and controller types for buildings. The value of the on-off controller type dead band is assumed to be 1.0°C and the proportional band of the P-controller type is also assumed to be 1.0°C.

Also, the ventilation system of different building types is studied. The 1960 building type has a mechanical exhaust ventilation system. The ventilation rate of this building type is based on the average ventilation rate of 55 Finnish houses with mechanical exhaust ventilation [115]. For the 1960s cases, the ventilation rate considered is 0.36 Air Change per Hour (ACH). The 2010 and Passive building types have a mechanical supply and exhaust ventilation system with heat recovery. The system of mechanical supply and exhaust ventilation with heat recovery is the most common ventilation system in new Finnish detached houses. Heat recovery with the efficiency of 60% and 80% for 2010 and Passive cases, respectively, has been employed. In the 2010 and passive building types, ACH is 0.5, in accordance with the guideline of the Finnish building code D2 (2012) [112].

3.2.6 Simulated control Algorithm/ Demand control strategy

Control algorithm A

This is the simplest algorithm that controls indoor temperature set point (Tset) according to HEP. To change the set point, if the HEP is less than the limiting price (LP), the normal indoor temperature set point is used; otherwise, it will be the minimum set point in the acceptable temperature range. The pseudo-code for the control mechanism is the following:

\[
\text{If } HEP < LP \text{ then } T_{set} = T_{set, normal}
\]

\[
\text{else } T_{set} = T_{set, min}
\]

End

The performance of this algorithm is simulated by using the following values of the parameters; Tset, normal is the normal set point temperature used for detached houses, in accordance with the Finnish building code (21.0°C) ([32] and [33]), Tset, min is the minimum indoor temperature set point defined in this study (see Section 5.2) and the assumed value of the LP is 50€/MWh. The assumed LP is significantly lower than the maximum HEP (300.1€/MWh) and higher than the average one (36.7€/MWh) to show the potential of controlling indoor temperature set point in accordance with the assumed LP.
Control algorithm B

The main idea of this new control algorithm is to manage the indoor temperature set point according to previous HEPs. This is done by comparing the median of previous hourly electricity prices (MHEP) and current HEP. The number of previous hours can be selected, and the optimal number of previous hours is analyzed in this study. At every hour when a new price is announced, the DR control modifies the indoor temperature set point, which can be either increased, kept constant, or decreased, depending on the electricity price. The control algorithm has two parts: the first part compares MHEP and HEP, and the second part concentrates on the indoor temperature and outdoor temperature trends. The pseudo-code for the control mechanism is the following:

\[
\text{If } HEP \geq MHEP, \text{ then } T_{set} = T_{set,min}
\]

\[
\text{elseif } \begin{cases} 
HEP < MHEP \\
T_{max} < T_{set,max} \\
T_{ave,24} < T_{out}^{lim}
\end{cases} \text{ then } T_{set} = T_{set,max}
\]

\[
\text{else } T_{set} = T_{set,normal}
\]

End.

Where Tmax is the maximum hourly indoor temperature of the building, Tset,max is the maximum acceptable indoor temperature, \( T\_out^{(ave,24)} \) is the average outdoor temperature of the previous 24 hours and \( T\_out^{lim} \) is the limiting outdoor temperature considered as the maximum outdoor temperature when the indoor temperature set point can be increased.

In order to improve the performance of the algorithm, the optimal number of previous hours was examined. These numbers of previous hours, ranging from 2 to 24 hours, were then used by the algorithm to simulate the annual energy cost of space heating (ECSH) of the building. Figure 4 shows the effect of previous hours on the ECSH for Massive Passive (M-Pass) building type simulated with HEP of three years (2010–2013). Because the HEP of 2011 is quite similar to the HEP of 2012, it was not studied; and the HEP of 2010 and 2012 or 2013 are quite different, Figure 4 shows results in two price scales. For minimizing the ECSH for the studied building types, the optimum number of previous hours among the studied time periods is 14. Moreover, it was found that the level of thermal insulation and thermal mass of the building does not affect the resultant optimum number of hours. Also, the optimum number of previous hours is independent of the studied time period and building types. Furthermore, the
optimal number of previous hours does not depend on the heat distribution systems and temperature controller types studied.

![Figure 4](image)

**Figure 4.** Total energy cost of space heating in M-Pass building (see Table 1) with different number of previous hours, which have been used in the algorithm B.

**Control algorithm C**

The principle of this new predictive control algorithm is to control the indoor temperature set point by adjusting it in accordance with future hourly prices. This algorithm generates a control signal by utilizing a maximum subarray problem. The maximum subarray problem calculates a contiguous subarray that has the largest sum within a one-dimensional array of numbers, containing at least one positive number \[34\]. By means of this concept, the HEPs can be accordingly sorted to realize their rising or falling trend; hence, corresponding control signals can be assigned to the limited future prices.

This control algorithm has two parts: first, the control algorithm calculates the control signal (CS); second, the indoor temperature set point of the building is controlled according to the CS, the indoor temperature and outdoor temperature trend (the indoor temperature and outdoor temperature trend rules are similar to the rules used with control algorithm B).

The principle of such a control algorithm is; that the algorithm generates \(CS = +1\) to increase the indoor air temperature set point to the maximum one before the HEP increases. As soon as the HEP starts to increase, the algorithm generates \(CS = -1\) to decrease the indoor air temperature set point to the minimum one. In other conditions, the algorithm generates \(CS = 0\) and the indoor air temperature set point is the normal set point temperature. The pseudo code of the control mechanism is the following:

\[
\begin{align*}
\text{If } CS &= -1 \quad \text{then } T_{set} = T_{set,min} \\
\text{elseif } &\begin{cases} CS = +1 \\
T_{max} < T_{set,max} \\
T_{ave,24th} < T_{out}\lim \end{cases} \quad \text{then } T_{set} = T_{set,max}
\end{align*}
\]
else $CS = 0$, then $T_{set} = T_{set,normal}$

End.

The optimal number of limited future hours was studied by simulating the annual ECSH of the building with different numbers of future hours ranging from 2 to 24 hours. The latter number of hours was used as a maximum period because HEPs are published 24 hours ahead [35].

3.3 Result and discussion

3.3.1 Fulfillment of the ASHRAE standard

To assess the speed of the indoor operative temperature change in the nine studied buildings, Figure 5 shows the results of the simulation during four hours of January from TRY2012. It shows that LW-1960 and Medium Weight 1960 (MW-1960) buildings do not fulfill the ASHRAE 55 standard [86], the variation of the indoor operative temperature exceeding the allowed variation. The ASHRAE 55 standard [86], states that higher variations may be acceptable because the studied temperature variations are created by the control system. The LW-1960 was selected for the energy and cost simulations because it represents the extreme building types from the thermal mass and thermal insulation point-of-view.

Figure 5. Fulfillment of ASHRAE 55 standard rule for operative temperature change for the nine studied buildings
3.3.2 Acceptable indoor temperature set points

The acceptable indoor temperature set point depends on various conditions such as different occupants’ behavior (e.g. different met levels and different clothing levels), heat distribution systems, and the controller types installed in different buildings. To find out about the influence of these conditions on acceptable indoor temperatures, this research studied different activity levels, clothing levels, and air velocities.

Table 6 presents the acceptable indoor temperatures for the ERHS and EFHS with the on-off and the P-controller types. The minimum and maximum indoor temperature set points are shown for three different thermal comfort categories defined in the EN 15251 standard.

| Category | LW-1960 | | M-Pass | | | |
| --- | --- | --- | --- | --- |
| | Min-Max of Tair (°C) | Min-Max of Top (°C) | Min-Max of Tair (°C) | Min-Max of Top (°C) |
| Electric radiator heating system, on-off control | | | |
| I | 22.4-22.5 | 22.6-22.7 | 22.6-22.8 | 22.7-22.9 |
| II | 21.0-22.9 | 21.2-24.0 | 21.2-23.6 | 21.3-24.1 |
| III | 20.0-24.0 | 20.2-24.4 | 20.2-24.4 | 20.3-24.6 |
| Electric radiator heating system, P-control | | | |
| I | 22.8-22.9 | 22.3-22.8 | 22.3-22.7 | 22.2-22.7 |
| II | 21.4-24.3 | 20.8-24.3 | 20.8-24.1 | 20.7-24.1 |
| III | 20.4-25.3 | 19.8-25.3 | 19.8-25.1 | 19.7-25.1 |
| Electric floor heating system, on-off control | | | |
| I | 22.5-22.6 | 22.7-22.8 | 22.6-22.8 | 22.6-22.8 |
| II | 21.0-23.0 | 21.3-23.5 | 21.2-23.5 | 21.2-24.0 |
| III | 20.0-24.1 | 20.3-24.4 | 20.2-24.5 | 20.2-24.7 |
| Electric floor heating system, P-control | | | |
| I | 21.8-22.2 | 22.1-22.4 | 22.0-22.3 | 22.1-22.5 |
| II | 20.4-23.6 | 20.7-23.7 | 20.5-23.9 | 20.6-24.1 |
| III | 19.4-24.6 | 19.7-24.7 | 19.5-24.9 | 19.6-25.1 |

The range of the acceptable indoor temperature depends on the considered thermal category and it is wider from category I to III. As the results of category
III are wider, they were used for the rule-based DR control algorithms strategies. The difference between results in the same situations is insignificant.

This thesis, in publication I, assessed the influence of acceptable indoor temperature on different activity levels, clothing levels, and air velocities, including the velocities of 0.1 m/s and 0.2 m/s, because they are typical air velocities in detached houses according to [117-118]. The effect of air velocity depends on the thermal comfort category; it means that by changing the air velocity from 0.1 m/s to 0.2 m/s, the minimum indoor air and operative temperature set point for categories I, II and III, shown in Table 6, increase from 0.6 °C to 1.0 °C depending on cases. The effect of activity level also depends on the thermal comfort category: the minimum indoor temperature set point can be increased up to 2.0 °C for categories I and up to 2.5 °C for category II or III by changing the activity level from 1.2 to 1. Moreover, the effect of a change in clothing level from 1.14 clo (shown in Table 6) to 0.96 clo is to increase the minimum indoor air and operative temperatures between 0.9 °C and 1.3 °C.

3.3.3 Total delivered energy and energy cost

Total delivered energy and energy cost were examined for different control algorithms with the on-off and P-controller types for LW-1960 and M-Pass building types. Because of the higher potential of the thermal comfort category III to achieve lower energy cost, it was selected for this examination. For this end, the related acceptable indoor temperature set points for each studied case were used. Air temperature was used as a control variable because it is more commonly used as a control variable in detached houses in Finland. The studied cases were compared with the reference one. The indoor temperature set point of heating in the reference case is a constant 21.0 °C. The reason is that this is the normal set point temperature used in detached houses in Finland recommended by the Finnish building code. To realize the lowest total delivered energy and cost, these were calculated according to the minimum indoor set point temperature for the whole year. This study considered two options for the maximum indoor temperature set point values used in the simulation: the higher one is the maximum acceptable indoor temperature set point according to this study and the lower one (22.0 °C) is to determine the effect of small temperature increase. Also, two options were considered for limiting outdoor temperature: the first one, 0.0 °C, to allow an increase in the indoor temperature set points and the second one, 21.0 °C, means that indoor temperature set points are not increased at all because that is the lowest outdoor temperature of the weather data used. The energy cost is calculated by the Finnish HEP of 2012 including energy, transfer prices, and taxes [116].

In most of the studied cases, the total delivered energy consumption and cost are decreased for the control algorithm backward-looking and predictive by two alternatives; the first one is to change the maximum indoor air temperature set point to a lower one (22.0 °C) and the second one is to decrease the limiting outdoor temperature to the lowest one (21.0 °C). In most of the studied cases, the backwards-looking control algorithm is more effective with different heat distribution systems, controller types, and options of $T_{set,min}$ and $T_{out}^{lim}$. 

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The backwards-looking and predictive control algorithms are able to save the total delivered energy consumption and cost in most of the studied cases. But, depending on the values of the parameters and the controller type used with the control algorithms, the backward-looking control algorithm increases total delivered energy consumption and cost by 5.4% and 26.1%, respectively; and the predictive control algorithm increases them by 3.6% and 20.7%, respectively in M-Pass building type with electric floor heating system. This indicates that the performance of the backward-looking and predictive control algorithms are sensitive to the values of the parameters and the controller types. When compared with the reference case, the maximum energy consumption and cost saved by the use of the momentary control algorithm are 0.8% and 2.1%, respectively. The backward-looking control algorithm can save total delivered energy consumption and cost up to 3.1% and 7.7%, respectively. The maximum total delivered energy consumption and cost saved by the use of the predictive control algorithms are 1.3% and 9.6%, respectively.

The reason for the higher savings by predictive DR control algorithms is that monitoring future HEPs makes heat-up buildings in the cheaper HEPs and avoids the expensive HEPs when the heat demand is needed in future hours.

### 3.4 Summary of the chapter

This study presented the acceptable range of indoor air and operative temperatures, complying with the thermal comfort categories recommended by the EN 15251 standard, for a detached house (nine different houses, including three different types of houses and structures) in a cold climate of Finland. This study minimized the total delivered energy and cost of electrically heated detached houses by means of three different demand response control algorithms, without sacrificing the occupants' thermal comfort.

The comfort category III of the EN 15251 standard has the potential for the studied control algorithms to save the total delivered energy and cost; thus, it was selected for this examination. According to the acceptable indoor air and operative temperatures found in this study, the three control algorithms were applied. When compared with the reference case (the indoor temperature set point of heating is a constant 21.0°C), the maximum total delivered energy and cost saved by the use of control algorithms are 3.9% and 10.1%, respectively. The control algorithm based on the previous hourly electricity prices is the most effective algorithm in most of the studied cases.

According to this study, based on the assumptions concerning building type, controller type, the behaviour of the occupants (activity and clothing levels), and comfort categories, the lowest and highest indoor operative temperature set points are 19.6°C and 25.1°C, respectively. They are higher than the recommended ones by the EN 15251 standard; thus, this standard is not suitable for the studied detached houses in the Finnish climate. The studied light and medium-weight houses with the lowest level of thermal insulation do not strictly fulfill the rule of the ASHRAE 55 standard for the maximum allowed operative temperature change. In some of the studied cases, the control algorithms
decrease the total delivered energy and cost more than using the constant minimum indoor temperature set point for the whole heating season. However, the performance of the control algorithms depends on house type, heat distribution system, controller type, and the parameters of the control algorithm. In most of the studied cases, the P-controller is more effective than the on-off controller to save the total delivered energy and cost with and without control algorithms.
4. Social acceptability of using low carbon building

The effect of low carbon building development on technologies and theory are of various facets [117]. It has been argued by [9] that the absence of a standardized concept of LCB poses a major challenge in the advancement of low carbon buildings. Thus, it is important to evaluate the social acceptance of low carbon buildings to understand the social perceptions of the people in terms of usage of low-carbon buildings and climate challenges [22] [23].

This chapter includes a study to investigate the level of awareness of using Low Carbon Buildings and climate change in Finnish Society.

4.1 Objectives

This research aims to identify the level of awareness of using Low Carbon Buildings and climate change in the Finnish Society. In addition, this paper also addressed how the acceptability rate of using low carbon buildings energy technology varies especially for participant’s own use in their buildings or near the environment. In this research, we focused on public awareness and knowledge about the cost of low carbon building energy applications, willingness to pay for green energy, and low carbon building acceptability.

The study results provide classical knowledge in many ways. For example, (1) they provide us with a new approach to knowing how and what kind of steps have already been taken to create awareness about low carbon building energy technology and climate change so far in Finland, and (2) they help us to analyze public perceptions towards low carbon building applicability and to acquire knowledge about what different kinds of low carbon building energy technologies they (participants) are aware of.

4.2 Methodology

As one of the widely assumed factors for the successful implementation of low carbon buildings, the term societal acceptance has received great importance [118], [23] [118][119]. More clearly, the concept of societal acceptance is a major concern in energy policy in terms of implementing the principles of low carbon buildings, and in the marketing of new innovative solutions [23]. Societal acceptance study contributes to the sustainable development of low carbon buildings meeting current and future-oriented societal needs. It will provide specific
observations concerning the impact of low carbon buildings on society. Additionally, the study effectively addresses user’s misconceptions into the wider acceptance of low carbon building applications.

User’s levels of acceptance of the low carbon building systems will be considered as a part of the process optimization. People using low carbon buildings and alternative energy sources at all levels today are forerunners, not average people. The societal acceptance study aims to find out: public awareness and knowledge about the cost of low carbon building energy applications, willingness to pay for green energy, and low carbon building acceptability.

4.2.1 Survey design and questionnaire

This study uses a survey questionnaire type of methodology that considers various users segment groups, in the financial community and among sellers, builders, and local national, and international level policymakers dealing with low carbon building solutions.

Questions for the questionnaire are divided into 4 different categories: individual perspective, social perspective, community, and market perspective as illustrated in Figure 6 below.

![Figure 6. Questionnaire design methodology.](image)

In total 27 questions were chosen. The background questions covered the demographic details of the interviewees (Q1–Q4). Questions (Q5-Q9) covered the social perspective, (Q10-Q14) covered the community perspective, and the rest of the questions covered the market perspective of LCB.

The survey questions first mapped the respondent’s awareness and choice of using LCB Q8 as a first-generation (fossil fuels) or second-generation (renewables). Secondly, how important was it to use LCB for them Q12. Thirdly, Q22-Q25 further highlights the respondent’s understanding of LCB and its technologies and their willingness to invest in LCB Q7. A room for an open answer and the ‘not known’ option was available for the questions.
4.2.2 Data Collection

An online surveying system was used to publish the questionnaire. On 27 July 2019, the public version of the survey was initiated. The question was connected to the Internet management and survey distribution network, which was used in various Internet panels to obtain the necessary amount of feedback. The target population was limited to Finnish citizens, and the research participants were divided into three classes (15-25; 26-40, and 41-60). Such groups of age were chosen to understand precisely the role of the age level towards the social acceptability of Low Carbon Buildings. Figure 7 shows the interviewee ratio for the above-mentioned data.

![Figure 7. Percentage of the respondents by age.](image)

Approximately 46% as most respondents were the age of 45-64 followed by the age group of 25-44 by 32%. The majority of the participants (Figure 8) were employed (74%), whereas the second largest group of participants were students (10%), and few of the participants were others (11%).
4.2.3 Data analysis

The data collected were exported to a spreadsheet for thorough analysis from our online survey system after closing our online survey. Based on our survey questions, two types of variables (independent and dependent) have been chosen as follows.

1) Independent variables through the questions: Q1–Q8, Q10–Q15
2) Dependent variables through the questions: Q16–Q19, Q22–Q38, Q40.

The open questions were analyzed through a simple qualitative content analysis, by identifying certain words and calculating their repetition for each question. Using the spreadsheet calculations, the data was analyzed and the selection of the statistical characteristic of the data was identified using standard statistical operations. Different kinds of statistical analyses have been used to analyze the data, for example, Co-relations, variables, and text mining analysis.

4.2.4 Background data

As discussed in most of the respondents were of the age of 45–64 years. Mostly living in the city side of Finland as shown in Figure 9.
Text mining analysis shows that most of the respondents are living in houses 40% followed by apartments 29.17%. Further Figures 10 and 11 below highlight the responses of Q 4. Additionally, we used word mapping by hierarchical and clustering analysis to analyze the reason behind their living in such houses/apartments.

**Figure 10.** Percentage of accommodation in which the respondent lives

**Figure 11.** Clustering analysis for the Q7.
Respondents chose to live in an apartment/house because of the following reasons as shown in Figure 10.

i) the price ii) location iii) good public transportation options iv) maintenance v) reliable and comfort vi) and environment friendly.

4.3 Results and discussion

4.3.1 Users perspective/understanding of LCB

The survey highlights (refer Figure 12) that the users have a greater understanding and awareness of LCB, and further they are willing to invest in it. Q8 highlights that 59.72% of the respondents have their opinion that using LCB can help to reduce greenhouse gas emissions. Respondents (Q15) are also highly equally considerate about aspects like building price, sustainability, and renewables in a building when they evaluate the building (refer Figure 13).

![Figure 12. Respondent's opinion about LCB (Q8)](image)

![Figure 13. These aspects the respondents consider the most important when evaluating different buildings](image)

4.3.2 Willingness to upgrade to LCB

The survey shows the respondents not only have the understanding but also, are willing to invest in upgrading their accommodations towards LCB. Q21 (refer
Figure 14) highlights that more than 53% of the respondents show their willingness to upgrade their accommodation to LCB.

![Figure 14. Percentage of the willingness of the respondents to upgrade to LCB.](image)

However, when asked if they want to hire any consultant to upgrade to LCB most of them don’t want any consultant. Q22 (70%) were not ready to hire any consultant because a majority having a problem in paying the upfront cost for LCB (Q 23) 49% of respondents, 39 percent of them have a concern about the payback period and the rest of i.e. 25% they are not sure of the consultants, in other words, there seems to be a lack of trust on the consultants. Nevertheless, Q 24 highlights even though the respondents are willing to upgrade, neither they want to hire any consultants for that, nor do they want to take the loan. We can conclude from the situation that people are willing to upgrade their houses/accommodation to LCB, however, lack of trust on the consultants and financial issues seem to be a hindrance.

### 4.3.3 Perception of energy efficiency towards LCB

When it comes to the knowledge of energy efficiency, Q25 highlighted that most of the respondents (37%) consider solar PV as one of the energy efficiency among others such as solar hot water, nuclear power, power plant, wind energy, solar power plants, etc.

As mentioned in the section above we saw that the respondents are willing to invest to upgrade, however, from the Q 27, they are only ready to accept a bit of upgradation in their existing building envelope. The reason could be again the lack of knowledge about LCB (Q 28) and lack of trust in the consultant (Q17 and the financial constraints Q25) and, they think that LCB development is too expensive Q20.

Q28 further clarifies that respondents are not aware of the difference between LCB and zero-energy buildings. Nevertheless, they are ready to educate themselves about LCB and zero-energy building. Q18 also sheds light on their willingness to know more about renewable energies in the Zero energy buildings. Also, they think that the government should do something to increase the awareness of LCB (Q19).
4.4 Summary of the chapter

The aim of this study is to identify the level of awareness of using low carbon buildings and climate change in Finnish Society. In addition, this study also addressed how the acceptability rate of using low carbon buildings energy technology varies especially for participant’s own use in their buildings or near the environment. To do so, we used an online survey questionnaire methodology that considered various user segment groups, in the financial community and among sellers, builders, and local national, and international level policymakers dealing with low carbon building solutions. Questions for the questionnaire are divided into 4 different categories: individual perspective, social perspective, community, and market perspective.

The total number of respondents was 72. Approximately 46% as most respondents were the age of 45-64 followed by the age group of 25-44 by 32%. Most of the participants were employed (74%), whereas the second largest group of participants were students (10%), and few of the participants were others (11%). The survey results convince us that the people in Finland are willing to know more about LCB and Zero Energy buildings and would like to invest in these technologies in their buildings. The survey highlights that the users have a greater understanding and awareness about LCB, However, they do not understand what the difference between LCB and Net Zero Energy Building is. Nevertheless, further, they are willing to invest in it and are also highly equally considerate about aspects like building price, sustainability, and renewables in a building when they evaluate the building. However, they showed a mixed-set acceptance regarding their building up-gradation towards LCB. Knowledge, perception, fear, and political beliefs are correlated with social acceptance in this regard. For example, a large number of respondents think that the government should do something to increase awareness of using LCB.

When it comes to the knowledge of energy efficiency, the Q25 survey, highlighted that most of the respondents consider renewable energy technologies (RETs) such as solar PV as one the energy efficiency among others such as solar hot water, nuclear power, power plants, wind energy, solar power plants, etc.
5. Building performance and optimization towards nZEB

There have been growing interests in net-zero energy buildings in recent years. And has been applied in many different fields, from fossil fuel [87] and nuclear power to renewable energy [88]. Net energy analysis is a technique used to compare the amount of energy delivered to society by technology to the total energy required to produce it in a useful form.

The implementation of Nearly Zero Energy Buildings (nZEBs) as the building target from 2018 onwards represents one of the biggest challenges to increase energy savings and minimize greenhouse gas emissions. This chapter discusses different technologies for envelope systems and technical systems for the detached house to develop the nZEB framework. The purpose of the study is to give guidelines for office building facade design from the perspective of energy efficiency and daylighting to architects, engineers, real-estate developers, etc.

5.1 Objectives

In this research study, a detached house has been modeled using a dynamic simulation tool, and the energy efficiency measures, concerning different technologies for envelope systems and technical systems, were set up as parameters in the dynamic simulation tool and simulated and analyzed.

The objective of this paper is to define the heating, cooling, and electricity demand of a residential building in a cold climate region. The façade parameters were optimized for the best possible energy performance, to be used as design guidelines for facades in low and nearly zero-energy buildings for architects and engineers. The purpose of the study is to give guidelines for office building facade design from the perspective of energy efficiency and daylighting to architects, engineers, real-estate developers, etc.

5.2 Methodology

5.2.1 Simulation method

This research study has used IES-VE dynamic simulation software. Key façade factors that influence the energy performance of buildings in particular, such as window types, wall insulation, WW, and shading systems, were configured in the case of a theoretical model of office floor and alternatively for the best achievable energy performance-building geometry. Over the last 50 years, the
IES-VE simulation tool has evolved into a robust and reliable simulation environment [120]. IES-VE has a sophisticated energy performance assessment capability compared to similar energy simulation tools [120].

5.2.2 Simulation weather file and climate

This research study has used the Finnish test reference year (TRY2012) as weather data for energy simulations. Finland has a temperate coniferous-mixed forest zone with cold, wet winters and it comes under climate zone 1. According to the National Building Code of Finland (NBCF) for energy performance and heating power demand calculations of buildings [110]. Finland is divided into four separate climate zones (I–IV). The annual average temperature for the Helsinki / Vantaa region is + 5.4°C [109].

5.2.3 Case study

Energy simulations were conducted based on a generic open-plan office three-floor model that was divided into 5 zones – 4 orientated to south, west, east, and north respectively and in addition one in the middle of the building (Figure. 15).

Figure 15. The general model of a single floor of an office building 3D view.

The initial data of the simulation model is shown in Table 7. Lighting and shading control principles were adopted from [121]. The energy simulations were conducted with the well-validated simulation tool IES-VE [120] and the test reference year of Helsinki was used [122]. The primary energy factor for district heating is 0.9 and for electricity 2.0.

Table 7. Simulation data for the building and the HVAC for energy calculations

<table>
<thead>
<tr>
<th>Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupant density</td>
<td>5 (W/m²)</td>
</tr>
<tr>
<td>Equipment density</td>
<td>12 (W/m²)</td>
</tr>
<tr>
<td>Lighting density</td>
<td>5 (W/m²)</td>
</tr>
<tr>
<td>Heating and Cooling set point</td>
<td>21, 25 C</td>
</tr>
<tr>
<td>Air flow rate</td>
<td>1.5(l/(sec.m²))</td>
</tr>
<tr>
<td>Radiators efficiency</td>
<td>0.97</td>
</tr>
</tbody>
</table>
The description of all glazing variants studied is shown in Table 8. The window widths are chosen as small as possible with a step of 50 mm so that the average daylight factor would not be below 2%. ECM names are made up in order, that the first number stands for the number of panes, “C” for clear, highly transparent, and “D” for tinted solar protection windows. “e” or “-” describes whether there is external shading or not respectively. For example, “2/C/-” stands for a double-glazed, clear window without external shading. Initially, 200 mm external wall insulation thickness (U = 0.16) was used with 2 and 3-pane windows and 300 mm insulation thickness (U = 0.11) with 4 and 5 panes.

Table 8. NZEBs performance level (kWh/m2) according to building type.

<table>
<thead>
<tr>
<th>S.no</th>
<th>Glazing type</th>
<th>Gas filling</th>
<th>U-Value, W/(m2·K)</th>
<th>g-Value</th>
<th>Visible transmittance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Double pane +low E, clear glazing with no shading</td>
<td>Argon</td>
<td>1.1</td>
<td>0.61</td>
<td>0.78</td>
</tr>
<tr>
<td>2</td>
<td>Double pane +tinted solar protection windows, with no shading</td>
<td>Argon</td>
<td>1.0</td>
<td>0.27</td>
<td>0.51</td>
</tr>
<tr>
<td>3</td>
<td>Triple pane + clear glazing with no shading</td>
<td>Argon</td>
<td>0.54</td>
<td>0.49</td>
<td>0.7</td>
</tr>
<tr>
<td>4</td>
<td>Triple pane + low E, clear glazing with shading</td>
<td>Argon</td>
<td>0.54</td>
<td>0.49</td>
<td>0.7</td>
</tr>
<tr>
<td>5</td>
<td>Triple pane + low E, clear solar glazing with no shading</td>
<td>Argon</td>
<td>0.54</td>
<td>0.36</td>
<td>0.6</td>
</tr>
<tr>
<td>6</td>
<td>Triple pane + low E, tinted solar glazing with no shading</td>
<td>Argon</td>
<td>0.54</td>
<td>0.24</td>
<td>0.45</td>
</tr>
</tbody>
</table>

The double and triple-glazing properties were calculated using window manufacturers’ calculation tools. Generally, low emissivity coating (ε = 0.03) was used in all gaps between panes (except for glazing with air fillings, only used in Section 3.4). In the case of solar protection window cases, the outer pane was a
solar protection glass with low emissivity. The quintuple glazing representing not a standard product was calculated with a detailed window model of IES-VE which is based on the method of [95].

It is remarkable that the highly transparent quadruple and quintuple glazing cases have solar heat gain coefficients (g-value) as low as 0.36 and 0.24 respectively, so basically, they can also be considered as solar protection glazing. The U-value of frames for double glazed windows was 1.2 W/(m² K).

5.3 Results and discussion

Figure 16. Delivered energy for the glazing types (South, east, west and north façade)
As can be seen from Figures 16 and 17, the room heating dominated the energy use and it was affected by the size of the window and the glazing type. Results highlight that supply air heating and cooling had the next largest energy needs followed by lighting. Lighting electricity varied by orientation; however, it was the same almost for each glazing. The space cooling energy need fluctuated most of the time, however, the influence on the total energy use was low. In comparison to highly transparent glazing, clear solar protection windows showed slightly worse energy use on each façade.

From Figure 16, in the case of similar U values highly transparent solar protection glazing results in better energy efficiency as compared to tinted solar protection.

The most energy-efficient cases (lowest primary energy, Figure 16) were by orientation the following:
- South- 3 C, with 300 mm insulation thickness
- East- 3 C with 300 mm insulation thickness
- West- 3 C, with 300 mm insulation thickness
- North- 3 C with 300 mm insulation thickness

The second most energy-efficient case was:
- South- 3 SC with 300 mm insulation thickness
- East- 3 SC with 300 mm insulation thickness
- West- 3 SC with 300 mm insulation thickness
- North- 3 SC with 300 mm insulation thickness

5.4 Summary of the chapter

Most energy-efficient facade solutions, including window properties, external wall insulation, window-to-wall ratio (WWR), and external shading were determined with energy and daylight simulations in the cold climate of Finland.
These facade parameters were optimized for the lowest life-cycle cost and alternatively for the best achievable energy performance to be used as design guidelines for architects and engineers working with facades in low and nearly zero energy buildings.

Heating dominated in the energy balance of office buildings in the case of conventional windows and therefore improving the U values of windows by increasing the number of panes and low emissivity coatings also improved energy performance.

In the comparison of clear low emissivity glasses to tinted solar protection glasses and clear solar protection glasses with high visible transmittance, the best energy performance was achieved with clear low emissivity glasses and the second best with clear solar protection glasses that followed the minimum size of windows determined by the daylight requirement. Also, the cooling load was possible to keep at a reasonable level with minimum size clear low emissivity glazing. Therefore, all optimal cases found in this study were with clear glazing, where a low emissivity coating was in each gap between the panes.

The solutions provided can be used as a guideline for the designers, who are responsible for converting the targets to technical solutions.
6. Attitudes of stakeholders towards nZEB

The role of key stakeholders in the industry becomes highly responsible for achieving energy performance targets. Particularly, this chapter assesses the attitudes, approaches, and experiences of Finnish construction professionals regarding energy-efficient buildings and nZEBs.

Stakeholders have a significant impact on the progress of projects, particularly in the case involving complex projects with heterogeneous stakeholders so their experience is indeed important for project management and delivery. Management of stakeholders is crucial for the performance of projects, especially in the case of a complex project [123]. Stakeholders can be described as a person or group of persons influenced by or able to influence a project [32]. For project success, strong collaboration among stakeholders is important as a project can be viewed as a temporary organization for stakeholders pursuing a goal together [32].

6.1 Objectives

When it comes to deep retrofitting, the engagement of the stakeholders plays a very vital role. The role of the key stakeholders in the industry becomes highly responsible for an informed understanding and decision making. To this end, this study aims to analyze the barriers and gaps toward nearly zero energy buildings by understanding the attitudes and approaches of the stakeholders.

This study will enable construction industry stakeholders to make provisions for overcoming the barriers, gaps, and challenges identified in the practices of the retrofit projects. It will also inform the formulation of policies that drive retrofit uptake.

6.2 Methodology

A three-tier methodology was designed comprising a literature review, surveys (60 respondents), and a series of in-depth interviews (4 participants). survey questionnaire that considers various user segment categories, the financial sector, and sellers and policymakers at the local, national, and international levels working on low carbon building solutions. Questions for the questionnaire are divided into 4 different categories: individual perspective, SDGs (Sustainable Development Goals),
Development Goals) goal perspective, material’s embodied carbon perspective, and market energy-efficiency perspective, as illustrated in Figure 18 below.

Figure 18. Questionnaire design methodology.

A semi-structured online questionnaire was compiled on webropol and distributed between May and August 2019 via email and public forums. The survey was composed of qualitative/open-ended and quantitative questions based on multiple-choice, rank order, Likert, and rating scales designed to capture the characteristics of individual retrofit businesses. Sixty detailed responses were received, giving a response rate of 15%. A purposeful sampling technique was applied to select the respondents from within Finland [41]. The total number of respondents was 60. Approximately 35% of the respondents were in the age range of 36–46 followed by the age group of 47–57 with 32%. Approximately 35% as most respondents were age of 36-46 followed by age group of 47-57 by 32%. Most of the participants’ stakeholders (Figure 13) were HVAC engineers (16%), followed by the largest group of participants Construction design engineers (15%) and property owners (11%). The other largest groups were ESCOs 12%, Builders (11%), Architect (10%), Tenant, Facility Managers, and Contractors by 7% each.
6.2.1 Data analysis

The collected data were exported from the Online Survey system to a spreadsheet for detailed review following the completion of our online survey. Two types of variables (independent and dependent variables) were selected according to our survey questions as follows.

(1) Independent variables by a question: Q1–Q8
(2) Dependent variables by a question: Q5–Q10

The open questions were analysed through a simple qualitative content analysis, by identifying certain words and calculating their repetition for each question. Using the spreadsheet calculations, the data was analysed and the selection of the statistical characteristic of the data was identified using standard statistical operations. Various forms of statistical analysis, such as co-relations, variables, and text mining analysis were used to analyze the data.

6.2.2 Background data

As discussed in most of the respondents were of the age of 36-46 years. Mostly working in the existing buildings of Finland as shown in Figure 20. The difference is not so big, 47% and 53% are quite close.
Text mining analysis shows that most of the respondent’s stakeholders own
60% of office buildings followed by office buildings 55 %. Further Figure 21
below highlights the responses of Q 4. Additionally, we used word mapping by
hierarchical and clustering analysis to analyse the reason behind their living in
such houses/apartments.

Figure 20. Building types where the stakeholders work.

Figure 21. Percentage of accommodation in which the respondent lives.

6.3 Results

6.3.1 Stakeholders Attitudes toward Importance of Energy Efficiency
and Embodied CO2

The results show that the importance of the embodied carbon CO2 in the mater-
rials is less important than the energy efficiency from the stakeholder's point of
view. Figure 22 highlights that “energy efficiency” is very important for ESCOs,
Attitudes of stakeholders towards nZEB contractors, and facility managers followed by architects, HVAC engineers, and construction design engineers.

![Figure 22. Stakeholder's consideration for the 'Energy Efficiency' factor towards nearly zero energy buildings.](image)

![Figure 23. Stakeholders point of view: Importance of Embodied carbon CO2 in the materials.](image)
Figure 24. Breakup of the stakeholders view on the importance of “Embodied energy CO2 in materials.”

When it comes to the responses of the importance of the “embodied energy CO2” toward nearly zero energy buildings (refer to Figure 23), the survey results highlighted that for architects, the importance of embodied energy CO2 ranked the highest. Figure 24 further shows that 83.3% of architects ranked 1 (very important) and 16.7% of them ranked 2 (which is important). As the architects are the designers of the buildings, embodied CO2 makes sense for them. However, it seems that for other stakeholders e.g., facility managers, tenants, property managers, and ESCOs, the importance of the embodied carbon is rather unimportant. It can be concluded from this result that these stakeholders might not be properly aware of the significance of embodied carbon in materials.

Several studies highlight that embodied carbon makes up between 27 and 58% of lifecycle carbon emissions[124]. In terms of building components, Hughes and Winter [125] have shown that the selection of the structural frame system has a more significant influence on the embodied carbon and cost than other building components such as (structural frame, and inner components (i.e., insulation and sheathing). Hence, the stakeholders need to understand the importance of expressing and understanding the diversity of the materials.
6.3.2 Usage of the UN Sustainable Goals in Your Work

Figure 25 shows the breakup of the individual stakeholder’s usage of the UN sustainable goals. It highlights that the architects, HVAC engineers, and property owners are the ones who consider the most usage of UN sustainable goals. This justifies the results from Q7 (where architects indicate the importance of embodied carbon in the material), as the building materials can contribute significantly to the achievement of UN goals [126].

![Figure 25. Breakup of the stakeholder’s usage of the UN sustainable goals.](image)

The results presented in this research [127] proved that building materials can contribute significantly to the achievement of the 13 goals and 25 targets of the SDGs. The framework showed that a direct positive contribution of building materials on the SDGs has been noticed in SDG 3, SDG 7, SDG 9, SDG 11, SDG 12, SDG 13, and SDG 15. However, the survey taken in this research study shows that the respondents do not have much knowledge about the UN goals, and 75.4% of the respondents (refer Figure 26) do not use UN goals in their work.

![Average % of stakeholders using UN SDG goals](image)
6.3.3 Importance of Carbon Neutrality Reaching the nZEB

Q10 assesses the stakeholder’s attitudes and approaches toward carbon neutrality in the building sector. This question was subdivided into ranking the opinion toward the most important actions in reaching carbon neutrality targeting the building sector. The important actions were listed as follows: (1) embodied carbon in materials, (2) running time carbon emissions, (3) both embodied and running time carbon emissions, (4) the use of renewable energies, and (5) the use of smart technologies for reducing running time carbon emissions.

Overall, the tenants, HVAC engineers, architects, and the ESCOs among the overall stakeholders seem aware of the nZEBs. In terms of the use of renewable energy (Q10) in nZEBs, tenants, HVAC engineers, architects, and ESCOs have listed it as the most important.

The reason behind the awareness could be the direct involvement in the construction of the buildings. However, property owners, facilities managers, construction design engineers, builders, and contractors ranked the usage of renewable energies as rather unimportant. Nevertheless, when it comes to the knowledge of energy efficiency, the survey [126] highlighted that most of the respondents consider renewable energy technologies (RETs) such as solar PV as one the energy-efficiency options among others such as solar hot water, nuclear power, power plant, wind energy, solar power plants, etc.

Renewable energy policies are necessary for achieving carbon neutrality, which is the main goal for climate change mitigation. The cities in the Helsinki metropolitan area have pledged themselves, through different initiatives on climate change and several measures for renewable energy utilization, to substantially reduce emissions of carbon [128]. However, the findings of [128] show that current renewable energy policies in the Helsinki metropolitan area are weak and many challenges exist. Nevertheless, numerous options to strengthen current practices are available.

The research study concludes that in the case of net zero energy buildings, the main impact occurs due to the building materials and technologies installed on the site [129].

The overall collective picture represents the attitudes and approaches of the industry stakeholders that define the shape and growth of the industry for future nZEBs.

6.4 Summary of the chapter

In Finland, an energy transition to a carbon-neutral society appears as a unifying sociotechnical imaginary shared by politicians at different levels. While the imaginary is precise, with carbon neutrality as a long-term societal goal to be
achieved in 2050, it is also interpretatively flexible, as carbon neutrality accom-
mmodates multiple views on the role of acceptable technologies, energy sources, and offsets [129].

Research highlights that “Energy Efficiency” is very important for ESCOs, Contractors, and facility managers followed by Architects, HVAC engineers, and Construction design engineers. However, when it comes to” Embodied carbon in materials”, ESCOs followed by tenants and facility managers rank it as unim-
portant. When it comes to the use ‘of renewable energy’, most of the stakeholders ranked it very important. ESCOs, tenants, HVAC, and Architects are among the highest respondents who ranked it very important. Nevertheless, there are some construction professionals like property owners, facilities managers, con-
struction design engineers, and builders who ranked it rather unimportant. The primary objective of the facilities manager is to oversee the maintenance and upgrading of the built-in environment of a specific workplace. A facilities man-
ager needs to integrate the employees of the firm with the dynamics of the in-
frasctructure on a single integrated platform. However, the current changes, par-
ticularly in the sustainability arena sparked by climate change, have also changed the roles and duties of facilities managers [49]. As described by S. Goyal et al [50] the future of facility managers will enhance with cost-effectiveness and environmental issues being the main concern in every field of eco-

Results highlight that the “Running time carbon emissions” are very im-
portant for: the property owner (78%), tenant (75%), facilities manager (75%), construction design engineer (67%), and HVAC engineer (90%). Nevertheless, it is splendid to see that 100% of the contractor and ESCO companies ranked 1 for the importance of “Running time carbon emissions” in reaching carbon neu-
trality in the building sector. Perhaps it is very fascinating to see from the survey that, “running time carbon emissions” has been ranked 1 (very important) and 2 (important) by all stakeholders. None of them ranked 3, 4, or 5, moreover, it confirms that stakeholders take seriously running time carbon emissions to-
wards nearly zero energy buildings.

Overall, the tenants, HVAC engineers, architects, and the ESCOs among the overall stakeholders seem aware towards the nZEBs. They also ranked renewa-
ble energy as very important towards achieving nZEB. Among the various stake-
holders, it can be summarised that the stakeholders are aware of renewable en-
ergy and its importance towards achieving nZEB. Deng et al. [130] introduced several promising and renewable energy-efficient measures for NZEB, such as solar heating systems, solar cooling systems, renewable source heat pumps, and power generation systems.[131] defined the priorities for a ZEB: the first factor was the question of energy efficiency and then, the application of renewable energy sources.

Renewable energy policies are necessary for achieving carbon neutrality which is the main goal for climate change mitigation. The cities in Helsinki have vowed to drastically reduce carbon emissions through numerous climate initiatives, in-
cluding some renewable energy use initiatives [128].
Detailed guidebooks, practical examples, and comprehensive training are essential for consumers as well as professionals to take up nZEB.

Future research tasks can involve the attitudes of the stakeholders focusing on country-specific case studies, and identifying the key barriers, gaps, and challenges. Together, this shall provide a holistic view of results in this direction. The overall worldwide collective picture can represent the attitudes and approaches of the industry stakeholders that define the shape and growth of the industry for future nZEBs.
7. Conclusion and outcome

The research methodology encompassed several key components. Initially, it involved evaluating the social acceptance of low carbon buildings, focusing on public opinions and knowledge. Additionally, it included an assessment of the attitudes, approaches, and experiences of Finnish construction professionals, particularly in the context of energy-efficient buildings, specifically nZEBs. Following this assessment, a detailed building simulation and optimization process were undertaken. The primary objective of this process was to develop low-energy building solutions while simultaneously ensuring optimal thermal comfort levels.

The four publications collectively provide valuable insights into different aspects of energy efficiency and low carbon building adoption in the cold climate of Finland. The findings underscore the importance of optimizing energy efficiency in building design, increasing public awareness and support for low carbon technologies, and providing incentives to overcome financial barriers. Implementing these insights can contribute to reducing greenhouse gas emissions and fostering sustainable building practices in the region.

7.1 Research outcome

Figure 2 in the section 1.6 illustrates the link of the following publications with the research questions (section 1.5).

**Publication I:** This study presented the acceptable range of indoor air and operative temperatures, complying with the thermal comfort categories recommended by the EN 15251 standard, for a detached house (nine different houses, including three different types of houses and structures) in the cold climate of Finland. This study minimized the total delivered energy and cost of electrically heated detached houses by means of three different demand response control algorithms, without sacrificing the occupants’ thermal comfort.

**Publication II:** This research study identified the level of awareness of using Low Carbon Buildings and climate change in the Finnish Society. In addition, this study also addressed how the acceptability rate of using low carbon building energy technology varies especially for participant’s own use in their buildings or near the environment. In this study, we focused on public awareness and knowledge about the cost of low carbon building energy applications, willingness to pay for green energy, and low carbon building acceptability.
This research study concluded that 59.72% of the seventy respondent’s opinion were using low carbon buildings (LCB) can help to reduce greenhouse gas emissions. In general, more than 53% of the respondents were willing to upgrade their accommodation to LCB. However, 70% of respondents were not ready to hire any consultant because the majority of them had a problem paying the upfront cost for LCB. Most of the respondents think that the public sector should do something to increase awareness of using LCB. Likewise, respondent’s point of view, the public sector should take the initiative for implementing LCB by providing incentives to encourage people to upgrade LCB in their buildings.

**Publication III:** This research study emphasized the importance of optimization of energy efficiency in the concept design phase.

**Publication IV:** This research study assesses the attitudes, approaches, and experiences of Finnish construction professionals regarding energy-efficient buildings, nZEBs. A two-tier investigation was conducted including surveys and expert interviews with several stakeholders.

This research highlighted that the importance of the Embodied Carbon CO2 in the materials is less important than the Energy Efficiency from many of the stakeholder’s points of view. “Energy Efficiency” is very important for ESCOs, Contractors, and facility managers followed by Architects, HVAC engineers, and Construction design engineers. Nevertheless, Architects ranked the most important “Embodied energy CO2” towards nZEB. When it comes to the importance of “running time emissions” towards nZEB, contractors and ESCO companies ranked 1 as its importance followed by the property owner (78%), and tenant (75%). Perhaps it is very fascinating to see from the survey that, “running time carbon emissions” has been ranked 1 (very important) by all stakeholders.

This research concluded that the respondents are willing to invest to upgrade their existing buildings, however, they are only ready to accept a bit of upgradation in their existing building envelope. The reasons for their unwillingness from our survey results are (1) the lack of knowledge about LCB lack of trust in the consultant and the financial constraints, and (2) they think that LCB development is too expensive.

Nevertheless, the people in Finland are willing to learn more about LCB and Zero Energy buildings and would like to invest in these technologies for their buildings. However, they feel financial constraints and have a lack of trust in the consultants for their building upgrade towards LCB. The solution could be that govt shall take some major steps to educate their people about LCB, and strengthen the regulations In conclusion, the findings suggest that a multifaceted approach is pivotal for promoting Low Carbon Buildings (LCB) in Finland. This entails the implementation of substantial government-led educational campaigns aimed at raising awareness and understanding among the populace regarding the significance and advantages of LCB. Additionally, the government could consider the facilitation of financial support mechanisms, such as cost-effective loans or targeted subsidies, contingent upon the attainment of LCB standards, as viable incentives to expedite the adoption of sustainable building
practices. Additionally, they can promote some Energy Performance contracting (EPC) business models to help them promote the upgradation of the buildings towards LCB [132]. Energy Performance Contracting (EPC) is a market mechanism provided by Energy Service Companies (ESCOs) and has been widely used as one of the most common contracting models for guaranteeing energy efficiency expectations and improving energy efficiency, and also considered one of the solutions to upgrade the building when there is a financial constraint from the client’s side. EPC business models [133] have emerged as one of the solutions to provide retrofitting solutions to existing buildings. Also, EPC has been promoted by the Energy Performance of Building Directive (EPBD) (2012/27/EU), and Energy Efficiency Directives (EED) to upgrade existing buildings to achieve EU energy targets by 2030.

Last but not least, the findings of this research dissertation will support policymakers, technology providers, stakeholders in the energy and building sector, and building engineers to enable the development and adoption of RETs for residential buildings, including nZEBs, in urban centers of Finland. This study will enable construction industry stakeholders to make provisions for overcoming the barriers, gaps, and challenges identified in the practices of the retrofit projects. It will also inform the formulation of policies that drive retrofit uptake.

7.2 Recommendations for further research

This dissertation is a step forward to developing the framework towards n ZEBs by taking various parameters like thermal comfort, assessing the awareness and acceptability of using Low Carbon Buildings and climate change in Finnish Society, assessing the attitudes, approaches, and experiences of Finnish construction professionals regarding energy-efficient buildings, nZEBs.

The presented results are somewhat limited to the considered case studies. So, additional sustainability indicators (e.g.: carbon-driven design), building types, geographical locations, and geometrical features are worth considering as future steps to develop a comprehensive approach.
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