Universitetet
i Stavanger

Department of Media and Social Sciences

Master in Energy, Environment and Society

Master Thesis

Nearly Zero Energy Buildings -
a viable contributor towards mitigating climate change?

Author: Stian Torstveit

Candidate number: 4025

17/06/2019

MASTER DEGREE IN
Energy, Environment and Society

MASTER THESIS

CANDIDATE NUMBER: 4025

SEMESTER: Spring 2019

AUTHOR: Stian Torstveit

SUPERVISOR: Professor Oluf Langhelle

MASTER THESIS TITLE: Nearly Zero Energy Buildings - a viable contributor towards mitigating climate change?

SUBJECT WORDS/KEY WORDS: Nearly zero energy buildings, climate change, Jampankaari, Kuopio

PAGENUMBERS: 59

Stavanger, 17/06/2019

……………………………………………….
DATE/YEAR

Summary

This master thesis investigates the potential for the nearly zero energy building concept to make any contribution towards mitigating climate change, as a result of the European Unions´ "Energy performance of buildings directive" from 2010, requiring that all new buildings must be nearly zero energy buildings as of 31 December 2020, as a means to decrease energy consumption and increase renewable energy production.

Based on the research question proposed together with supportive sub-questions, a deductive and qualitative methodological approach was applied to the case studies of two nearly zero energy building projects in Jampankaari and Kuopio, Finland, in order to either validate or dismiss assumptions regarding the nearly zero energy building concept on the matter of mitigating climate change – that the nearly zero energy building concept will be an important contributor towards mitigating climate change.

Findings throughout the research of this master thesis, showcased evidence that nearly zero energy buildings as a concept stand in stark contrast to the fossil-fuel based electricity production and subsequent anthropogenic climate change witnessed today.

The core of the concept is that the nearly zero energy required should be covered to a very significant degree by energy from renewable energy resources, including renewable energy produced on-site or nearby. Taking into consideration that the cost for energy efficient buildings has decreased in recent years due to the reduction in cost of solar panel production, together with the possibility to sell excess electricity produced back to the utility grid, nearly zero energy buildings will in the long run also become cost-efficient.

Through the research, findings and discussions of this master thesis, it becomes evident that nearly zero energy buildings as a concept is a highly potent contributor towards mitigation climate change. The conclusion though, is that it will not be a major contributor at this point of time.

Table of Contents

1. Background

With the industrial revolution the economy, society and environment would see drastic and rapid changes. “By 1800 complex social organizations, including larger and more elaborate bureaucratic state structures and systems of economic exchange, technology, and communication had emerged…” (Burke et al. 2009, p.41). The steam engine utilising coal would enhance energy production greatly, economies flourished as never before, but the unknown factor in all of this was the pollutants created by coal production and the significant effect this would have on the environment in the years to come. As Burke puts it, the steam engine and other machinery would enhance human’s ability to produce goods in such vast quantities it would be “…altering the balance between man and nature” (Burke III, E. and Pomeranz, K., 2009, p.43).

The discovery of fossil fuels prompted a development-trajectory leading to the modern-day society we are a part of today. With significant technological development over the years, including the development of the combustion engine, petroleum firmly stated its place as a source of energy. The resources were vast, businesses such as extraction, processing and transportation of fossil fuels were booming and so was the economy - the twentieth century world ran for the most part on coal and oil. But, as we all know, sadly, this extreme development came at a cost. Fossil fuel extraction and combustion generates pollution and the effects of global warming might be threatening our way of life. Is continuing on a “fossil fuel”-path sustainable for mankind? Do we have the resources to continue this path? Fossil fuels are finite, they will eventually deplete. Energy efficiency is improving greatly and may prolong the pace of fossil fuel depletion, but do we really want to stay on this path? We need to make a shift towards more utilisation of infinite energy resources, such as solar, wind and hydropower. Renewable energy is cleaner and healthier for the environment and society. A more sustainable use of natural resources will not endanger the possibility of future generations to cover their needs.

With this in mind, the topic of the thesis is hereby introduced - the nearly zero energy building concept - and through this thesis the discussion will revolve around what possibilities and / or limitations are present on that matter with regards to mitigating climate change.

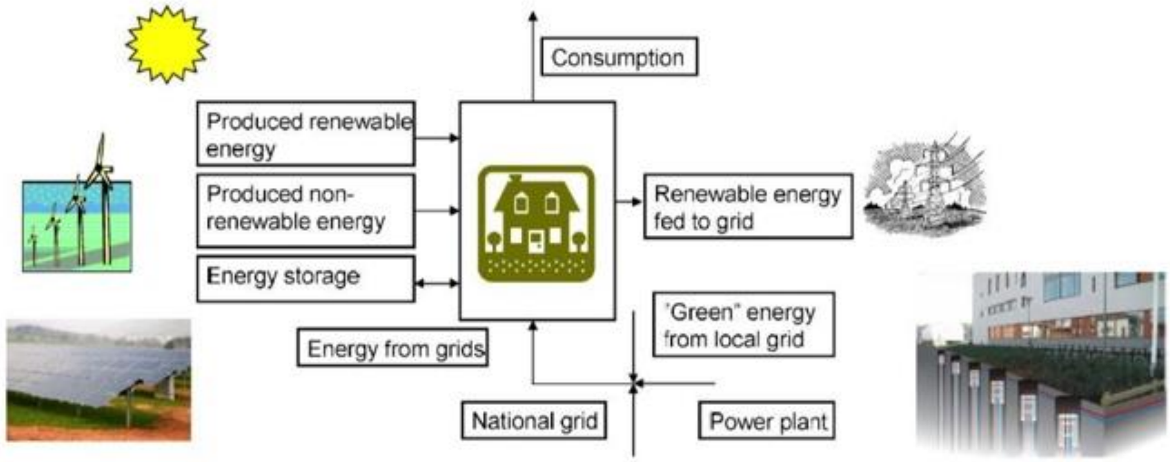


Fig.1: Net zero energy principle. (Nieminen, 2011, p.4)

The rationale for choosing to write about the nearly zero energy building concept stem from an inherent interest in smart technology and finding the energy synergies applied in nearly zero energy building projects very intriguing. See figure 2 below for an example of an energy management system in a typical nearly zero energy building Combined with the EU directive from 2010, the nearly zero energy building concept as a topic is very much on the agenda and will be even more in the near future, and as such, make for a great subject for this thesis.

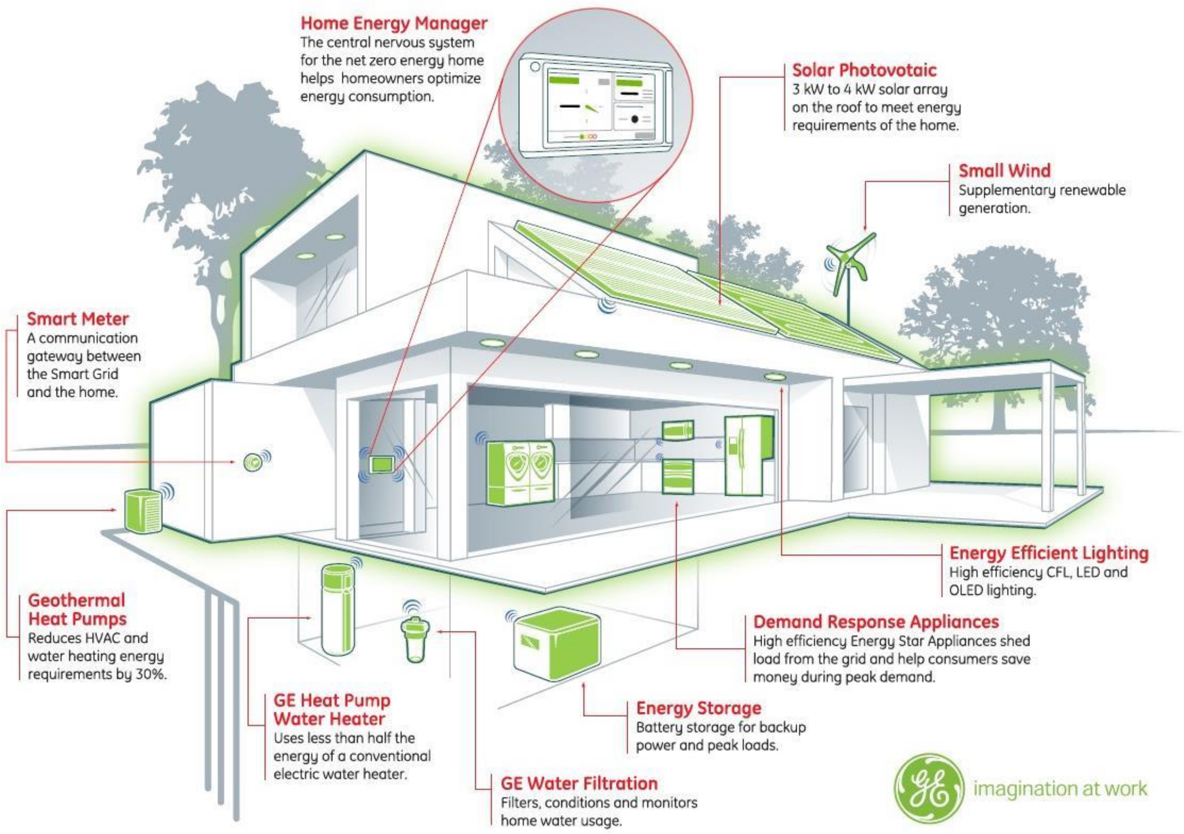


Fig.2: Application of an energy management system in a typical nearly zero energy building. (Xiaodong C., Xilei D. and Junjie L., 2016, p.42)

The European Union "Energy Performance of Buildings Directive" from 2010 requires that from 31 December 2018 all the new buildings occupied and owned by public authorities are nearly zero energy buildings, and from the end of 2020 all new buildings are nearly zero energy buildings. (The European Parliament, 2010).

What are nearly zero energy buildings? One can kind of understand what it is from the name itself, but let us give it some sort of definition. Nearly zero energy buildings are buildings with very high energy performance and where the energy needs of said building is covered to a very high degree by energy from renewable energy sources. What does it actually mean for a building to have a high energy performance? How does one determine whether a building actually is a nearly zero energy building? The below transcript from the "Energy Performance of Buildings Directive" gives an outline of what is meant by energy performance;

"1. The energy performance of a building shall be determined on the basis of the calculated or actual annual energy that is consumed in order to meet the different needs associated with its typical use and shall reflect the heating energy needs and cooling energy needs (energy needed to avoid overheating) to maintain the envisaged temperature conditions of the building, and domestic hot water needs.

2. The energy performance of a building shall be expressed in a transparent manner and shall include an energy performance indicator and a numeric indicator of primary energy use, based on primary energy factors per energy carrier, which may be based on national or regional annual weighted averages or a specific value for on- site production." (The European Parliament, 2010, p. L 153 / 29).

According to the EU in the "Energy Performance of Buildings" the definition of a nearly zero energy building is "a nearly zero-energy building means a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby", meaning that a nearly zero energy building is an energy efficient building with low energy demand, where said energy demand for the most part is produced from renewable energy resources on site.

This is all good and technical, but let us simplify what we actually mean by nearly zero energy building. In a nearly zero energy building, solar energy as a renewable energy resource is harnessed through various technologies and the electricity generated is applied to buildings. Do this mean one can put solar panels on the roof of a giant shopping mall and suddenly this shopping mall is "green", environmentally aware and a nearly zero energy building? This is not the idea at all. A near zero energy building is a building that due to the way it has been constructed, needs a lot less energy to be run than the typical shopping mall (or office building or private households for that matter). As such, the renewable energy needed to cover the nearly zero energy buildings energy need, is far less than what would be needed in the shopping mall example above. And this again is the reason such buildings can be run on renewable energy resources only, because the need for energy has been drastically reduced in the way it has been constructed compared to the typical commercial building.

What is the main point to take from the discussions above? Clearly, what is needed is a shift towards renewable energy sources, such as wind power, solar power and hydropower. But it’s easier said than done. Even though the environment and renewables are on the agenda, the revenue stream from the oil and gas business are still enormous. How do you convince the largest oil producers to change their focus to renewables? Can politics and policies save us all? Carbon tax have been introduced to lessen the emissions of carbon dioxide. There’s the possibility of Carbon Capture and Storage, which could mitigate as much as 90% of the carbon dioxide produced from the use of fossil fuels in electricity generation and industrial processes. The drawback of Carbon Capture Storage is that it is an expensive technology that companies are not willing to take upon themselves. We need Governments to step up in aid for the environment with stricter policies regarding mitigation of pollutants such as carbon dioxide. And even more support the shift to more renewable energy resources. This is easier said than done. Politics is periodical. After a certain period, a new group of politicians with a different agenda might come to power. So, it is difficult to advocate renewables, where the results might not come into effect for many years, when other pressing and present topics are on the horizon, not to mention the focus on staying in government. And, possibly the biggest stumbling block, our advanced societies and economies of today has arisen mostly due to the fossil fuel industry, so for a government to severely alter this industry might be too difficult to do.

Andrew Dobson’s comment is very intriguing, “is there a trade-off between sustainability and prosperity? Will high-energy societies always be unsustainable societies?” (Dobson, 2016, p.11). I hope not and truly believe not. The potential of utilising energy from renewable resources are huge, technologies are advancing rapidly, and the awareness of the environmental challenges, though sometimes difficult, are on the political agenda.

1.1 Energy consumption

"The rapidly growing world energy use has already raised concerns over supply difficulties, exhaustion of energy resources and heavy environmental impacts (ozone layer depletion, global warming, climate change, etc.). The International Energy Agency has gathered frightening data on energy consumption trends. During the last two decades (1984 – 2004) primary energy has grown 49 % and CO2 emissions by 43 %, with an average annual increase of 2 % and 1.8 % respectively" (Pérez-Lombard, L., Ortiz, J. and Pout, C. 2008, p.394). These findings are from Pérez-Lombard et al.´s review of building energy consumption, and through their analysis they make it clear this is due to, as discussed earlier in this section, the rapid growth of economies and the improved living conditions this brings, and go on by concluding that "current energy and socio-economic systems are definitively unsustainable." (Pérez-Lombard et al., 2008, p.395).

These numbers and discussions by Pérez-Lombard et al. are scary and the worst part is they have not diminished the last 10 – 15 years. But times are changing as we speak, there´s a reason we are attending this master thesis program. We know what possibilities are available to combat the current trend of unhealthy exploitation of resources and the negative effects it has for the climate.

According to the World Energy Outlook 2018 (The International Energy Agency´s flagship publication), "Major transformations are underway for the global energy sector, from growing electrification to the expansion of renewables, upheavals in oil production and globalization of natural gas markets. Across all regions and fuels, policy choices made by governments will determine the shape of the energy system of the future…

The WEO´s scenario-based analysis outlines different possible futures for the energy system across all fuels and technologies. It offers a contrast with different pathways, based on current and planned policies, and those that can meet long-term climate goals under the Paris Agreement, reduce air pollution, and ensure universal energy access…

In power markets, renewables have become the technology of choice, making up almost two-thirds of global capacity additions to 2040, thanks to falling costs and supportive government policies. This is transforming the global power mix, with the share of renewables in generation rising to over 40% by 2040, from 25% today, even though coal remains the largest source and gas remains the second-largest."

This shows the determination and efforts needed to mitigate climate change, and hopefully down the road, if said actions is implemented the world will be a better place for future generations. Governments are becoming more and more aware of the responsibilities and role they have to play in mitigating climate change, and the continued falling cost for renewables combined with supportive policies, should lay grounds for a foundation for both a private and public effort on the matter.

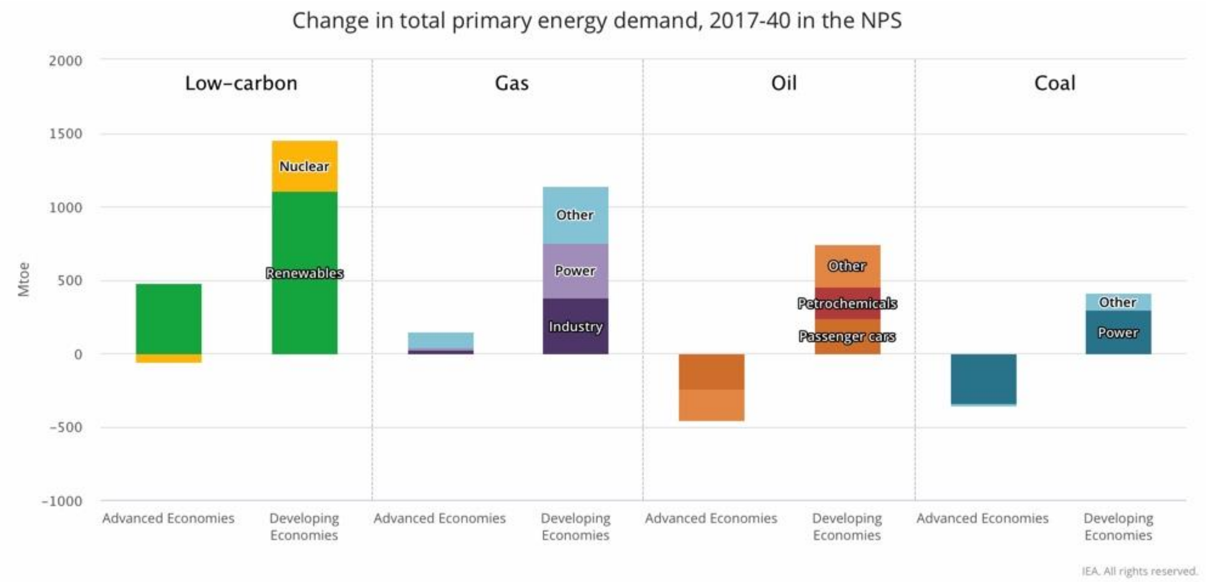


Fig.3: Change in total primary energy demand 2017-2040 (World Energy Outlook, 2018)

With the above discussion and evidence of the role renewables will have today, and even more in the future (see fig.3), the purpose of this thesis will be looking into what role the nearly zero energy building concept might have to play on the matter of mitigating climate change.

2. Introduction

As the average temperatures continue to increase, bringing with it more extreme weather events, all due to anthropogenic climate change, there is a strong need for urgent action taken in utilizing cleaner energy. One particular area is buildings, wherein it is of the utmost importance to be able to maintain a comfortable living environment for occupants, while at the same time minimizing the energy use in buildings.

The goal of this master thesis is to gain advanced knowledge of the nearly zero energy building concept, and during this process, have a discussion whether the nearly zero energy building concept, in the big picture, can have an impact on global climate change or if it is just too little too late.

In order to do so, proposing the most applicable research question are of the utmost importance as a groundwork for developing a master thesis of meaning. Proposing a too vague or not specified enough research question, might open the possibility of a wide array of directions for the author to go, threatening to render the research irrelevant. A clear, precise and applicable research question have to be set forth, in order to be able to research and discuss the nearly zero energy building concept in a concise and focused manner. These claims are further backed by the following quote from Blaikie on the importance of research questions;

"Research questions are needed to define the nature and scope of the research. By selecting questions, and paying attention to their wording, it is possible to determine what is to be studied, and, to some extent, how it will be studied. The way a particular research question is worded can have a significant influence on how much and what kind of research activity will be required." (Blaikie, 2010, p. 58)

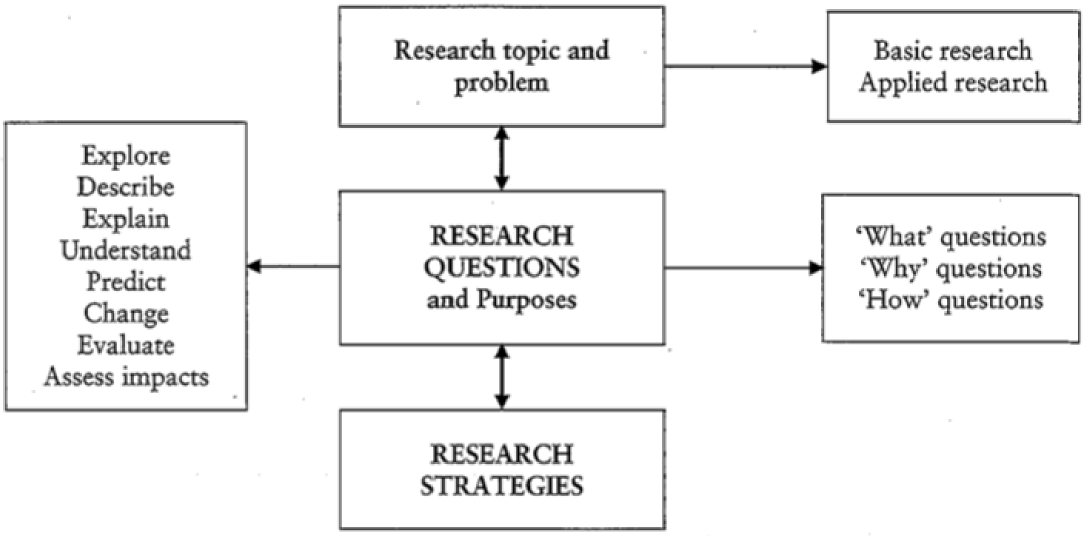


Fig.4: Research questions and purposes. (Blaikie, 2010, p. 58)

To achieve a thorough understanding of the subject in hand, to enable me to dissect the Nearly Zero Energy Building concept as outlined above, this Master Thesis will at its core deal with the following research question;

- **Is there a potential for the Nearly Zero Energy Building concept to make any serious contribution towards mitigating climate change?**

In the case study part of this master thesis, the following two sub-questions will be discussed in relation to the main research question of this master thesis, acting as support to any proposed recommendations or conclusions derived from the case study findings;

1. "Will the nearly zero energy building concept always be cost effective?"
2. "Is it viable to apply the nearly zero energy building concept to existing buildings?"

The state of the earth of today has come about mainly due to anthropogenic climate change. The over-exploration and utilization of fossil fuels has finally caught up and are threatening our way of life, and more ominous, the future of our kids. So, on that matter, is it interesting to be discussing buildings? Why spend time on buildings? The most important thing to help aid the environment must be to stop the fossil fuel exploitation, isn't it?

Obviously, the big bad wolf regarding climate change is in fact the fossil fuel exploitation. But, many of us are fortunate enough to have a living arrangement. Sadly, not all, but that is a discussion for another time. If one takes a minute to reflect what is going on in a house or apartment, or a commercial building for that matter, over the course of a day, one might realize that a lot of energy is used for a wide range of activities. And again, reflecting on the humongous amount of living arrangements spread around the earth, the math may start to add up a bit, maybe it would be interesting to have a discussion around buildings on the matter of climate change after all.

In their study on zero energy buildings, the discussions by Torcellini, Pless and Deru seems to give leeway to look at buildings as a part of climate change. Not as a part of the problem, but as a part of the solution. “Buildings have a significant impact on energy use and the environment. Commercial and residential buildings use almost 40% of the primary energy and approximately 70% of the electricity in the United States (EIA 2005). The energy used by the building sector continues to increase, primarily because new buildings are constructed faster than old ones are retired. Electricity consumption in the commercial building sector doubled between 1980 and 2000, and is expected to increase another 50% by 2025 (EIA 2005). Energy consumption in the commercial building sector will continue to increase until buildings can be designed to produce enough energy to offset the growing energy demand of these buildings.” (Torcellini et al. 2006, p.1).

These are big numbers and support the reason why it would be interesting to look at buildings on the matter of climate change. And as can be seen at the end of the above quote, the claim is that the nearly zero energy building concept will be an important part of reducing the energy usage in buildings. Torcellini et al.´s claims and findings is further supported by the European Commission´s report on the energy performance of buildings from a couple of years later;

“Buildings account for 40 % of total energy consumption in the Union. The sector is expanding, which is bound to increase its energy consumption. Therefore, reduction of energy consumption and the use of energy from renewable sources in the buildings sector constitute important measures needed to reduce the Union’s energy dependency and greenhouse gas emissions. Together with an increased use of energy from renewable sources, measures taken to reduce energy consumption in the Union would allow the Union to comply with the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), and to honour both its long term commitment to maintain the global temperature rise below 2°C, and its commitment to reduce, by 2020, overall greenhouse gas emissions by at least 20 % below 1990 levels, and by 30 % in the event of an international agreement being reached. Reduced energy consumption and an increased use of energy from renewable sources also have an important part to play in promoting security of energy supply, technological developments and in creating opportunities for employment and regional development, in particular in rural areas. (The European Parliament, 2010, p. L 153 / 13).

As such, with the above statements in mind, a discussion around the nearly zero energy building concept with regards to climate change, would be very applicable for this Master program, and an interesting subject for this master thesis. To do so, I will do a case study of two nearly zero energy projects. The first is a zero-energy house in Jampankaari, which was the first zero-energy house development project in Finland. The second is the Kuopas apartment building, a nearly zero energy building in Kuopio. The Kuopio apartment building was a part of the Jampankaari project.

The purpose of this master thesis is to explore the nearly zero energy building concept through a case study on the buildings in Jampankaari and Kuopio, and discuss the findings in relation to the research question proposed in this master thesis.

3. Framework

The European Commission did a study on nearly zero energy buildings in 2012, in which they define a nearly zero energy building as “a building that has a very high energy performance… The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby”. (European Commission, 2012). This definition will follow the discussion around the nearly zero energy buildings concept throughout this master thesis. This seems to be a clear and concise definition of the nearly zero energy buildings concept, but I will also look into another study for comparison to be able to get a real understanding of how the nearly zero energy building concept is defined.

In their study on the definition of zero energy buildings, Torcellini et al. discussed how the “zero” in the zero-energy building concept may vary from case to case, such as what the objective of the building in question is, or if any environmental regulations are present in the local area.

They continue to review four of the most common definitions found in applicable literature, and discuss what the advantages, disadvantages and applications of said definitions are. According to Torcellini et al., a good nearly zero energy buildings definition has to prioritize energy efficiency over renewable energy capacity, in which a reduced load will require less installed capacity of renewable energy. This will in turn lead to significant cost savings, making grounds for the nearly zero energy building concept.

Futhermore, Torcellini et al. use the nearly zero energy buildings´ connection to the utility grid as means to account for total net usage. Four definitions of the nearly zero energy buildings concept is discussed, that being net-zero site, net-zero source, net-zero costs, and net-zero emissions;

“**Net Zero Site Energy**: A site ZEB produces at least as much energy as it uses in a year, when accounted for at the site.

Net Zero Source Energy: A source ZEB produces at least as much energy as it uses in a year, when accounted for at the source. Source energy refers to the primary energy used to generate and deliver the energy to the site. To calculate a building’s total source energy, imported and exported energy is multiplied by the appropriate site-to-source conversion multipliers.

Net Zero Energy Costs: In a cost ZEB, the amount of money the utility pays the building owner for the energy the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year.

Net Zero Energy Emissions: A net-zero emissions building produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources." (Torcellini et al., 2006, p. 5).

Torcellini et al. argues that the design of a building influence the definition of the nearly zero energy building concept, and opposite, the definition of the nearly zero energy building concept influence the design. Depending on how one chooses to define the nearly zero energy building concept, focus areas can be the likes of energy efficiency, what supply strategies for energy is available, or other factors that might influence the design and operation of a building with regards to practicality. Furthermore, to build on this, in due time, when battery storage of excess electricity becomes a reality, the discussed definitions in this part of the master thesis might see drastic changes with regards to energy usage accounting. But for now, we leave battery storage for the future.

The below table displays an overview of advantages and disadvantages of the four definitions discussed in this section of the master thesis;

Defini-tion	Pluses	Minuses	Other Issues
Site ZEB	• Easy to implement. • Verifiable through on-site measurements. • Conservative approach to achieving ZEB. • No externalities affect performance, can track success over time. • Easy for the building community to understand and communicate. • Encourages energy-efficient building designs.	• Requires more PV export to offset natural gas. • Does not consider all utility costs (can have a low load factor). • Not able to equate fuel types. • Does not account for nonenergy differences between fuel types (supply availability, pollution).	
Source ZEB	• Able to equate energy value of fuel types used at the site. • Better model for impact on national energy system. • Easier ZEB to reach.	• Does not account for nonenergy differences between fuel types (supply availability, pollution). • Source calculations too broad (do not account for regional or daily variations in electricity generation heat rates). • Source energy use accounting and fuel switching can have a larger impact than efficiency technologies. • Does not consider all energy costs (can have a low load factor).	• Need to develop site-to-source conversion factors, which require significant amounts of information to define.
Cost ZEB	• Easy to implement and measure. • Market forces result in a good balance between fuel types. • Allows for demand-responsive control. • Verifiable from utility bills.	• May not reflect impact to national grid for demand, as extra PV generation can be more valuable for reducing demand with on-site storage than exporting to the grid. • Requires net-metering agreements such that exported electricity can offset energy and nonenergy charges. • Highly volatile energy rates make for difficult tracking over time.	• Offsetting monthly service and infrastructure charges require going beyond ZEB. • Net metering is not well established, often with capacity limits and at buyback rates lower than retail rates.
Emis-sions ZEB	• Better model for green power. • Accounts for nonenergy differences between fuel types (pollution, greenhouse gases). • Easier ZEB to reach.		• Need appropriate emission factors.

Fig.5: Nearly zero energy building definitions (Torcellini et al., 2006., p.11)

As a definition of the nearly zero energy building concept hereby have been established through a literature review, this section of the chapter will go on by looking at in what way the research question in this master thesis are interlinked with the definition of the nearly zero energy building concept, and from that, present theories on how to proceed to seek an understanding of the main question of this master thesis, that being the possibilities of the nearly zero energy building concept to have an impact on climate change.

In research, theories are used to explain and understand the world we live in, and often, to challenge existing knowledge within the limits of assumptions. The theoretical framework forms a structure that supports the theory of a research study, and strives to explain why the research question in question is under study.

Furthermore, the framework should limit the scope of data relevant to the research question at hand, by defining the area from which data will be collected for the researcher to be able to conduct a precise analysis and interpretation of said data. This will in turn give an understanding of variables in the study by either validating or challenging theoretical assumptions.

The assumptions, or theories, for the research in this master thesis, is that the nearly zero energy building concept both is, and even more, will become, a very welcome and contributing concept in the matter of mitigating climate change, and a strong belief that the findings will be able to support this is present. In order to either support or dismiss any assumptions, a case study of two nearly zero energy buildings located in Finland will be conducted (see section 6.6 Case study).

In order to evaluate the research question in this master thesis and to, in the end, either support or dismiss my assumptions, it is imperative going forward, to have in mind what the problem is present for this research to be conducted, what purpose the research has to possibly be able to deal with said problem, and in the end, what significance the research might have in connection with the problem.

Problem. As discussed earlier in this master thesis, the average temperatures continue to increase, bringing with it more extreme weather events, all due to anthropogenic climate change. As such, there is a strong need for urgent action taken in utilizing cleaner energy.

Purpose. The purpose of this research is to gain knowledge of the nearly zero energy building concept, and from there, either support or dismiss my assumptions of whether the nearly zero energy building concept can provide any viable contribution towards mitigating climate change.

Significance. Again, referring to earlier discussions, mitigating climate change is of utmost importance. Mankind is responsible for the climate change present today, and also responsible for rectifying the damage done before it is too late. Should my assumptions be supported through my research, the nearly zero energy building concept might have a significant role to play in the near future on the matter of mitigating climate change.

4. Methodological approach

This chapter will present and discuss the methodological approach employed to study the nearly zero energy building concept in relation to the research question proposed.

"Methodology means understanding the entire research process - including its social-organizational context, philosophical assumptions, ethical principles, and the political impact of new knowledge from the research enterprise. Methods refer to the collection of specific techniques we use in a study to select cases, measure and observe social life, gather and refine data, analyze data, and report on results. The two are closely linked and interdependent." (Neuman, 2011, p. 2).

The purpose of this chapter is to describe the data collection process and the following analysis of said data for the master thesis and research question proposed. The methods used will be presented and how and why they were used, and also what ontological and epistemological approaches the methodology is based on.

4.1 Deductive approach

In order to answer the research question proposed in this master thesis, and possibly provide some sort of recommendation regarding the nearly zero energy building concept, the research going forward will be conducted in a deductive manner. According to Neuman, "To theorize in a deductive direction, we start with abstract concepts or a theoretical proposition that outlines the logical connection among concepts. We move next to evaluate the concepts and propositions against concrete evidence. We go from ideas, theory, or a mental picture toward observable empirical evidence." (Neuman, 2011, p. 69). Going in a deductive direction means developing a theory that begins with theoretical relationships moving towards concrete empirical evidence.

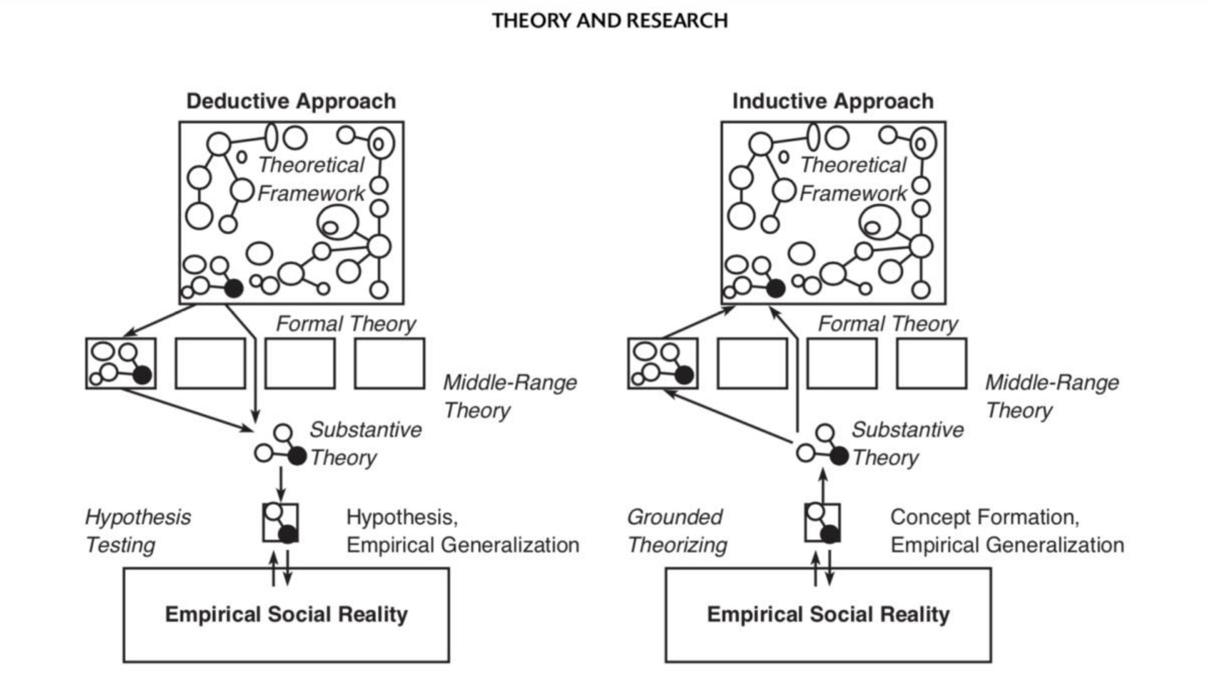


Fig.6: Deductive and inductive theorizing (Neuman, 2011, p. 70)

A deductive approach to the research paved the way for developing hypotheses regarding the nearly zero energy building concept based on the research question set forth for this study. The research design aims to test the assumptions presented in the previous chapter, and an analysis of the nearly zero energy building concept through the case studies outlined for this master thesis should enable me to deduct conclusions from the premises and propositions discussed throughout this paper.

4.2 Qualitative research

The research question in this master thesis aims to gain a thorough understanding of the nearly zero energy building concept, and from findings through the case studies, possibly present a conclusion regarding the viability of the nearly zero energy building concept to have any impact on the climate changes we are facing today.

To do so, a qualitative methodological approach has been chosen as this is deemed to be the most appropriate approach. What exactly is a qualitative research strategy? According to Nahid Golafshani, “Qualitative research uses a naturalistic approach that seeks to understand phenomena in context-specific settings, such as "real world setting [where] the researcher does not attempt to manipulate the phenomenon of interest" (Patton, 2001, p. 39). Qualitative research, broadly defined, means "any kind of research that produces findings not arrived at by means of statistical procedures or other means of quantification" (Corbin and Strauss, 1990, p. 17) and instead, the kind of research that produces findings arrived from real-world settings where the "phenomenon of interest unfold naturally" (Patton, 2001, p. 39). Unlike quantitative researchers who seek causal determination, prediction, and generalization of findings, qualitative researchers seek instead illumination, understanding, and extrapolation to similar situations (Hoepfl, 1997)." (Golafshani, 2003, p. 600).

In sum, the purpose of a qualitative research strategy is to understand social phenomena, structures and human experiences, and I found using a qualitative research strategy was very applicable towards studying issues related to the nearly zero energy building concept, as it allowed me to gain a thorough knowledge of the concept itself, combined with insight into social phenomena related to the concept through the particular case studies presented in this master thesis. "The strength of qualitative research is its ability to provide complex textual descriptions of how people experience a given research issue. It provides information about the "human" side of an issue – that is, the often contradictory behaviors, beliefs, opinions, emotions, and relationships of individuals. Qualitative methods are also effective in identifying intangible factors, such as social norms, socioeconomic status, gender roles, ethnicity, and religion, whose role in the research issue may not be readily apparent. Although findings from qualitative data can often be extended to people with characteristics similar to those in the study population, gaining a rich and complex understanding of a specific social context or phenomenon typically takes precedence over eliciting data that can be generalized to other geographical areas or populations." (Mack, Woodsong, MacQueen, Guest and Namey, 2005, p.1).

For this section of the qualitative research part of the thesis, a review of the different steps of the qualitative approach to social research will follow. It starts with an outtake from Neuman´s book on social research methods, and thereafter a comparison and presentation of how it applies to this specific research regarding the nearly zero energy building concept;

"**1.** *Acknowledge self and context.* Social scientists also start with a topic as with quantitative research, but the start is simultaneous with performing a self-assessment and situating the topic in a socio-historical context. Many qualitative researchers rely on personal beliefs, biography, or specific current issues to identify a topic of interest or importance.

2. *Adopt a perspective.* Qualitative researchers may ponder the theoretical-philosophical paradigm or place their inquiry in the context of ongoing discussions with other researchers. Rather than narrowing down a topic, this means choosing a direction that may contain many potential questions.

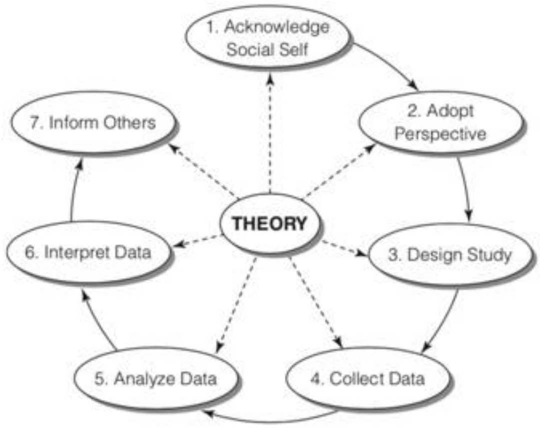


Fig.7: Steps in the Qualitative Research Process. (Neuman, 2011, p. 21)

3–6. *Design a study and collect, analyze, and interpret data.* As with quantitative research, a qualitative researcher will design a study, collect data, analyze data, and interpret data. More so than the quantitative researcher, a qualitative re- searcher is likely to collect, analyze, and interpret data simultaneously. This is a fluid process with much going back and forth among the steps multiple times. Often the researcher not only uses or tests a past theory, but also builds new theory. At the interpret data stage, the qualitative researcher creates new concepts and theoretical interpretations.

7. *Inform others.* This is similar for both approaches, but here again, the style of a report varies according to the approach used." (Neuman, 2011, p. 20)

As mentioned above, a review of the different steps of the qualitative approach to social research in relation to the nearly zero energy building concept hereby follows;

Acknowledge self and context. As being part of this Master Program, I have an underlying, above the average, interest for the environment. Throughout the program the state of the earth has been very well documented, and multiple possibilities for combatting climate change has been discussed. From these discussions, and through readings, I found a particular interest in the energy usage, and often in-efficiency, in buildings, which is why I wanted to study the nearly zero energy concept, to be able to gain a deeper understanding on whether or not the energy-efficiency of buildings can play a role on the subject of mitigating climate change.

Adopt a perspective. The physical-social setting is two nearly zero energy projects in Jampankaari and Kuopio, Finland. Through a case study of each of these projects, based on the research question proposed for this master thesis, the aim is to gain advanced knowledge of all factors and perspectives regarding the nearly zero energy building concept, through which a conclusion/recommendation regarding the concept can be presented in the final remarks of this study.

Design a study and collect, analyze, and interpret data. Through the case studies, the data collected should be sufficient to do a proper analysis based on the research question, enabling the possibilities for further assumptions regarding the nearly zero energy building concept, as well as being supportive towards any conclusions to be proposed.

Inform others. The final step in the different steps of the qualitative approach to social research is about informing others. The style of communication for this study is the master thesis itself, which will be available online for any interested parties.

4.3 Ontological and Epistemological assumptions

In order to discuss and provide any possible solutions or conclusions to the research question proposed in this master thesis, the inclusion of meta-theory will be of significance. “Meta-theory is concerned with discerning underlying ontological and epistemological assumptions that a body of theory or a theoretical perspective uses. (Blaikie, 2010, p. 138). This basically means to be looking at the nearly zero energy building concept in an ontological and epistemological manner. What does this mean? To begin with it would be beneficial to explain what these two terms mean. According to Neuman, ontology is “An area of philosophy that deals with the nature of being, or what exists; the area of philosophy that asks what really is and what the fundamental categories of reality are.”. On the other hand, epistemology is “An area of philosophy concerned with the creation of knowledge; focuses on how we know what we know or what are the most valid ways to reach truth.” (Neuman, 2011, p. 94 - 95).

How do this apply to the nearly zero energy building concept? Reviewing the concept in an ontological manner basically means stating what findings are present from the case studies in relation to the research question. What do my case studies reveal about the nearly zero energy building concept? Are there pros and/or cons? Are the findings applicable and sufficient to be able to discuss the research question? I am stating the facts that has been discovered. On the other side, reviewing the concept in an epistemological manner, concerns in what way the findings will be applied. Based on findings from the case studies, importance is put on sourcing applicable information in order to produce knowledge, and consider the best implementation of said information to be able to present conclusions and/or recommendations in a scientific manner.

4.4 Data Collection Limitations

The discussions around the research question proposed for this master thesis will be based on knowledge gained throughout this master program, accompanied with the findings from the case studies as proposed. There are many ways in which one can collect data for a study. In this case, the collection of qualitative data will be conducted without the common interviewer-participant interaction. This might be seen as too limited in some cases, but for this particular study I am confident the method chosen will enable me to present a very good case and final conclusions/recommendations.

As can be seen in figure 8 below, taken from the article "Promoting novelty, rigor, and style in energy social science: Towards codes of practice for appropriate methods and research design." by Sovacool, Axsen and Sorrell, the data collection method applied to this master thesis can be seen as "Limited to the perspective, agenda and biases of those who produced the documents" (Sovacool et. al, 2018, p.29). This may be so. But if one take into consideration that the two projects to be discussed through the case studies are open for the public, available for scrutiny, in combination with the author of this master thesis´ understanding of the nearly zero energy building concept, the data collection method set forth in this master thesis shall be deemed trustworthy, sufficient and applicable for the discussions around the research question and any final conclusions/recommendations.

	Category	Appropriate for :	Limitations
Qualitative methods of data collection	Interviews (semi-structured or unstructured)	Accessing individual stories, understandings, explanations and meanings	Vulnerable to interviewer bias and social desirability bias
	Focus groups	Accessing collectively formed ideas and meanings; testing theories at reduced cost	Vulnerable to interviewer bias; collective patterns of response might differ from individual patterns
	Direct (naturalistic) observation	Observing actual behavior (rather than relying on self-reports)	May misinterpret actor interpretations and meanings
	Participant observation (ethnography)	In-depth access to a culture or context (observation and interaction)	Very time intensive (months or years); immersion may not be possible
	Documents or media	Accessing social discourse as presented by particular stakeholders	Limited to the perspective, agenda and biases of those who produced the documents
Qualitative methods of data analysis	Content analysis	Well-structured research questions, with a priori analytical categories	Requires highly-structured framework; can lack depth of analysis
	Narrative or discourse analysis	Accessing greater depth, explanation and meaning	Methods vary widely; difficult to make transparent
	Grounded theory	Developing new theory; investigating empirical topics with very little literature or theory to draw from	Methods vary widely; difficult to make transparent

Fig.8: Qualitative methods of data collection. (Sovacool et. al, 2018, p. 29)

Even though Sovacool et. al state limitations as discussed above, they also confirm the authors assumptions that the chosen method of data collection for this study is a valid and sufficient method of collecting qualitative data, producing applicable findings to be able to answer any research questions; “The final category we consider is analysis of documents, such as reports, letters, websites and news media. Such data sources can provide insight into the information, frames and storylines presented by different actors, as well as the social interactions among them.” (Sovacool et. al, 2018, p. 29).

Finally, to further validate the chosen method for collecting data for this master thesis, I will end this section with a transcript regarding document analysis from Glenn Bowen´s publication “Document Analysis as a Qualitative Research Method”;

- *Efficient method*: Document analysis is less time-consuming and therefore more efficient than other research methods. It requires data *selection*, instead of data *collection*.
- *Availability*: Many documents are in the public domain, especially since the advent of the Internet, and are obtainable without the authors’ permission. This makes document analysis an attractive option for qualitative researchers. As Merriam (1988) argued, locating public records is limited only by one’s imagination and industriousness. An important maxim to keep in mind is that if a public event happened, some official record of it most likely exists.
- *Cost-effectiveness*: Document analysis is less costly than other research methods and is often the method of choice when the collection of new data is not feasible. The

data (contained in documents) have already been gathered; what remains is for the content and quality of the documents to be evaluated.

- *Lack of obtrusiveness and reactivity*: Documents are ‘unobtrusive’ and ‘non-reactive’ - that is, they are unaffected by the research process. (Previous studies found in documents are not being considered here.) Therefore, document analysis counters the concerns related to reflexivity (or the lack of it) inherent in other qualitative research methods. With regard to observation, for instance, an event may proceed differently because it is being observed. Reflexivity - which requires an awareness of the researcher’s contribution to the construction of meanings attached to social interactions and acknowledgment of the possibility of the investigator’s influence on the research - is usually not an issue in using documents for research purposes.
- *Stability*: As a corollary to being non-reactive, documents are stable. The investigator’s presence does not alter what is being studied (Merriam, 1988). Documents, then, are suitable for repeated reviews.
- *Exactness*: The inclusion of exact names, references, and details of events makes documents advantageous in the research process (Yin, 1994).
- *Coverage*: Documents provide broad coverage; they cover a long span of time, many events, and many settings (Yin, 1994). (Bowen, 2009, p. 31)

5. Case study

As previously described in this master thesis, its purpose is to gain a thorough understanding of the nearly zero energy building concept. To do so, the proposed research question will be discussed through a case study of two nearly zero energy buildings in Finland; the nearly zero energy building projects in Jampankaari and Kuopio, Finland. The Jampankaari building was the first zero-energy house development project in Finland, a project that also involved a similar house in Kuopio, which was designed to be used as student apartments.

The reason a case study was selected for this master thesis is that the purpose of the study is to understand the nearly zero energy building concept in practice, and to do so, a qualitative research has to be conducted in order to understand the variables present in such projects.

What is a case study? Sovacool et. al reviews a case study as "an in-depth examination of one or more subjects of study (cases) and associated contextual conditions. Case studies can use both quantitative and qualitative research techniques. George and Bennet define a case study as a "detailed examination of an aspect of a historical episode to develop or test historical explanations that may be generalizable to other events" [89], while Yin defines it as "an investigation of a contemporary phenomenon within its real-life context when the boundaries between phenomenon and context are not clearly evident" [90]. (Sovacool et. al, 2018, p.18).

In order to be able to support any conclusions or recommendations derived from the findings from the case study, findings that are based on the proposed research question, an inclusion of the following sub-questions and subsequent review will be of importance for both dissecting the research question and when providing any final statements regarding the nearly zero energy building concept;

1. "Will the nearly zero energy building concept always be cost effective?"
2. "Is it viable to apply the nearly zero energy building concept to existing buildings?"

With the parameters introduced in the above, the purpose of this case study is to collect data through the case study, and following an analysis of the findings, achieve an understanding of the nearly zero energy building concept in order to provide recommendations or conclusions with regards to the nearly zero energy building concept, based on the research question proposed. In the next part of this chapter a presentation of the two zero energy building projects will be presented.

5.1 Zero-energy house in Jampankaari

The first case study of this master thesis is the zero-energy house in Jampankaari. The building in Jampankaari, Finland, was the first zero-energy house development project in Finland. As previously discussed in this master thesis, the aim of a zero-energy house is to produce as much energy as it consumes per year. The goal of the zero-energy house project in Jampankaari was to find an optimal concept in terms of economy and operation for the implementation of zero-energy buildings, while at the same time being in accordance with the EU regulations coming into force in 2020.

Fig.9: Jampankaari zero energy house under construction #1 (Vallox.com, 2019)

Fig.10: Jampankaari zero energy house under construction #2 (Vallox.com, 2019)

Heating in the Jampankaari building was implemented with two geothermal wells. These are also used in the summer for cooling of the dwellings. The domestic water for the building is heated with 35 solar collectors with an area of 2,5 m^2 and the electricity for the building is produced with 72 solar panels with an area of 1,5 m^2.

Fig.11: Solar panels on the Jampankaari building (Nieminen, 2011, p.16)

Furthermore, the braking energy from the lift is being re-used and utilised as electricity. On the outside of the building, the solar shading structures has built in photovoltaic panels, and as such, also contribute in providing electricity to cover the energy needs of the building.

Fig.12: Solar shading with built in photovoltaic panels on the Jampankaari building (Nieminen, 2011, p.16)

The ventilation system of the building utilises up to 80% of the heat energy of extract air for heating supply air. Furthermore, the dwelling is also heated with waste heat from the household appliances, where heat produced by the residents take part in the heating/cooling process of the building. During the summertime, heat recovery is bypassed and cold liquid from the heat wells is circulated through the ventilation system.

Calculations performed for the Jampankaari zero energy house shows that "renewable energy sources produce circa 4500 kWh more energy than is needed in the property for electricity and heating" (Vallox.com, 2019). Excess solar heat energy is utilised in a service house situated in the same courtyard. In economic terms, such excess energy can be introduced and sold into to utility grid as well to the benefit of the building.

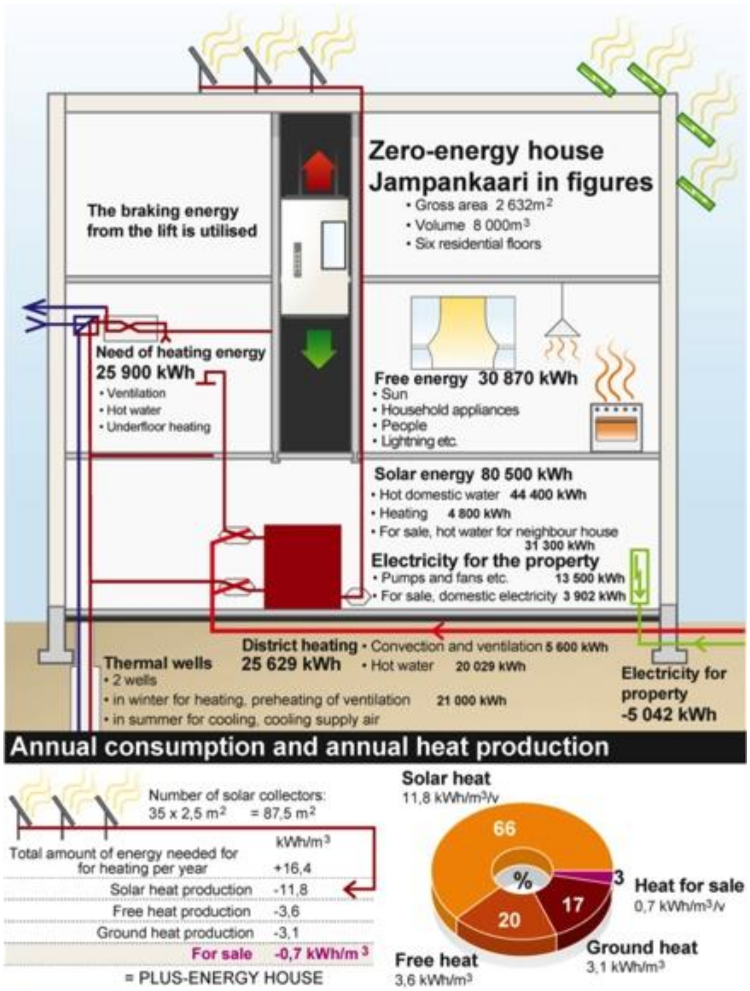


Fig.13: Functionality of a zero energy block of flats (Vallox.com, 2019)

In addition, the developers of the Jampankaari zero energy house set out to employ an energy reporting system that would be applicable for properties utilising renewable energy in order to produce clearly visualised reports enabling users to easily understand how energy efficient the property operates through the seasons. In cooperation with Nuuka Solutions (www.nuukasolutions.com), a system containing applicable necessary features for renewable energy reporting was created and implemented.

From this reporting system energy balance calculations can be produced visualising how large the energy consumption of the building is by energy type, what share the building own energy production is, how much energy is purchased and what amount of excess energy is available for re-selling.

This type of reporting system is not only beneficial and helpful for residents concerned with energy usage and efficiency, but also for specialists, whom through consumption analysis and trends resulting from the system, are enabled to a very precise degree to monitor the buildings´ energy efficiency, the performance of HVAC and the electricity processes. Taking learnings from such monitoring will be highly beneficial for future nearly zero energy building projects, for the construction of the best possible energy efficient buildings.

A sample of different types of data available from the Jampankaari zero energy house through the reporting system implemented in cooperation with Nuuka Solutions are presented in the following. Such in depth online monitoring is not widespread for existing nearly zero energy buildings, but it shows the potential in energy monitoring for both layman and specialist, enabling all interested parties to follow trends in cost, efficiency, seasonal changes etc.

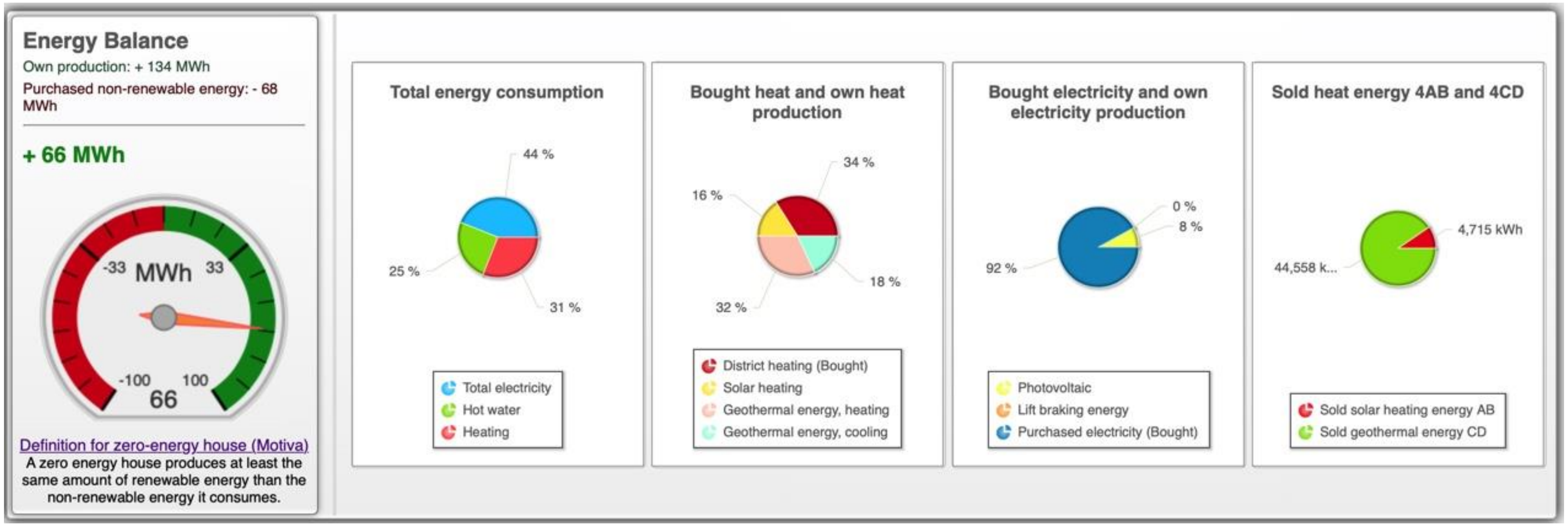


Fig.14: Available data from energy reporting system - 1 (Nuukasolutions.com, 2019)

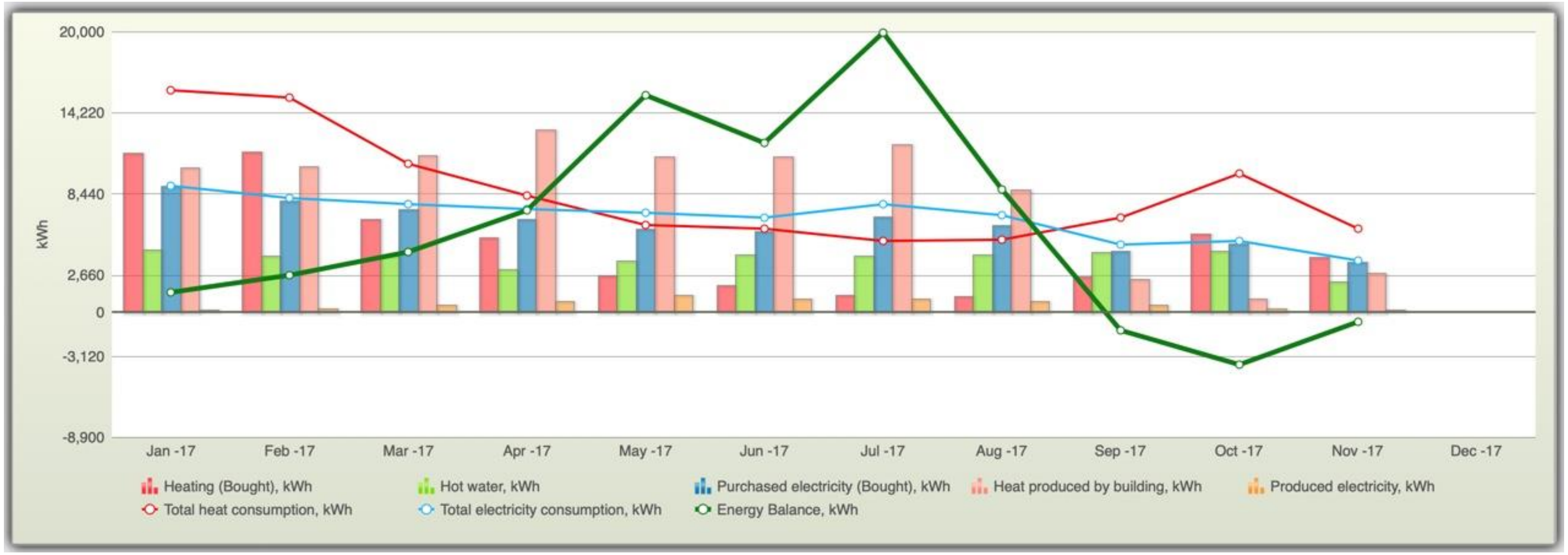


Fig.15: Available data from energy reporting system - 2 (Nuukasolutions.com, 2019)

Fig.16: Available data from energy reporting system - 3 (Nuukasolutions.com, 2019)

Energy type	Jan -17	Feb -17	Mar -17	Apr -17	May -17	Jun -17	Jul -17	Aug -17	Sep -17	Oct -17	Nov -17	Dec -17	Total	
1: Energy produced by the building (kWh)														
Solar heating	140	1,230	2,310	4,090	5,750	5,950	5,020	3,440	1,900	490	260	0	**30,580**	
Geothermal energy, heating	10,156	9,150	8,797	8,917	5,262	5,135	6,942	5,286	428	448	2,489	0	**63,010**	
Geothermal energy, cooling	0	0	0	5	9,136	5,782	13,809	5,494	207	0	0	0	**34,433**	
Photovoltaic	53	200	429	738	1,170	939	888	696	451	181	69	0	**5,814**	
Lift braking energy	19	16	15	19	17	17	18	16	17	18	9	0	**180**	
	10,367	**10,596**	**11,551**	**13,769**	**21,336**	**17,823**	**26,676**	**14,932**	**3,003**	**1,137**	**2,827**	**0**	**134,017**	
2: Purchased energy (kWh)														
District heating	14,281	13,682	7,706	4,241	2,351	1,965	1,360	2,009	5,087	9,210	4,821	0	**66,713**	see: renewable ener... generated in proximity
Purchased electricity	8,939	7,945	7,287	6,559	5,879	5,756	6,761	6,182	4,332	4,844	3,556	0	**68,039**	
	23,220	**21,627**	**14,993**	**10,800**	**8,230**	**7,721**	**8,121**	**8,191**	**9,419**	**14,054**	**8,377**	**0**	**134,752**	
3: Sold energy from the production (kWh)														
Sold electricity	0	0	1	3	50	22	11	12	30	7	1	0	**138**	
Sold heat	7,215	6,648	6,680	6,427	4,934	4,947	6,291	4,324	355	36	1,416	0	**49,273**	
	7,215	**6,648**	**6,681**	**6,430**	**4,984**	**4,969**	**6,302**	**4,336**	**385**	**43**	**1,417**	**0**	**49,411**	
4: Annual balance (kWh)														
Total heat	10,296	10,380	11,107	13,007	11,012	11,085	11,962	8,726	2,328	938	2,749	0	**93,590**	
Total electricity	-8,868	-7,729	-6,842	-5,797	4,444	982	7,953	25	-3,657	-4,645	-3,478	0	**-27,612**	
	1,429	**2,651**	**4,265**	**7,210**	**15,456**	**12,067**	**19,915**	**8,751**	**-1,329**	**-3,707**	**-729**	**0**	**65,978**	
5: Water consumption (M3)														
Total water	196	180	173	185	194	188	183	186	189	193	95	0	**1,959**	
	196	**180**	**173**	**185**	**194**	**188**	**183**	**186**	**189**	**193**	**95**	**0**	**1,959**	
6: Energy consumption of the building (kWh)														
Total electricity	9,010	8,162	7,731	7,316	7,067	6,712	7,666	6,894	4,800	5,043	3,633	0	**74,032**	
Hot water	4,435	3,936	3,957	3,021	3,588	4,091	3,960	4,077	4,225	4,358	2,123	0	**41,772**	
Heating	11,340	11,380	6,580	5,320	2,580	1,870	1,150	1,090	2,510	5,550	3,860	0	**53,230**	
	24,785	**23,478**	**18,268**	**15,656**	**13,235**	**12,673**	**12,776**	**12,061**	**11,535**	**14,950**	**9,617**	**0**	**169,035**	

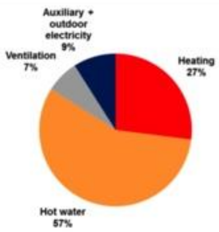
Fig.17: Available data from energy reporting system - 4 (Nuukasolutions.com, 2019)

To conclude the Jampankaari zero energy house part of the case study, an outtake from a report of the Jampakaari house detailed from the European Commissions´ Energy performance of buildings directive is presented;

4.7.1 *Järvenpää Zero Energy House*

Author(s):	Riikka Holopainen, Miimu Airaksinen, VTT				
Illustration:					
Project aim:	First nearly zero-energy house in Finland				
Building address:	Jampankaari 4 ED, Järvenpää				
Building type:	Residential	Non-residential	Public	New	Renovated
	X			X	
	A home for elderly people				
Building size:	2,124 m² gross floor area				
Building envelope construction:	Sandwich structure concrete walls with 300 mm SPU (polyuerthane) insulation				
Building envelope U-values:	Wall	0.08 W/m²K			
	Window	0.76 W/m²K			
	Roof/ceiling to the attic	0.07 W/m²K			
	Cellar ceiling/ground slab	0.10 W/m²K			
Building service systems:	Water-based heating system, low-energy lighting, mechanical supply and exhaust ventilation system with heat recovery.				
Included renewable energy technologies:	Solar thermal collectors, solar electricity (PV) and geothermal heating.				

Final energy use:	Calculated	X	Calculation method:	VTT House simulation tool
	Measured		Monitored in year:	-
	Heating	12 kWh/m².year		
	Hot water	25 kWh/m².year		
	Cooling	0 kWh/m².year		
	Ventilation	3 kWh/m².year		
	Lighting	Unknown		
	Electrical appli-ances (household electricity)	Unknown		
	Auxiliary + outdoor electricity	4 kWh/m².year		
	Total	44 kWh/m².year		



Primary energy use:	Total	No data available	Primary energy requirements were introduced after the building permit was given.
Renewable energy contribution ratio:	100% of the total final energy (the excess energy during summer is sold to nearby house compensating the district heating consumption during winter)		
Improvement compared to national requirements:	- 50%	Compared to:	Requirements in National Building Code of Finland, part D3
Experiences/ lessons learned:	Ground source heating was originally used without heat pump for pre-heating of the warm service water. A heat pump was later installed. It is important to sufficiently cool the inverter room of the solar system, as hot temperatures decrease the solar electricity supply rate.		
Costs:	Additional costs due to energy efficiency and renewable energy systems were roughly 400 €/m² or 15% higher than typical new elderly homes, according to the Finnish energy requirements for new buildings. Re-use of the concept is expected to reduce the extra costs down to 10% when compared to typical elderly homes with the same level of services.		
Funding:	A long-term interest-subsidised loan		
Awards:	Most environmentally conscious apartment house 2013 Climate award of Helsinki region 2013 *Järvenpää* award for sustainable building 2011 Constructor of the year 2011 Most influential residential actor 2010		
Links to further information:	http://www.nollaenergia.fi/jarvenpaantalo.php		

Fig.18: Järvenpää Zero Energy House (Energy performance of buildings, 2019)

5.2 Kuopio nearly zero energy building

The Jampankaari building was the first zero-energy house development project in Finland. But that project also involved a similar house in Kuopio. The Kuopio zero energy building is a four-storey apartment building consisting of 47 apartments for disabled students.

Fig.19: Kuopio zero energy building under construction (Käkelä, P., Viitanen, A. and Finnäs, K., 2013, p.4).

Fig.20: Kuopio zero energy building (Käkelä et. al, 2013, p.4).

As with the Jampankaari building, both solar water heating, solar electricity and geothermal heating and cooling are utilised in order to produce electricity, together with energy produced from the braking of the lift in this building as well. During winter-time, geothermal energy is used to pre-heat air through the ventilation system, and opposite, during summer-time, to pre-cool the air. Both the Kuopio and Jampankaari buildings are reference buildings with regards to the nearly zero energy building concept, and as discussed in the previous section, energy consumption is constantly monitored in real time through the energy reporting system by Nuuka Solutions.

In order to produce the electricity needed, to adhere to the nearly zero energy building concept, the Kuopio building consist of a total of 73 solar panels. 37 of which are water heating solar panels, with a total surface coverage of 126 m², and 36 solar panels which are electricity producing solar panels, with a surface coverage of 108 m².

Fig.21: Water heating solar panel (Käkelä et. al, 2013, p.7).

Fig.22: Electricity producing solar panel (Käkelä et. al, 2013, p.7).

The ventilation system of a building usually represents the largest portion of heat energy consumption, and as such, it is highly advised to utilise a mechanical ventilation with as high efficiency of heat recovery as possible. A counter-flow plate heat exchanger is utilised in the Kuopio building, providing around 73% heat recovery efficiency.

Referring to previous discussion regarding the energy reporting system, energy monitoring is available for both layman and specialists to follow trends in cost, efficiency, seasonal changes etc., and an example from the Kuopio building is presented below, in another fashion than that of the Jampankaari building, displaying the versatility of the energy reporting system from Nuuka Solutions;

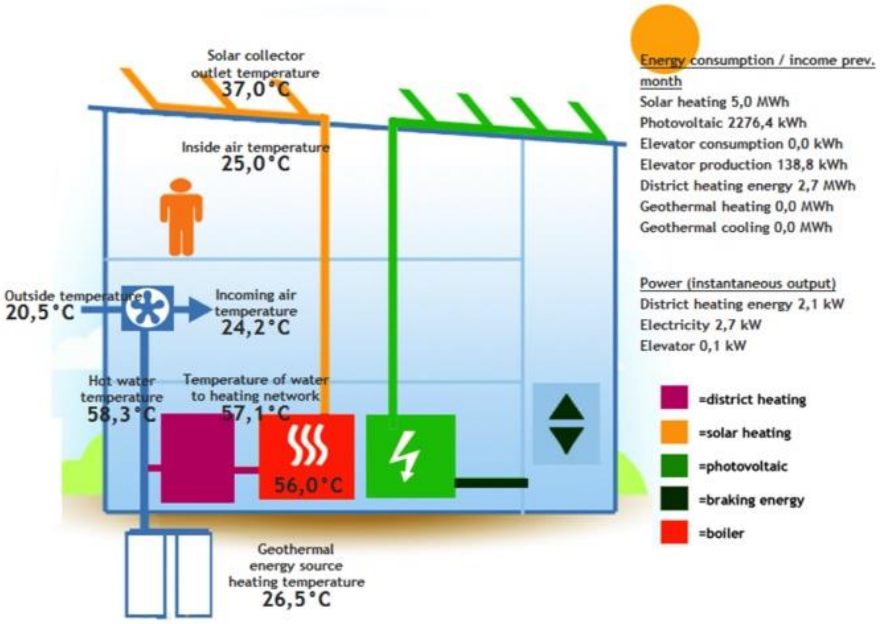


Fig.23: Online monitoring of energy consumption - Kuopio zero energy building (Käkelä et. al., 2013, p.8).

The two case studies for this master thesis regarding the nearly zero energy building concept has hereby been presented. The findings from the case study will be further discussed in the discussion section of this master thesis, in relation to the research question set forth, including the proposed sub-questions, acting as support to any conclusions or recommendations proposed in the concluding remarks of this master thesis.

6. Discussion

6.1 Power of the sun

“Every 10 minutes the surface of the earth receives enough energy from the sun to provide the primary energy needs of humankind for a whole year.” (Coley, 2008, p.397). With such a statement from Coley´s book the discussion whether to go with fossil fuels or renewable energy resources should be ended. Harness the sun and drastically limit the anthropogenic impact on the environment and every human being living on this precious place called earth will have their energy needs covered.

One can only wish! There’s more to it than just harnessing the sun and everything is ok. But what can be, and should be taken from Coley, is the potential in solar energy. Solar energy is infinite, meaning it is a renewable energy source. And there is a lot of it to harness and to convert into the likes of electricity. The good news is that great progress has been made in many areas of solar energy the last 10 years, ever since Coley wrote his book. And not only solar energy as a renewable energy resource, but also hydropower, wind power and geothermal energy, but the focus will be on solar energy as a renewable energy resource in this master thesis.

6.2 Solar Photovoltaics

The “Energy Performance of Buildings Directive” from the European Union requires all new buildings to be nearly zero energy buildings by the end of 2020. A zero-energy building is a building with zero net energy consumption, this means that the amount of energy used by the building over a year is almost equal to the amount of renewable energy created on the site.

Is it possible to just remove the cable feeding electricity from the utility grid into a building or a giant shopping mall? Electricity which has most likely been generated from fossil fuels. Is it possible to run a whole building, with heating, air conditioning, lighting and so on, only by electricity produced nearby? If every building in the world generated electricity to cover its own energy needs, that would mean a lot less energy production generated from fossil fuels. This sounds super environmental friendly.

On a more serious note, this will not save the world. But it will be a great addition to mitigating climate change. Harnessing the power from the sun via solar cells can create a lot of electricity and heat, which in turn can be used to heat or cool a building amongst other. And as mentioned earlier, from Coley´s book, there is a heck of a lot of solar energy to harness.

So how does it work? Solar, or photovoltaic cells, convert the energy from the sun into electricity. They rely on the photoelectric effect - the ability of matter to emit electrons when a light is shone on it. Silicon is known as a semi-conductor. This means that it shares some of the properties of metal and some properties of an electrical insulator which makes it a key ingredient in solar cells. So, what happens when the sun shines on a solar cell?

Sunlight consists of particles called photons which radiate from the sun. When the photons hit the silicon atoms of the solar cell, their energy is transferred to lose electrons, removing them from the atoms. From here, these freed up electrons has to be put into an electric current. To do this an electrical imbalance is created within the cell. This electrical imbalance acts like a slope where the electrons flow in the same direction.

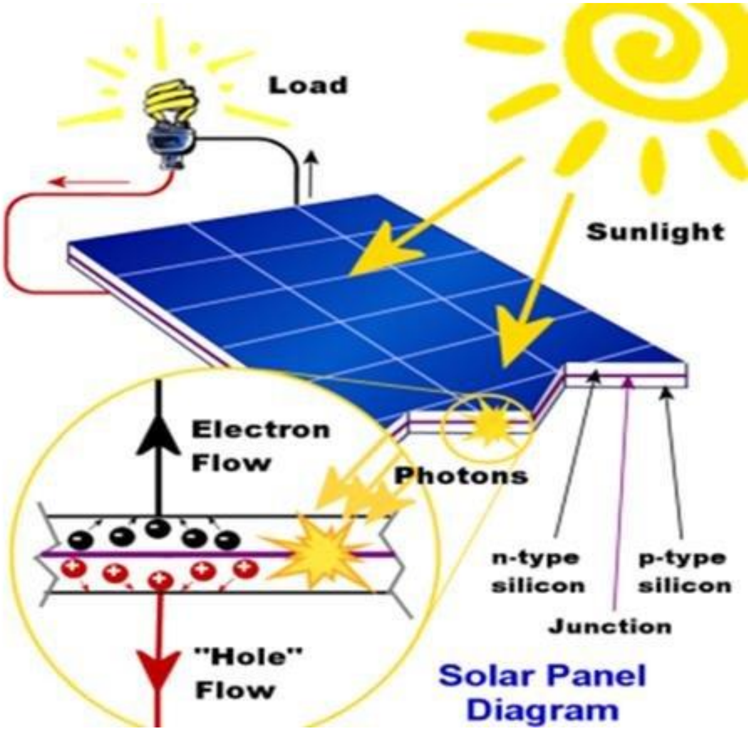


Fig. 24: Description of the photovoltaic effect in a solar cell. (Voudoukis, 2018)

“Creating this imbalance is made possible by the internal organisation of silicon. Silicon atoms are arranged together in a tightly bound structure. By squeezing small quantities of other elements into this structure, two different types of silicon are created: n-type, which has spare electrons, and p-type, which is missing electrons, leaving ‘holes’ in their place. When these two materials are placed side by side inside a solar cell, the n-type silicon’s spare electrons jump over to fill the gaps in the p-type silicon. This means that the n-type silicon becomes positively charged, and the p-type silicon is negatively charged, creating an electric field across the cell. Because silicon is a semi-conductor, it can act like an insulator, maintaining this imbalance. As the photons smash the electrons off the silicon atoms, this field drives them along in an orderly manner, providing the electric current to power calculators, satellites and everything in between.” (Physics.org, 2014).

In principal, there are three types of photovoltaic cells. “Their individual percentage efficiencies indicate how much of the incoming solar radiation will convert into electricity leaving the cell (there will be further losses in the control systems and cabling):

- Monocrystalline: Typical efficiency of 15% (about 100kWh per m^2 per year in the UK). These are typically dark coloured with close lines of thin conductors.
- Polycrystalline: Typical efficiency of at least 13% (around 100kWh per m^2 per year in the UK). These are likely to have a truly crystalline appearance.
- Thin film: Typical efficiency of 7% (about 60kWh per m^2 per year in the UK). These may be integrated onto brise-soleil, roof tiles or glass panels.

Crystalline photovoltaics currently account for over 90% of installed systems. The cost of the materials is generally highest for the more efficient types of cell although the integration of thin-film technologies into building elements adds to their cost.” (Designingbuildings.co.uk, 2018).

6.3 Solar Technology Roadmaps

The International Energy Agency is leading the development of a series of Roadmaps concerning some of the most important energy technologies. These roadmaps are as one can expect heavily focused on the environment, and the most important points to be taken from these roadmaps are such as achieving a consensus on low-carbon milestones, priorities for technology development, investment needs and so on. They are groundworks to provide solid analytical advice to enable national policy makers and industries to develop specific technologies.

In 2012 the International Energy Agency developed the report "Technology Roadmap - Solar Heating and Cooling" which envisaged the development and deployment of solar heating and cooling by 2050, by when solar energy could produce as much as 16% of total final energy use for low temperature heat (solar heating) and nearly 17% of total energy use for cooling (solar cooling) (International Energy Agency, 2012, p. 1).

Solar heating and cooling technologies can play an important role in reaching set targets for mitigating climate change, economic development and, not at least, energy security. It is compatible with almost every source of back-up heat, and extremely applicable due to the ability to deliver hot water, hot air and cold air. Most of the cost for solar heating and cooling technologies is taken at the moment of investment. The operational cost is minimal and the exposure to the volatility of oil, gas or electricity prices are almost non-existent. In addition, regarding solar heating in commercial buildings and residential buildings, this is supply of local energy, energy produced on site, which reduces energy transmission, enhance efficiency and is much more cost effective. On a side note, drawing a comparison to the least developed countries, such local solar heating and cooling technologies can play a significant role in stabilizing food prices by reducing the necessity of other energy commodities.

The technology roadmap for "Solar Photovoltaic Energy" from 2014 visualise a detailed prediction of solar energy presence in the energy mix in 2050;
-Solar energy is to supply 16% of the global electricity (6,300 terawatt (TWh))
-Total installed photovoltaic capacity to reach 4 600 gigawatt (GW)

-Solar energy to contribute as much as 19% of the power sector emission reductions (4 giga tonnes of carbon dioxide per year) (International Energy Agency, 2014).

6.4 Photovoltaics in buildings

Solar photovoltaics is becoming cheaper and cheaper. “In September 2017, the U.S. Department of Energy announced that the U.S. solar industry had achieved the 2020 utility-scale solar cost target of US $0.06/kWh, three years ahead of schedule and is moving toward the 2030 goal of $0.03/kWh. The following month, a solar tender for a 300 MW PV plant in Saudi Arabia was bid at the low price of US $0.179/kWh. This record was soon broken in Mexico with solar at $0.177/kWh November.” (Renewableenergyworld.com, 2018).

These numbers should lay a solid groundwork for a further expansion of the use of solar photovoltaics, and especially for renewable solar energy in commercial buildings and residential buildings. But is there a reason to be worried? China, who has been in the front seat with regards to production of solar cells, and for the cheaper and cheaper production of said solar cells, suddenly decided to drastically slash subsidies for renewable energy. Not at all. This was just a measure to curb the enormous growth China has had in the solar industry. According to the Chinese Government “the allocation of quotas for new projects had been halted until further notice” and this measure was aimed at “promoting the solar energy sector’s sustainable development, enhancing its development quality and speeding up reduction of subsidies.” (Forbes.com, 2018).

Due to the immense efforts from the Chinese in the solar industry, solar has become one of the least expensive options when it comes to new power generation. It is a lot cheaper than the cost of most fossil fuel powered generators, which in turn will continue to enable the installation of solar capacity to expand faster than other fuels. And this is what leads us to commercial buildings and residential buildings. How can this technology be utilised to massively deploy renewable energy resources in commercial buildings and residential buildings? Is it viable to replace fossil fuel generated electricity with electricity produced from renewable energy resources like the sun? Is it beneficial?

First of all, photovoltaic modules are technically well proven, with an expected lifespan of at least 30 years. And due to the drastic price drop in recent years expenditures involved in solar projects has become very attractive. In most cases, when installing a solar system in a building, there will be an immediate reduction on the electricity bill. This is due to the buildings reduced reliance on the grid - as mentioned earlier, the exposure to the volatility of oil, gas or electricity prices are almost non-existent. This is in a way future proofing a building against such volatility. In addition, the investment in the solar system will pay for itself over time.

Another very valid argument for going "green" by investing in renewable energy resources to cover a buildings´ energy needs, is that it sends a powerful message to the public. Solar power systems worldwide are very important contributors in mitigating climate change. As such, for a commercial building, the business´ public image will be seen as being environmentally aware, socially responsible and focused on the future.

But the biggest argument for investing in renewable energy resources is of course the fact that a building completely run on renewable energy produced on site (harnessing solar energy and turning it into electricity) is generation of energy that do not produce any greenhouse gas emissions the way that fossil fuel generated electricity do while at the same time reducing some types of air pollution in the process.

6.5 Constructing nearly zero energy buildings

Through the discussions in this master thesis, a thorough understanding of the nearly zero energy building concept has been gained. In this next part, a brief discussion around the actual construction of nearly zero energy buildings and its surroundings.

At the core of the construction phase of nearly zero energy buildings is the utilization of the latest and greatest energy saving technologies available. Furthermore, and an obvious part of the concept, is increasing the amount of insulation for walls and floors and ceilings. Another cost-effective measure is air sealing, which means eliminating air leaks from the entire building, such as around windows, doors, electrical outlets, plumbing and other building penetrations. There is also both double and triple pane windows with low emission coating that can either help capture or reject solar heat. With the aforementioned precautions taken through various energy saving technologies, the building would need a lot less energy to be run than an ordinary building. In short, it is a very energy efficient building, with the potential to be run almost completely on renewable energy due to the energy efficiency properties of the construction.

The choice of source to power a building is taken in the architectural design stage of the building process. The most common source of energy regarding the nearly zero energy building concept is solar power. There are many different forms of solar energy solutions to apply to a building, but some standard solutions are;

- The typical rooftop solar system, where roofing materials are replaced with photovoltaic material. Or sometimes even replacing the whole roof itself.
- Integrating photovoltaics on the sides of buildings, wherein you replace the traditional windows with semi-transparent thin-film or crystalline solar panels. In most cases this solution has less access to direct sunlight than rooftop systems, even though it offers a larger available area.
- And there is glazing, where ultra-thin solar cells are used to create semi-transparent surfaces where daylight are allowed to penetrate while at the same time generating electricity.

A nearly zero energy building have a reduced reliance on the electricity grid. But it is obviously still connected to the grid, and all buildings pay for the energy they buy from the utility grid, which is based on rates determined by demand. To combat these charges, it would be smart to plan for on-site batteries during the planning stages of the building, as this can dramatically reduce demand charges by storing excess solar energy that is used for the high-rate periods of peak demand. And with advanced energy management systems in place this process can be controlled for optimum financial benefit. A side note, which actually is a very important message to convey, is that for some near zero energy buildings, the renewable energy system, or parts of it, is based offsite, nearby. In such cases this system can help provide the energy needed for the building process itself. It is a known fact that the building process is an energy-thirsty process, so providing this process with short travelled, clean energy is very beneficial for the environment.

6.6 Case study

All the discussions and considerations until this point of the master thesis has been about clarifying and visualizing the nearly zero energy building concept, while at the same time, presenting theories, methodological approaches, assumptions and case studies as preparations for discussing the research question and subsequent sub-questions in relation to the nearly zero energy building concept.

Choosing a deductive approach to the research, implied theorizing about the nearly zero energy building concept, and from that the research question was set forth. From developing the theory, the aim was to seek empirical evidence to either support or dismiss any assumptions regarding the research question through case studies. To reiterate previously discussed assumptions/theories; the nearly zero energy building concept is, and even more, will become, a very welcome and contributing concept in the matter of mitigating climate change

Applying a qualitative research strategy was chosen to understand the social phenomena, structures and human experiences regarding the nearly zero energy building concept, and I found using a qualitative research strategy very applicable towards studying relevant issues.

The nearly zero energy building concept has been discussed at length throughout this master thesis. What really stands out is how environmentally friendly a nearly zero energy building is. As has been presented, the aim of a zero-energy house is to produce as much energy as it consumes per year. This means a nearly zero energy building is self-supplied with regards to electricity, and as such, do not rely on the utility grid at all. So, by these terms, the nearly zero energy building concept has no anthropogenic impact on the environment at all. As such, in relation to the research question set forth in this master thesis, the nearly zero energy building concept has a great potential to help mitigate climate change;

- *Is there a potential for the Nearly Zero Energy Building concept to make any serious contribution towards mitigating climate change?*

As in all business, economy matters. By studying the nearly zero energy building concept in depth as part of this master thesis, it is clear that a nearly zero energy building has a lot more to it than that of a ”regular” building. It seems futuristic and intricate, which often might be interpreted into expensive. But having learned in detail the ins and outs of the nearly zero energy building concept through this master thesis, the economic part of it should not be a deterring factor. As we have seen, most of the cost for solar heating and cooling technologies occurs at the moment of investment. The operational cost is minimal and the exposure to the volatility of oil, gas or electricity prices are almost non-existent.

Findings regarding cost from the Jampankaari project as an example, where the goal was to find an optimal concept in terms of economy and operation for the implementation of the nearly zero energy building concept, revealed that the implementation of both energy efficient and renewable energy systems did generate an additional cost of around 15% compared to a “regular” building. That being said, the Jampankaari and Kuopio projects was early phase of the nearly zero energy building concept, and re-using the concept from the Jampankaari project was expected to reduce the additional cost to 10%, a trend that continues worldwide with the recent drop in solar panel production cost. A rather large advantage in relation to the nearly energy building concept, is the possibility of over-production of electricity, which in turn can be sold to the utility grid. This will benefit the residents with reduced cost over time, adding to the cost-effective potential of the nearly zero energy building concept. An added bonus for residents of a nearly zero energy building, is the improved living conditions with high indoor air quality and comfortable indoor climate.

With the reduced production costs of solar panels as discussed earlier, in combination with the nearly zero energy building concepts´ great potential for decreased energy consumption and increased renewable energy production, it is both viable and environmentally advantageous to apply the nearly zero energy building concept to existing buildings. But, taking Europe as an example - the building stock existing in Europe today is old, inefficient and slowly renovated. Retrofitting buildings is a big challenge, mainly due to the differences in construction materials, typologies, climates and systems characterizing the European building stock. So, although applying the nearly zero energy building concept to existing buildings is viable, it is such a large task going forward with the immense amount of non-nearly zero energy buildings existing, that retrofitting existing buildings will not have any considerable impact on mitigating climate changes in the near future.

6.7 Final remarks

Do nearly zero energy buildings help the environment or is it just a building? Self-produced electricity based on renewables is environmental friendly and as discussed, the reliance on the fossil fuel based utility grid is next to nothing. But for buildings to help save the environment sounds a bit farfetched. Can buildings be discussed in the same breath as environmentally hazardous oil-rigs, coal extraction and combustion engines and so on? The following transcript from the European Commission might fuel some interesting thoughts on the matter;

"Buildings are responsible for approximately 40% of energy consumption and 36% of CO_2 emissions in the EU. Currently, about 35% of the EU's buildings are over 50 years old and almost 75% of the building stock is energy inefficient, while only 0.4-1.2% (depending on the country) of the building stock is renovated each year. Therefore, more renovation of existing buildings has the potential to lead to significant energy savings – potentially reducing the EU's total energy consumption by 5-6% and lowering CO_2 emissions by about 5%. Improving the energy efficiency of buildings can also generate other economic, social and environmental benefits. Better performing buildings provide higher levels of comfort and wellbeing for their occupants, and improve health by reducing illnesses caused by a poor indoor climate. It also has a major impact on the affordability of housing and on the concept of energy poverty. Improvement of the energy performance of the housing stock and the energy savings it brings would enable many households to escape energy poverty. Investments in energy efficiency also stimulate the economy, in particular the construction industry, which generates about 9% of Europe's GDP and directly accounts for 18 million direct jobs. SMEs would particularly benefit from a boosted renovation market, as they contribute more than 70% of the value added in the EU building sector." (European Commission, 2018).

It is fair to say that the nearly zero energy building concept have a part to play in mitigating climate change. With the current mass of buildings consuming energy and emitting CO_2 at such high levels, while at the same time ¾ of the buildings are energy inefficient, the potential for improvements and contribution towards mitigating climate change are clearly present.

Climate change is happening in front of our eyes. Mitigating actions are set into play but it is too early to say if the 2-degree targets will be reached. As fossil fuels continue to be extracted at full throttle, we might not even be close to reaching the 2-degree target. In reality, no one can see the future, so no one really knows what will happen if targets are not reached. But, the amount of knowledgeable people around the world dedicating their lives on the matter, combined with the advanced technology of today, says that their predictions should be seriously taken into consideration.

7. Conclusion

The main purpose of this research was seeking in depth knowledge of the nearly zero energy building concept, while at the same time investigating relations between the concept and the matter of mitigating climate change.

As a foundation for the research, the following research question was set forth;

- **Is there a potential for the Nearly Zero Energy Building concept to make any serious contribution towards mitigating climate change?**

To investigate the nearly zero energy building concept on the matter of climate change, a case study was chosen as research strategy to gain the in-depth knowledge needed to propose any assumptions regarding the concept in relation to the research question of this master thesis. An assumption set forth was that the nearly zero energy building concept indeed will be a contributing factor in the matter of mitigating climate change. A deductive approach to the research was applied as a means to developing theories derived from the research question, while seeking empirical evidence to support or dismiss any assumptions regarding the research question. A qualitative research strategy was deemed most appropriate considering a case study was chosen, enabling an understanding of the social phenomena a nearly zero energy building concept is. Studying a real-world setting, through case studies of two nearly zero energy building projects, presented non-manipulated findings that provided valuable information to both the understanding of the concept itself, while also acting as a supplement to discussions and support to any conclusions.

The particular case studies revealed a 15% additional cost for a nearly zero energy building compared to your standard building, due to the implementation of energy efficient systems and renewable energy systems, but in recent years the concept has become more cost-efficient, reinforced with the attractive potential of selling excess production of electricity back to the utility grid and the improved living conditions with high indoor air quality and comfortable indoor climate.

The EU energy performance of buildings directive from 2010 requires all new buildings to be nearly zero energy buildings as of 31 December 2020. Retrofitting the existing stock of buildings, i.e. applying the nearly zero energy building concept, is a highly viable approach to improve energy-efficiency. Sadly, though, due to differences in construction materials, typologies, climates, systems and energy-inefficiency in general, retrofitting existing buildings is such a tremendous task that it will unfortunately not have any considerable impact on mitigating climate change in the near future.

To finalize, there is no doubt that the research conducted on the nearly zero energy building concept throughout this master thesis has revealed major support for the concept. In relation to the research question proposed, nearly zero energy buildings as a concept is deemed to be a highly viable contributor towards mitigating climate change.

That being said - based on the discussions, the conclusion to be drawn is that the concept will not be a major contributor. At least not in this point of time.

8. References

Blaikie, N. (2010). *Designing Social Research* (2nd ed.). Cambridge, UK: Polity Press.

Bowen, G. A. (2009). Document Analysis as a Qualitative Research Method. *Qualitative Research Journal, 2009* (vol. 9, no. 2), p. 27-40. Retrieved from https://www.researchgate.net/profile/Glenn_Bowen/publication/240807798_Document_Analysis_as_a_Qualitative_Research_Method/links/59d807d0a6fdcc2aad065377/Document-Analysis-as-a-Qualitative-Research-Method.pdf

Burke III, E. and Pomeranz, K. (2009). *The Environment and World History*. Berkeley: University of California Press

Coley, D. (2008). *Energy and climate change: creating a sustainable future*. New Jersey: John Wiley & Sons, Ltd

Corbin, J. and Strauss, A 1990. Grounded Theory Research: Procedures, Canons, and Evaluative Criteria. *Qualitative Sociology* (vol.13), 3-21. Retrieved from https://med-fom-familymed-research.sites.olt.ubc.ca/files/2012/03/W10-Corbin-and-Strauss-grounded-theory.pdf

Designingbuildings.co.uk (2018). *Solar photovoltaics*. Retrieved from https://www.designingbuildings.co.uk/wiki/Solar_photovoltaics

Dobson, A. (2016). *Environmental Politics. A Very Short Introduction*. Oxford: Oxford University Press

Energy Performance of Buildings (2019). *Selected examples of Nearly Zero- Energy Buildings. Detailed report.* Retrieved from https://www.epbd-ca.eu/wp-content/uploads/2011/05/CT5_Report_Selected_examples_of_NZEBs-final.pdf

European Commission (2018). *Buildings*. Retrieved from https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings

European Commission (2012). *Towards nearly zero energy buildings.* Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/nzeb_full_report.pdf

Forbes.com (2018). *Why Did China Tap The Brakes On Its Solar Program?* Retrived from https://www.forbes.com/sites/rrapier/2018/06/05/why-did-china-tap-the-brakes-on-its-solar-program/#e72c2fe686f9

Front page photo - Zontar, K. (2019). *Modern eco house standing out from the crowd*. Retrieved from https://www.shutterstock.com/cs/image-illustration/modern-eco-house-standing-out-crowd-73394443

George, A. L., Bennett, A. (2004). *Case Studies and Theory Development in the Social Sciences*. Harvard University Press, Cambridge, MA, 2004. Retrieved from https://pdfs.semanticscholar.org/94e9/eec015c650880356853533c4dc9b2dac42bb.pdf

Golafshani, N. (2003). *Understanding Reliability and Validity in Qualitative Research.* The Qualitative Report, 8(4), 597-606. Retrieved from https://nsuworks.nova.edu/tqr/vol8/iss4/6

Hoepfl, M. C. (1997). Choosing Qualitative Research: A Primer for Technology Education Researchers. *Journal of Technology Education* (vol.9), 47-63. Retrieved from https://scholar.lib.vt.edu/ejournals/JTE/v9n1/pdf/hoepfl.pdf

International Energy Agency (2012). *Technology Roadmap: Solar Heating and Cooling.* Retrieved from https://www.iea.org/publications/freepublications/publication/Solar_Heating_Cooling_Roadmap_2012_WEB.pdf

International Energy Agency (2014). *Technology Roadmap: Solar Photovoltaic Energy.* Retrieved from https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapSolarPhotovoltaicEnergy_2014edition.pdf

Käkelä, P., Viitanen, A. and Finnäs, K. (2013). *Implementing zero energy buildings in harsh Nordic climate conditions*. Retrieved from http://www.laganbygg.se/UserFiles/Presenationer/Session_1_-_Pasi_Kakela_-_Presentation_SPU_Kakela-Viitanen-Finnas_paper_47.pdf

Mack, N., Woodsong, C., MacQueen, K. M., Guest, G., Namey, E. (2005). *Qualitative Research Methods: A Data Collector´s Field Guide*. North Carolina: Family Health International. Retrieved from https://www.fhi360.org/sites/default/files/media/documents/Qualitative%20Research%20Methods%20-%20A%20Data%20Collector%27s%20Field%20Guide.pdf

Merriam, S. B. (1988). *Case study research in education: A qualitative approach*. San Francisco: Jossey-Bass. Retrieved from http://www.appstate.edu/~jacksonay/rcoe/merriam.pdf

Neuman, Lawrence W. (2011). Social Research Methods: Qualitative and Quantitative Approaches (7th ed.). Boston: Pearson.

Nieminen, J. (2011). Finnish Solutions for Zero Energy Building. Retrieved from https://www.vtt.fi/files/sites/eescu/seminar_16052011/9_Zero_energy_buildings_Nieminen.pdf

Nuukasolutions.com (2019). *Zero energy house status*. Retrieved from https://nuukacustompages.azurewebsites.net/Jarvenpaa_Jampankaari?culture=en-us

Patton, M. Q. (2001). *Qualitative Research & Evaluation Methods.* (3rd ed.). California: Sage Publications, Inc.

Pérez-Lombard, L., Ortiz, J. and Pout, C. (2008), "A review on buildings energy consumption information". *Energy and Buildings*, 2008 (40), p. 394–398. Retrieved from http://www.esi2.us.es/~jfc/Descargas/ARTICULOS/PAPER_LPL_1_OFF-PRINT.pdf

Physics.org (2014). *How do solar cells work?* Retrieved from http://www.physics.org/article-questions.asp?id=51

Renewableenergyworld.com (2018). *Solar in 2018: Better Technology, Record-Breaking Installations*. Retrieved from https://www.renewableenergyworld.com/articles/print/volume-21/issue-1/features/solar/solar-in-2018-better-technology-record-breaking-installations.html

Sovacool, B. K., Axsen, J. and Sorrell, S. (2018). Promoting novelty, rigor, and style in energy social science: Towards codes of practice for appropriate methods and research design. *Energy Research & Social Science, 2018* (45), p. 12-42. Retrieved from https://www.sciencedirect.com/science/article/pii/S2214629618307230

The European Parliament (2010). *Official Journal of the European Union. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings*. Retrieved from: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0031&from=EN

Torcellini, P., Pless, S. and Deru, M. (2006). *Zero Energy Buildings: A Critical Look at the Definition.* Retrieved from https://www.nrel.gov/docs/fy06osti/39833.pdf

Vallox.com (2019). *Zero-energy house Jampankaari*. Retrieved from https://www.vallox.com/en/references/zero-energy_house_jampankaari.html

Voudoukis, N. (2018). *Photovoltaic Technology and Innovative Solar Cells*. Retrieved from https://www.researchgate.net/publication/323833347_Photovoltaic_Technology_and_Innovative_Solar_Cells

World Energy Outlook (2018). Retrieved from https://www.iea.org/weo2018/

Xiaodong C., Xilei D. and Junjie L. (2016) “Building energy-consumption status worldwide and the state-of-the-art technologies for zero-energy buildings during the past decade”. *Energy and Buildings*, 2016 (128), p. 1-58. Retrieved from https://www.researchgate.net/publication/304712030_Building_energy-consumption_status_worldwide_and_the_state-of-the-art_technologies_for_zero-energy_buildings_during_the_past_decade

Yin, R. K. (1994). *Case study research: Design and methods* (2nd ed.). Thousand Oaks, CA: Sage. Retrieved from http://www.madeira-edu.pt/LinkClick.aspx?fileticket=Fgm4GJWVTRs%3D&tabid=3004