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Cost optimality analysis of nearly-zero energy buildings in different climates.

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Abstract

The effects of climate change on human life in the modern era are extremely significant. Every citizen in the European Union is contributing, in their own way, to the creation of a more environmentally friendly and sustainable community with fewer emissions of greenhouse gases every day. The manufacturing and construction industries are jointly responsible for 36% of Europe's and 38% of the world's CO2 emissions. In addition, the European Union (EU) is in the process of formulating its energy policies by placing an emphasis on the energy use of the building stock. They apply directives to each Member State that are referred to as Energy Performance of Building Directives (EPBD), so that each state can define its own legislation regarding the performance of buildings. The goal of Nearly Zero Energy Buildings (NZEB) is presented, as a cost-optimal methodology that proposes reducing the amount of primary energy consumed.

This thesis examines single-family residential houses that is already in existence in the building stock of the Member States of the European Union. The research initiates in Turin, Italy, which is located in an area that has a humid subtropical climate and medditerranean. With its pre-defined building components and system configurations, the very same house is re-implemented in a software program called "Edilclima." A monthly time step is used in the calculation of the house's consumption of non-renewable primary energy using the UNI/TS 11300 standard. In addition, the total cost of the home was determined by employing the EN15459 cost optimality calculation standard over a period of fifty years. This was done in order to calculate the global cost. Following that, particular refurbishment scenarios were selected for the building envelope and system measures, and the process was then carried out once again. There were a total of six distinct building envelope configurations, each of which was combined with one of three distinct generation systems. Additionally, these situations were combined with four various PV systems to produce a total of 72 unique scenarios. After sorting the findings according to whether or not they meet the criteria for an NZEB, the cost-effective option for that particular environment is selected. The study is taken to an even deeper level by switching the climate zone to Sweden and Denmark which results in the generation of two more sets of scenarios, bringing the total number of possible cost-optimal solutions to 216.

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1. Normative Framework

The recognition that the climate is changing was the impetus for beginning discussions regarding the consumption of energy on a worldwide scale. At the close of the 20th century, it became abundantly evident that a different approach to the expansion of the industrial sector was going to have to be taken. The first step toward committing the developed countries and industrialized economies in transition to limiting their usage of greenhouse gas (GSG) emissions was the signing of the Kyoto protocol in 1997. This was the first stage. The protocol is credited with laying the groundwork for all of the laws and regulations that the European Union (EU) currently acknowledges as valid. It only applied to the developed countries because it was believed that these nations were to fault for the majority of the factors contributing to the rising levels of GHG emissions. As a continuation of the Kyoto Protocol, the Doha Amendment was signed into law in the year 2012. This time, 147 parties signed the protocol, and it is expected to go into effect sometime after the end of 2020. The Paris Agreement, which was reached in December of 2015, is yet another significant pact that needs to be noted. 197 nations have agreed to participate in this legally binding international pact on climate change. The temperature increase should be kept below 2 degrees Celsius, and if possible, the target should be kept below 1.5 degrees Celsius[1]. The pact requires countries to take immediate action in order to create a world free of climate change by the year 2050. This was the first legally binding pact for all 197 countries involved to cooperate toward the same objective. The 2030 Agenda for Sustainable Development was approved by every single member state of the United Nations in 2015. The agenda laid out a road that may lead to wealth and peace for both people and the world as a whole. It was revealed that there will be 17 Sustainable Development Goals (SDGs)[2]. The goals were developed with all of the world's challenges in mind, including inequality in education and health care, poverty, and climate change. A fresh report on the Sustainable Development Goals (SDGs) is released on an annual basis. This thesis paper also takes goals 7, 9, 11, 12, and 13 into consideration. In the next parts, we will delve deeper into the aims and explore them.

1.1 The European Directives

According to the Energy Performance Building Directives (EPBD), member states are required to make certain that after the 31st of December in 2018 and the 12th of December in 2020, respectively, all new buildings, as well as new buildings occupied and owned by the public, as well as new buildings occupied and owned by public authorities are defined as NZEBs. The EPBD evaluates the cost-optimal levels connected to the development of energy performance criteria in buildings. These requirements are to be met by buildings.[3]

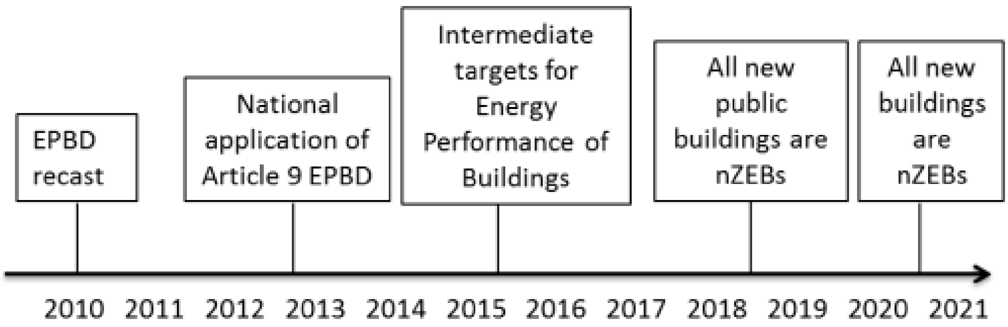

Figure 1.1.1 Evolution timeline of the EPBD [4]

36% of all CO2 emissions in the EU are caused by commercial and residential structures [5]. If sustainable energy policies and supporting programs successfully ensure reductions in emissions from the building sector, buildings have the potential to reduce carbon dioxide emissions by the greatest amount[6]. By 2050, the Union intends to have a decarbonized, competitive, secure, and sustainable energy system. By then, it should be technically feasible to cut world energy consumption for space heating and cooling in the existing building stock by 70% while also reducing the consumption by 30% and the corresponding emissions by about 40%. In relation to 2005 numbers, this situation is predicted.

The member states must find a solution between lowering the carbon usage for existing energy supplies and reducing the total energy use. To this end, the Member States and investors need a clear sight to direct their policies and investment plans. This vision should include suggestive national benchmarks and steps for energy efficiency in order to achieve the short-term (2030), mid-term (2040), and long-term (2050) objectives.

In accordance with the commitments made in Kyoto and in anticipation of the Paris agreement, as well as with the objective of maintaining economic development and competitiveness throughout the energy transition, the leaders of the EU took note in 2011 of the European Commission's Communication on the De-carbonization Roadmap, which a goal, set for 2050, of cutting GHG emissions by 80 percent from 1990 levels. This was done in comparison to the levels seen in 1990. The figure below shows the trajectory of the GHGs in order to reach the decarbonization goal by 2050.

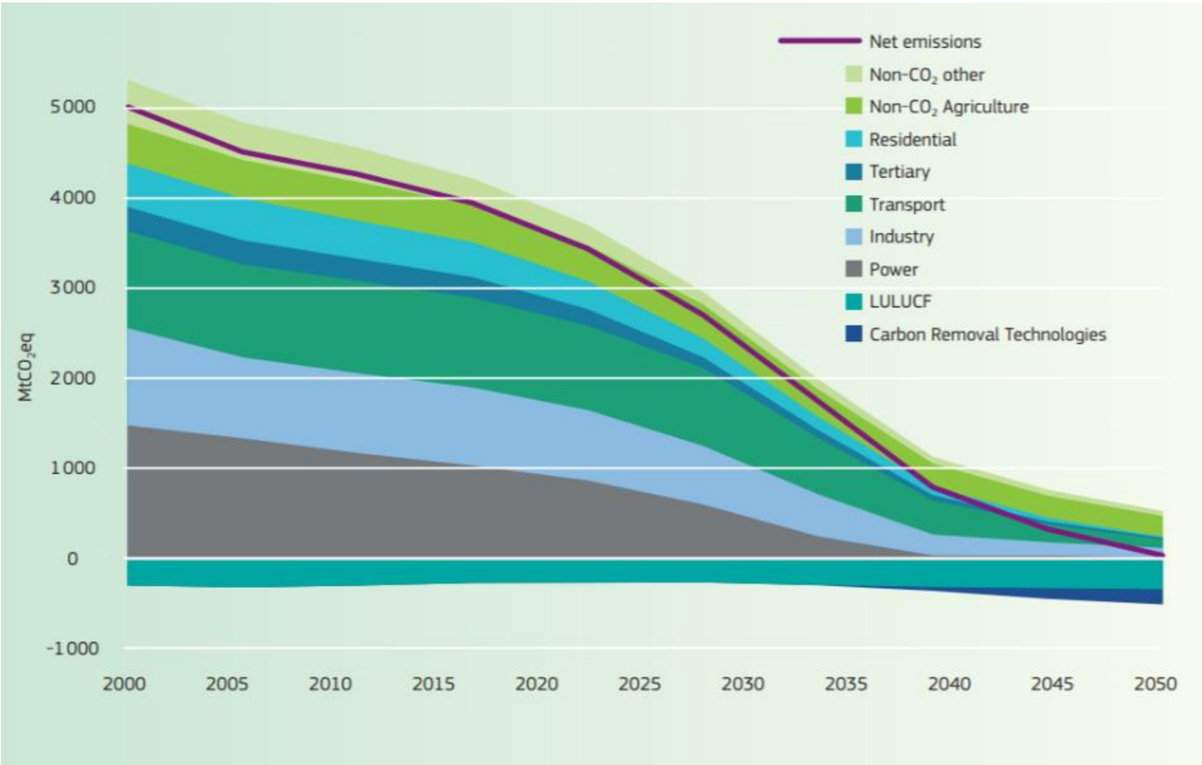

Figure 1.1.2The Trajectory of GHGs to reach the decarbonization goal [7]

Legislative recommendations for reducing greenhouse emissions were developed and submitted in July 2015 and July 2016, based on the European Council Conclusions in 2014.

The Clean Energy Package, which was introduced in November 2016 and contains parliamentary proposals for the expansion of efficiency, as well as the implementation of varying forms of renewable energy into the electricity market.The following goals for 2030 are included in the package:

- binding reduction in greenhouse gas emissions of at least 40% from 1990 levels by 2030
- at least 27% of EU energy consumption coming from renewable sources.
- At EU level, an increase in energy efficiency of at least 27% .

The consideration demonstrates that the Member States are working toward achieving a cost-effective balance between a supply of energy that has been decarbonized and a reduction in the overall energy consumption of buildings. This implies a massive step towards a nearly zero energy level, where "nearly" means that the definition is dependent on the cost. This leads to dependency in the cost of non-renewable systems and the cost to reduce the building’s energy use.

The United States efforts to decarbonize its building stock are strengthened by the 2015 Paris Climate Agreement, which was reached after the COP 21 Conference of the Parties to the United Nations Framework Convention on Climate Change. The achievement of the Union's energy and climate goals is tied to the Union's attempts to remodel its buildings by giving priority to energy efficiency and taking into consideration the deployment of renewables. Considering that almost 50% of the Union's final consumption is used for heating and cooling, of which 80% is used in buildings.

The Clean Energy Package mandates that the Member States develop comprehensive plans for energy consumption and the environment, with the following items on the list serving as the primary goals:

- decarbonization
- security in energy
- internal market
- competitiveness and research

Submitting a progress report became necessary by each member every 2 years.

In order to ensure that all buildings, both new and old, fulfill minimum energy efficiency requirements, the EPBD requires that Member States adopt the appropriate measures.. Encouraging each member state to install highly efficient systems that are technically and economically feasible. These systems must address to improve the indoor air quality, safety against possible fire breakthrough and earthquakes. [3]

The EPBD does not provide standardized requirements for NZEBs because it recognizes that climatic and local conditions can vary significantly from place to place. The Directive requires the Member States to plan their very high-performance buildings with mostly renewables. The installations must be in alignment with the local characteristics and national legislation. This is to ensure that the Directive is implemented in a manner that is consistent with the requirements of the Directive.

The EPBD Recast, which introduced guidelines on a "whole building" approach, marked an important turning point in the design of buildings. If an approach is preferred for retrofit actions, a performance-based approach based on overall results is preferred for renovations and brand-new building projects. Thus, it is essential to switch from a framework that typically only considers the peak allowable U-value to a more comprehensive one that also takes into account technical system requirements in the case of brand-new constructions. As a result, finding the best match between the HVAC configuration and the envelope features in light of the various climatic conditions is essential today to reduce energy consumption.

The system boundary is altered in accordance with the EPBD requirements and used along with on-site renewable energy production. According to the demand for energy, usage of energy, imported and exported energy. These boundaries are shown in the figure below.

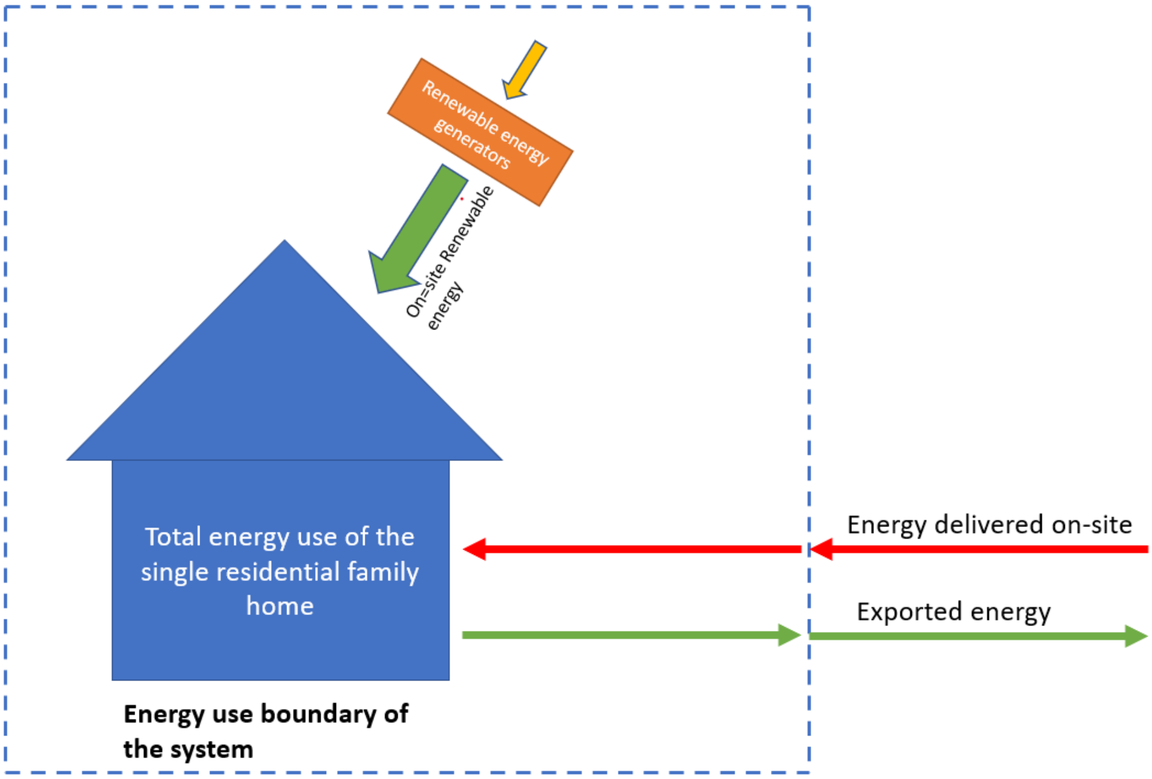

Figure 1.1.3 Boundary of the system

The figure above shows a brief energy balance of a residential family home. The term "energy used" includes all conversions and losses of the energy generated.

The total energy required to meet a building's needs, which primarily include lighting, appliances, domestic hot water (DHW), heating, cooling, and ventilation, is known as the "energy demand" The balance must take into account both solar and internal heat gains.

The generation of electricity that can be produced either on-site or off-site, as well as energy for space heating and cooling, is referred to as "Energy produced by renewables" This could be any plant nearby.

Locally produced electricity, fuels, district heating, and cooling systems are all possible sources of energy.

The Availability is contingent on the type of on-site energy source which could be sun, wind or maybe even water, renewable generation options can be either on-site or off-site. Starting with low-energy technologies, the on-site primary energy demand is decreased. This decrement could be achieved through high-performance insulation, daylighting, a highly efficient HVAC system and natural ventilation. Options for on-site supply that make use of RES that are located within the building's surroundings or on top of the building[8]. Examples of this could be a solar thermal system, Photovoltaics (PV). Off-site generation options use RES that is available off-site to produce energy locally. Biomass could be an appropriate example.

Regarding balance type, Renewable energy generation in off-grid zero energy buildings is required to balance out energy consumption. There are two possible balances in grid-connected buildings: energy use and renewable energy production, or energy sold to the grid and bought from the grid. The main distinction is when it is used: the first is better suited for building design, whereas the other is more appropriate for monitoring because it balances energy input and output..

The application of NZEBs is closely related to the evaluation of cost-effectiveness and highly effective systems in buildings. The EPBD suggests the Member States to make certain that the measures taken to enhance energy performance include all pertinent components and technical systems rather than just the building envelope. Insofar as it is technically and financially feasible, Member States shall inspire the replacement or upgrade of technical building systems when buildings undergo significant renovations. Using technical building systems is essential for saving money and maintaining or improving the quality of the indoor environment. In order to assess whether or not the renovation was successful, it is recommended by the directive that Energy Performance Certificates (EPCs) be compared before and after the work was done, or that thorough energy audits be conducted. The directive prioritizes the quality and legality of energy retrofits.

1.1.1 The most recent EPBD recast-The Fit For 55 Package

As a component of the 'Fit for 55' legislative package, the European Commission approved a significant update to the Energy Performance of Buildings Directive (EPBD) on December 2021. This is known as the final recast up to date. The latest recast includes a number of proposed legislations to meet the new European Union objective of a minimum reduction of 55 percent in greenhouse gas (GHG) emissions by the year 2030 in comparison to 1990 levels. It is an essential component of the European Green Deal, which has as its overarching goal the positioning of the EU firmly on the road leading to climate neutrality by the year 2050 and net zero greenhouse gas emissions by that year.

The primary goals of the recast EPBD are to significantly cut greenhouse gas emissions and final energy consumption in the building sector by the year 2030 and to create a far-reaching plan to make the European Union's building stock carbon neutral by 2050. Both of these goals are intended to be accomplished. To this end, the revised EPBD seeks to quicken the pace at which energy-efficient buildings are renovated, enhance the availability of data regarding buildings' energy efficiency and environmental impact, ensure that all newly constructed structures in the European Union adhere to stringent "zero emission building" standards, and guarantee that all structures constructed or renovated after 2020 comply with the latest climate neutrality prerequisites. These goals can be summarized as follows: speed up and deepen the renovation of energy-efficient buildings; enhance data on energy performance and sustainability. [9]

The critical changes on the EPBD recast are listed below;

- *"The recast EPBD introduces a* ***new definition of 'zero emissions building'****. This is to be understood as a building with very high energy performance in line with the energy efficiency first principle, where the very low amount of energy required is fully covered by energy from the building itself or from locally produced renewables. The zero emissions building would replace nearly Zero Energy Buildings (nZEB) as the* ***standard for all new buildings from 2027 and for all renovated buildings from 2030****. The technical requirements for zero emissions buildings are set out in Annex III."*
- *"The life-cycle* ***Global Warming Potential*** *(GWP) of all new buildings would need to be calculated from 2030, according to a formula set out in Annex III. This GWP calculation would apply to all large new buildings (>2000 square metres) from 2027 onwards. In addition to energy performance, all new buildings would need to ensure healthy indoor climate conditions; be able to adapt to climate change; address fire safety risks; address risks related to intense seismic activity; address carbon removals associated with carbon storage in/on buildings; and be accessible for disabled persons."*
- *"The recast EPBD would oblige future buildings to meet EU-wide* ***minimum energy performance standards****, with Member States free to set more ambitious performance standards if they so choose."*[9]

Although the recast hasn't been implemented just yet, it will place significant obligations on the Member States.

There is no doubt that switching to zero-emission buildings will help member states achieve their goals more rapidly. For the reason that it eliminates distractions and addresses the core issue. A significant modification brought about by the recast is the method by which the global warming potential is determined. Each structure must not only be high-performing and emission-free on that date but must also be capable of maintaining their quality for many years to come. The recast also encourages countries to set higher standards for themselves than the mandatory minimums.

1.2 The Regulations

EPBD establishes objectives for energy performance but leaves regulation to individual member states. Due to Europe's size and the wide range of climates found there, it would be unfair to impose uniform rules on the bloc's member states. This chapter will examine the regulations that will be defined in this thesis work for each member state. In this case, it was decided that Italy, Denmark, and Sweden would be involved. In Section 4, we'll dive deeper into the reasoning behind these regions' selection process.

1.2.1 The Italian Regulation

The minimum energy requirements and energy demands of buildings in Italy are set forth in a ministerial decree issued on June 26, 2015, in accordance with the 2010 EPBD recast. There are two parts to the decree. The baseline for energy efficiency during construction and post-completion certification. Primary energy consumption is where the two halves diverge most sharply. In contrast to the minimum energy performance phase, which takes both renewable and non-renewable sources of energy into account, the latter phase only considers the latter when calculating energy consumption. The figure below explains the differentiation in a clearer manner.

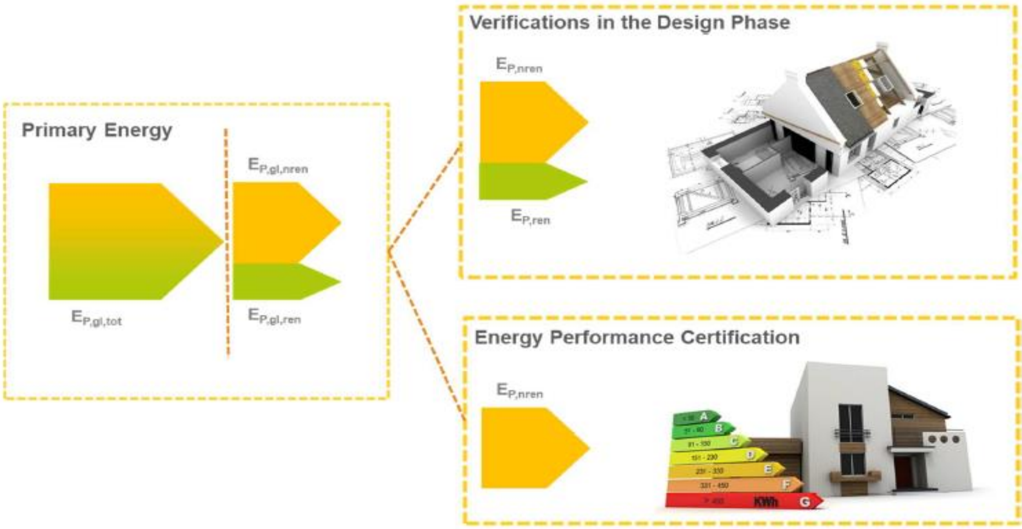

Figure 1.2.1 Portion of primary energy considered in the design phase and the certification phase [10]

It is important to note that in Italy, the Regions have been delegated the expertise to pass legislation on energy efficiency. As a result, in many cases, there are laws and commitments that are distinct from the national ones, but they still serve as a basic reference. This is something that should be taken into consideration.

The individual regions decide how to calculate the energy performance of a building, both for the verifications that take place during the design phase and for the energy certification that the building receives at the end of the process.

All of them, on the other hand, have complied with the following technical standards:

- *UNI/TS 11300 - 1 – Calculation of the building's thermal energy needs for summer and winter air conditioning*
- *UNI/TS 11300 – 2 Calculation of primary energy needs for winter air conditioning, hot sanitary water production, ventilation, and lighting in non-residential buildings*
- *UNI/TS 11300 – 3 Calculation of primary energy requirements and yields for summer air conditioning*

- *UNI/TS 11300 – 4 Use of renewable sources and other generation methods for winter air conditioning and hot sanitary water production*
- *UNI/TS 11300 – 5 Calculation of primary energy and the share of energy from renewable sources*
- *UNI/TS 11300 – 6 Calculation of energy requirements for lifts and escalators*

The calculations that are going to take place in this thesis work will be done with software that uses the standard that was just mentioned. Edilclima is the name of the software, and more information about it will be provided in section 3 of this thesis work.

The regulations split the design phase requirements up into three distinct categories. Both Energy requalification and second-level renovations of existing buildings fall under the first and second category respectively. Newly constructed and first-level renovations have the final and most stringent requirements. Given that the house under investigation in this study is not a pre-existing structure, this point is particularly significant. Thus, the third-party rules and regulations will be considered.

1.2.1.1 Regulations for New Construction and First-level Renovation of Existing Buildings

The same Decree that defines these building interventions also defines the NZEB3 for which it does not fix any absolute energy performance limit but gives the indication that the designer must implement and verify immediately the recognition of permissible limits for the thermo-physical characteristics and for the efficiency of the building from 2021.

1. The *average global transmission heat exchange coefficient per unit of building surface must be less than the maximum allowed global transmission heat exchange coefficient per unit of the building surface. These values are defined by each climate zone on the decree.*

2. *The ratio of the solar area used in the building and the useful surface area is limited to a value by the decree depending on the use of the building such as residential or commercial.*
3. *The thermal performance index useful for heating and cooling the building must be less than a limit value depending on the size of the building*
4. *The overall energy performance index is defined by the total primary energy requirements from the heating. Domestic hot water and ventilation.*
5. *There is a limit for the seasonal efficiency of heating, domestic hot water and ventilation depending on the region of Italy.*
6. *50% of the energy required for domestic hot water operation must be from renewable energy sources.*
7. *50% of the energy requirement for heating, cooling and domestic hot water must be from renewable energy sources.*
8. *There is a minimum renewable energy source installation of each home depending the surface area of the building.*

1.2.1.2 The Energy Performance Certification

When determining whether or not a building meets the criteria for NZEB status, only primary energy sources that are not renewable are taken into account for certification purposes. A global index for nonrenewable primary energy is calculated by adding the amounts of nonrenewable primary energy needed for winter heating and air conditioning, domestic hot water, winter cooling and air conditioning, ventilation, artificial lighting, and transportation of people and goods. This index is then divided by the reference building value, an amount established by ordinance and calculated using the square footage of the structure in question. that characterizes the structure. The following chart graphically illustrates the categorization.

	Classe A4	$\leq$ 0,40 $EP_{gl,nren,rif,standard\ (2019/21)}$
0,40 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	**Classe A3**	$\leq$ 0,60 $EP_{gl,nren,rif,standard\ (2019/21)}$
0,60 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	**Classe A2**	$\leq$ 0,80 $EP_{gl,nren,rif,standard\ (2019/21)}$
0,80 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	**Classe A1**	$\leq$ 1,00 $EP_{gl,nren,rif,standard\ (2019/21)}$
1,00 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	**Classe B**	$\leq$ 1,20 $EP_{gl,nren,rif,standard\ (2019/21)}$
1,20 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	**Classe C**	$\leq$ 1,50 $EP_{gl,nren,rif,standard\ (2019/21)}$
1,50 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	**Classe D**	$\leq$ 2,00 $EP_{gl,nren,rif,standard\ (2019/21)}$
2,00 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	**Classe E**	$\leq$ 2,60 $EP_{gl,nren,rif,standard\ (2019/21)}$
2,60 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	**Classe F**	$\leq$ 3,50 $EP_{gl,nren,rif,standard\ (2019/21)}$
	Classe G	> 3,50 $EP_{gl,nren,rif,standard\ (2019/21)}$

Figure 1.2.2 Building classification scale based on the global non-renewable energy performance index [10]

The decree also includes a section on total values. Because Italy is in such a geographically and climatically varied region, the Italian government has made it clear that it will never attempt to impose a uniform standard. However, after further projects, it is determined that a 4-unit single-family home's primary energy demand cannot exceed 90 kWh/m2.

It would be unrealistic to assume that the technical systems being installed could solely determine the building's energy requirements. Construction materials are also vitally important for a finished structure. The EPBD specifies maximum allowable thermal transmittance values for all building elements. Below is a visual representation of the range of thermal transmittance values for a given region and component.

Elements/Components	Validity period	Thermal Transmittance U [W/m2K]				
		Climatic zone				
		A and B	C	D	E	F
Walls	**From 2021**	**0.38**	**0.32**	**0.28**	**0.24**	**0.22**
Roofs	**From 2021**	**0.34**	**0.34**	**0.24**	**0.22**	**0.20**
Floors	**From 2021**	**0.42**	**0.36**	**0.28**	**0.26**	**0.24**
Doors, windows, and shutter boxes	**From 2021**	**3**	**2.20**	**1.80**	**1.40**	**1.10**
Indoor Partitions	**From 2021**	**0.80**	**0.80**	**0.80**	**0.80**	**0.80**

Table 1.2-1 Limit values for building components in Italy from the EPBD [3]

1.2.2 The Swedish Regulation

The energy performance regulations in Sweden, in contrast to those in Italy, are mainly based on measured delivered energy. These regulations include energy performance requirements for heating, cooling, domestic hot water, and other general uses of the building. New buildings are required to be constructed in accordance with the regulations (BFS 2011:6) in such a way that limits the amount of energy that is used. This can be accomplished through the use of heating and cooling systems that are efficient, as well as the use of electricity that is efficient.[11]

Existing structures will also be affected by the new guideline in certain way. These brand-new guidelines are only put into effect when there is construction or remodeling done inside the structure. As an illustration, there are no rules that have been applied to a window that has already been installed. However, once the window has been replaced, it is important for it to conform to the criteria outlined in the table below. It is also important to point out that the values that are displayed below are the same as the standards for structures that have recently been completed. Therefore, the steps for the refurbishment are handled as though a new structure was going to be constructed.

The primary focus of EPBD and Italian regulations is on cutting back on energy consumption. Maximum allowable energy use for Sweden's climate zone 3, which is also the most populous, is shown in the table below. In climate condition 3, the thesis work will be done as well. Sweden requires

	U-value [W/m²/K]
Residential Buildings	**0.4**
Non-residential Buildings	**0.6**
Buildings < 50m2	**0.33**

Table 1.2-2Maximum average U-value in Sweden for newly constructed buildings and renovations [11]

. When deciding on regulatory requirements, Sweden takes into account the mean U-value of a building. Meanwhile, the regulations in Italy had specific requirements for each part of the structure. The table below shows the requirements for the building’s average thermal transmittance.

Despite the fact that the measured delivered energy use restrictions of electrically heated single-family dwellings are 55 kWh/m2a, there are several exceptions. The maximum allowed for residences that are not heated by electricity is 90 kWh/m2a.

1.2.3 The Danish Regulation

To implement Directive 2002/91/EC, the Danish government adopted the current energy performance requirement techniques for new and existing residential and non-residential buildings in 2006.[12]

Denmark is one of the Member States that is in the lead when it comes to making regulations to reduce the amount of energy that is consumed. Since the first regulation was passed in 1961, there has been a significant decrease in the amount of energy that is being consumed by newly constructed buildings. In addition, beginning in the year 2006, they began aligning the regulations with those of the EPBD.

In its pursuit of renewable energy, Denmark has set some extremely lofty targets for itself. They have set the year 2050 as their target for complete independence from fossil fuels. In addition to this, they want to run all of their public transportation on renewable energy sources by the same year. They plan to use only renewable sources to generate all of the building's electricity and heating by the year 2035. In addition, these laws for zero-energy buildings will become mandatory for all new construction by the year 2050.[13]

In 2016, the "Low-energy Class 2015," which had been optional in the past, was made definitive and obligatory, and it was given the name "Danish Building Regulation 2015."Or also known as BR2015. This standard establishes minimum requirements for the energy performance of all brand-new building types. BR 2015 establishes requirements for a consensual low-energy class known as "Building Class 2020," in addition to the minimum standards. If everything goes according to plan, the voluntary class of 2020 will become the minimum requirement in the year 2020. This will be the final step in the implementation of the Energy Agreement of 2008 in regard to the energy requirements of new buildings. [12]

The BR2015 establishes a value for the minimum energy performance that must be met by all different kinds of buildings in order for them to be eligible for the designation of NZEB. The "maximum allowed primary energy demand" of the building is what determines the performance of the building. The calculation of primary energy must always include renewables as an important component. Reduce the annual demand for primary energy by at least 25-kilowatt hours per square meter. This is a requirement for renewable energy sources.

When it comes to putting a cap on the amount of heat that can be lost through various building components, the BR2015 standard takes a methodical and specific approach. The u-value restrictions for each element are detailed further down the page.

All existing buildings	Changed use and extensions	Single component requirements for new / replaced parts	Holiday homes	Minimum requirements*
U-value requirements [W/m²K]				
External walls and basement walls towards ground	0.18	0.15	0.25	0.30
Slab on ground, etc.	0.10	0.10	0.15	0.20
Loft and roof constructions	0.12	0.12	0.15	0.20
Windows	-	1.80 (doors)	1.80	-
Roof windows	-	-	1.80	-
Thermal bridges [W/(m K)]				
Foundations	0.12	0.12	0.15	0.40/0.20
Joints between windows and walls	0.03	0.03	0.03	0.06
Joint between roof structure and windows in the roof	0.10	0.10	0,10	0.20
Minimum energy gain [kWh/m².year]				
Facade windows	-17	-17	-	-17
Roof windows	0	0	-	0

Table 1.2-3 Minimum requirements for renovation of building components in existing building in Denmark according to building type[12]

During the phase of designing the building and constructing the thesis work, the requirements of Italian, Swedish, and Danish regulations will be taken into consideration. The house will adhere to the standards of these parts of the world.

1.3 The NZEB Characterization

The boundary and the measurement system used to define a zero-energy building allow for multiple possible definitions. Depending on the aims of the project and the priorities of the person in charge of the designer and the building owner, alternative definitions may be more appropriate. When it comes to a building's finances, one common concern is the cost of utilities. The Department of Energy and similar agencies care about the country's aggregate energy consumption and focus primarily on mainly primary energy demand. The energy requirements of a building may pique the designer's interest in the site's energy consumption. Those who worry about climate change and air pollution from fossil fuel combustion and power plants may be seeking ways to reduce emissions. There are four common ways of defining "net zero energy," and they are: net zero site energy building, net zero source energy building, net zero cost building and net zero emissions building. [14]

Foregoes the use of any external sources of energy; instead, a **Net zero site energy** structure uses only those resources available on-site to energy itself. There is no alternative, far-off energy source that powers the structure. A photovoltaic (PV) array installed on the roof or a heat pump supplemented by another on-site energy source are examples of possible on-site generation systems. On-site measurements can be used to both implement and verify the site ZEB. All the power is generated on the premises, so it is immune to fluctuations in the power grid. When ZEB reaches a location, it promotes energy efficiency in buildings. Due to its inability to use natural gas, a large renewable energy system must be installed. There is no consideration for utilities prices.

When a home generates as much energy as it consumes from the grid, it is said to **have "net zero source" energy**. These are contributions to the effort from off-site. This is the initial form of energy used to supply the structure with power. Since on-site energy production and energy from the source each undergo a unique process, a primary energy factor must be taken into account during the conversion of total primary energy used. Using this definition, it is possible to include fuel type in the final energy calculation. It's an easier target and a better template for a national mandate. The resulting contamination, as defined by the site ZEB, is not considered. Trying to picture how much gas is used is pointless. Although the fuel utilized might have a greater effect on primary energy, the difference would be invisible after being transformed to a value comparable to that generated locally. Ultimately, governments make the call on the site-to-source conversion variables, and these factors may change as the economy and the necessity dictate.

Money made from selling excess energy back to the grid must match the sum paid for all of the energy used within a building for it to be considered "net zero cost". ZEB costs may be easily quantified and confirmed via regular electricity bill checks. However, its value might change dramatically over time, making its tracking challenging.

The term "net zero emission buildings" refers to a level of energy efficiency in which the amount of energy generated from renewable sources and the amount generated from sources that emit greenhouse gases are equal. The requirements of the most recent EPBD have migrated toward this definition of the Fit For 55 package. This definition of green power is the most appropriate in this instance. It classifies different forms of energy according to the amount of pollution they produce, and it's not a particularly challenging target. The major problem, the choice of emission variables, is again politically oriented. Governments must make responsible decisions when selecting emission parameters. On the other hand, it's quite easy to use for partisan gain.

As was just discussed, the concept of what constitutes a "zero energy building" varies considerably from one nation to the next around the globe. While the European Union (EU) has its own EPBD and its modifications depending on each member state, such as Denmark's (BR2015) and Germany's (EffizienhausPlus), the EPBD is defined as a net zero source building in both of those countries. There is a zero-carbon standard directive in place in the UK and Norway, and it defines buildings in terms of their ability to produce net zero emissions. While adversely, the USA defines its NZEB by the net zero site building approach. The following table provides a summary of the factors that are being considered by various countries when defining an NZEB. [13]

Country	Definition	Metric			System Boundary		Min. requirements	
		Primary (source) energy	Final (site) energy	Carbon emissions	On-site	Off-site	Energy efficiency	Renewables share
EU	EPBD	X			X	X	X	X
Germany	Effizienhaus Plus	X			X	X	X	X
Denmark	BR10	X			X	X	X	
Switzerland	Minergie-A	X			X		X	
Norway	Zero-emission building			X	X	X	X	X
UK	Zero-carbon standard			X	X	X	X	X
USA	Zero-Net-Energy Building		X		x	X	X	

Table 1.3-1 Zero energy building definitions by leading world regions [13]

1.4 The Sustainable Development Goals

Sustainable Development Goal 7: Affordable and clean energy. Guarantees that all people have access to energy that is both affordable and reliable while also being up to date. The purpose of this goal is to raise the amount of energy that is generated from renewable sources, as well as to raise the proportion of renewable sources in total energy consumption. In the work for the thesis, an explanation will be provided of the ways in which the use of renewable energy sources will be beneficial, both financially and in terms of the amount of energy they provide, in the future. It will explain how and why the houses should install renewable systems in their homes, and it will encourage them to work towards achieving the goal that has been set.

Sustainable Development Goal 9: Industry, Innovation, and Infrastructure. Develop infrastructure that is resistant to damage, encourage an inclusive and sustainable industrialization, and encourage innovative thinking. To accomplish this goal, the construction of the newly designed infrastructures must be of a high quality. This includes the design of the building's heating systems as well as the facades of the building. The consistency and dependability of the product's quality are both absolutely essential. The work for the thesis will demonstrate how a heating and cooling system with higher performance or an envelope with higher performance will have a significant impact on the energy goals. Which will demonstrate how significant the ninth goal really is.

Sustainable Development Goal 11: Sustainable Cities and Communities. Make cities and other human settlements more welcoming, secure, resilient, and environmentally friendly. The number of cities that put together comprehensive plans and policies to adapt to the effects of climate change should, ultimately, be increased as a priority. Utilizing high-performance renewable systems and increasing awareness of the significance of the NZEB target are two ways in which the work done for the thesis contributes to this goal. Additionally, it complies with the policies of the EPBD.

Sustainable Development Goal 12: Responsible consumption. Guarantee sustainable patterns of consumption and production. The consumption of fossil fuels is going to be cut back and made more efficient as part of this goal. Additionally, it necessitates that nations improve their toolkits and technological capacities in order to promote more sustainable forms of production and consumption. The thesis will provide an overview of the most advanced technologies for a sustainable environment, and as a result, it contributes directly **to** the achievement of this objective.

Sustainable Development Goal 13: Climate Action. It is imperative that immediate action be taken to fight climate change and the effects of it. aims to incorporate strategies and policies designed to address climate change at the national level. And to raise awareness about the significance of taking action regarding climate change. During the process of designing the single-family dwelling and the energy generation systems within it, the work for the thesis will take into consideration the national policies. To measure how effectively the plans on global warming are being implemented, this will be a helpful indicator.

2. Literature Review

This section of the thesis introduces the idea of a Cost Optimality Analysis (COA). It further summarizes, with analysis, of the research that was done on cost optimality analysis

Although it is now theoretically possible to achieve very high energy performance in buildings and there are numerous instances of NZEB building designs that have been successful throughout Europe, these structures are still not cost-effective, and this is the primary obstacle to their widespread deployment. To advance the national minimum energy performance criteria, cost optimization has been adopted toward achieving the NZEB targets that are fiscally viable.

The EPBD recast mentioned in the previous chapter also includes the Cost Optimal Analysis. Regarding the design of high-energy performance buildings and the evaluation of their performance, this serves as the normative reference for the EU. The EPBD in 2010 contains the following quote for each Member State (MS) "must ensure that minimum energy performance requirements are set with a view of achieving at least cost-optimal levels". The COA was introduced to encourage each MS to set their energy requirements to reach the necessary cost-optimal levels. It also advises them to apply new policies and implement policies that would enable them to lean towards net zero energy because there is no single definition for an NZEB, and each MS must define the performance levels for their own NZEB as mentioned on Section 1 of this thesis work.

The first step when commencing the Cost Optimality Analysis is to define a reference building. The reference building must be compliant with the regulations for each MS. The reference building is defined in the 4^{th} section of this thesis work.

The second step is the selection of energy efficiency measures. The outlined measures should include renewable options that are technically and economically feasible [15] and may have an impact on a building's principal energy demand, as well as high-efficiency alternative system solutions. The evaluated EEMs must comply to the current minimum performance standards.

To increase the number of measurements taken into account in the computations, creative solutions built on existing MS experiences are encouraged.

The third step is to assess the energy performance of the sized system. The definition of the building's total final energy demand, the calculation of the energy generated by the system, the energy used by the building out from the generated, and the primary energy use are all steps in the energy performance assessment. The EPBD merely demands that calculations be carried out in accordance with national standards that have been harmonized with European Standards.

The EN ISO 13790 standard should be used to evaluate the energy requirements for heating and cooling. In addition, the guidelines advise using a dynamic method to complete calculations rather than a quasi-steady one.

The fourth step is to proceed with the global cost calculations. The goal of the EPBD recast is to analyze the entire lifecycle while defining cost-effective levels. All energy-related lifespan costs, not just the typically taken into account investment cost, should be addressed in the cost evaluation. The economic assessment of the energy renovation methods was calculated using a global approach for the cost calculation in order to achieve this goal. The EN 15459 standard is applied when performing cost calculations. It's crucial to remember that the total cost only accounts for expenses linked to energy. As a result, the idea of global cost as it was intended in the EBPD recast does not comply with a total life cycle estimation. It also takes into account the cost created by environmental damage.

Finally, the process yields a cost-optimal graph, as shown in Figure 2, where the primary energy use of the building is on the horizontal axis and the overall cost is on the vertical axis.
The graph is normally a curve with specific points that underline the necessary scenario. The shape of the curve is irrelevant but the coordinate of the points are important for the study. The point with the lowest value on this graph is referred as the cost-optimum point, and the energy performance that corresponds to that point is the cost-optimal performance point.

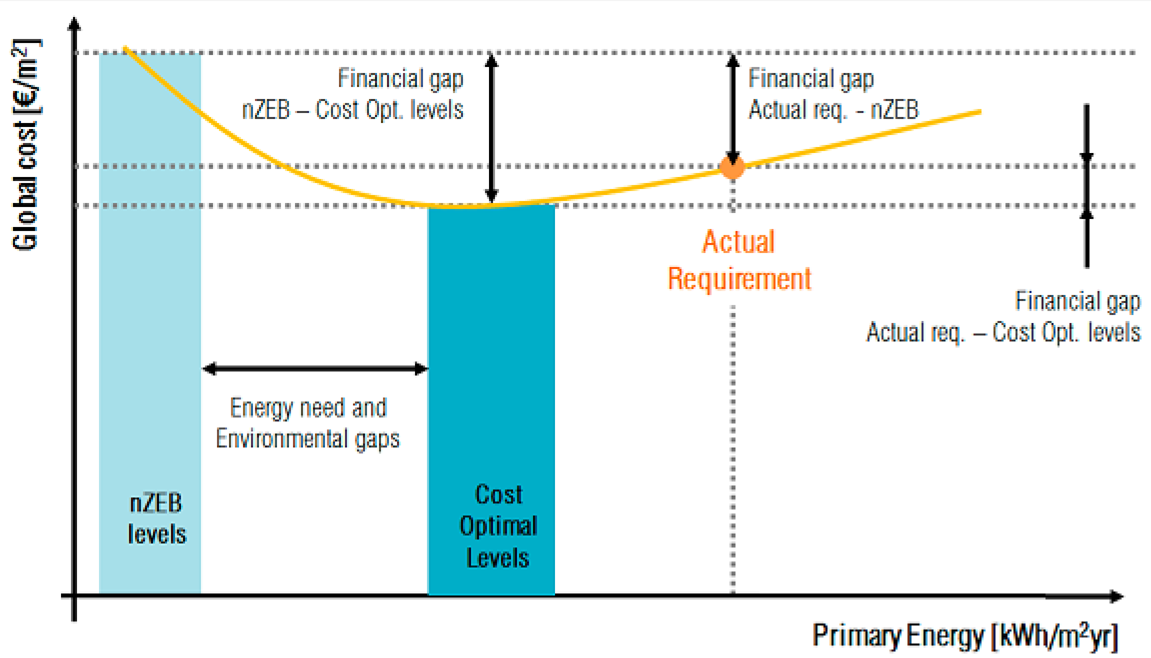

Figure 1.4.1Example of a primary energy vs global cost graph[15]

2.1 The Global Cost Calculation Method

[16]To carry out this procedure, one must first determine a net present value for each of the expenditures that will be incurred over a certain time period. It also covers the expenses of components that have longer lives, whereas components that have shorter lifetimes are replaced by ones that have longer lifespan. The global cost formula is expressed below.

$$C_G(\tau) = C_I + \sum_j [\sum_{i=1}^{\tau} \left(C_{a,i}(j) x R_d(i)\right) - V_{f,\tau}(j)]$$

where;

$C_G(\tau)$ is the global cost from the initial year of calculation;

C_I is the sum of all investment costs;

$C_{a,i}(j)$ is the yearly cost for the chosen component j at the year i;

$V_{f,\tau}(j)$ is the final value of the chosen component j at the end of the calculation period;

$R_d(i)$ is the discount rate for the year i.

Since the methodology for calculating overall costs on a worldwide scale has already been discussed, there is a pressing need for more investigation into the subject of cost-effectiveness. This methodology is essential to making the conclusions of the thesis more clear. A significant amount of new research has been released in the time since the first casting for EPBD. These studies differ from one another in terms of the type of building (residential, non-residential, office, etc.), geographical location, construction components, technical system configurations, time step calculation differences, or different software approaches. . In this literature study, the primary attention will be placed on the application and the outcomes obtained when the aforementioned factors are altered from one another.[17]

2.2 The reference building

Before digging further into the process of cost-optimality analysis, it is vital to briefly discuss a concept known as reference building. This will prepare the reader for the subsequent discussion. When doing an analysis of this kind, the point of departure is the reference building. It is the least efficient and most straightforward method of construction. The member states of the EU currently use the reference buildings to decide on and compare the energy performances of their newly constructed buildings. This chapter will provide an overview of the many types of reference buildings as well as their respective definitions.

2.2.1 The Definition of a Reference Building

There is no single definition for a reference building. But the Annex III of the EPBD recast defines the reference buildings as "buildings characterized by and representative of their functionality and geographical location, including indoor and outdoor climate conditions".[18] The objective is to create a model that is representative of a typical structure when situated in a certain environment and utilized for a particular purpose, such as in a commercial or residential capacity. While this concept was in use, there were some experts who advocated for defining RBs in accordance with the average stochastic distribution of existing buildings. It was determined that this is not just unrealistic but also far too complicated. Additionally, the definition was split depending on whether pre-existing buildings or recently built ones were being evaluated. The goal of this research is to categorize the energy efficiency of different types of buildings. In order to propose an approach that is both efficient and economical, the EPBD mandates the definition of a reference building. In order to implement a specific amount of energy reduction, it is required to have an accurate representation of the national building stock. And finally, a comparison is made between this application and the prior reference structure. In order to comply with the EPBD, each member state is required to define at least two reference buildings for preexisting building structures. And one for recently constructed structures. The RBs can be broken down into the following categories: single-family residences, dwellings with multiple families, offices, and other non-residential buildings. In total, each and every MS is required to define a minimum of nine structures.

As soon as the RB has been defined, the next step is to generate it. The process of constructing the Reference building might be considered to be fairly complicated. There are many different temperature zones, architectural styles, and cultural traditions in Europe, all of which have an impact on how buildings are utilized. As a consequence of this, the process of building references is an extremely delicate subject. It can be challenging at times to track down the appropriate sources to use while defining the reference building. Therefore, academics typically prefer to compile their data from government stats.

The definition of the reference building includes four distinct characteristics. The shape of the structure is one of these factors to consider. It raises problems about the kind of building and the geometrical data associated with it. The second component is called the envelope, and it refers to the materials that are employed in the building's envelope as well as the thermophysical qualities of those materials. The third one is the system that serves as the generator for the heating, cooling, and domestic hot water systems. And last, there is the operation, which refers to the utilization of the components of the structure, such as the lighting or the equipment usage schedule. These characteristics can also be classified according to their age, region, and form.

2.2.2 Gathering the information on Reference Buildings

After determining what information is required for the study, the next step is to determine how to go about collecting that information. In order to analyze the data, Corgnati[18] has devised three distinct ways. The first thing to do is to construct an example reference structure from the ground up. This methodology is utilized in situations in which there is insufficient historical data to move on with the reference building design. To be able to apply this system, one needs to have extensive knowledge of both building construction and architectural design. Therefore, this strategy is the most difficult to implement. The second strategy involves selecting an actual building to use as a reference. This strategy indicates that the structure that will be created will most likely be comparable to a real building that occupies the same amount of space and experiences the same kind of weather. As a result, a genuine building serves as the basis for the reference building. This demands an understanding of the entire inventory of buildings. The final strategy is one that has been given the name "creating a theoretical reference building." The structure is designed using statistics and principles of commonality using this procedure. It does this by selecting materials and systems that have most likely been utilized in previous research and work.

The remarks made by Corgnati are depicted in a more understandable manner in the image that follows.

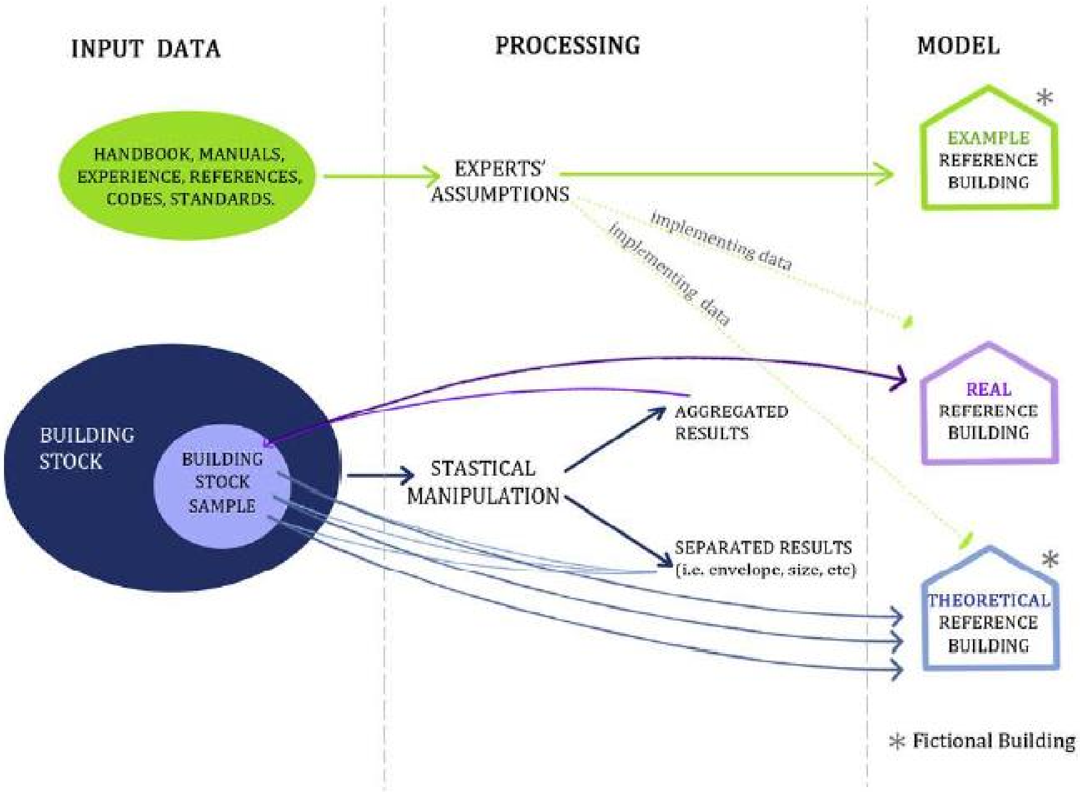

Figure 2.2.1 Differences of reference building models [18]

2.3 Analysis of selected articles from literature

2.3.1 Case Study 1

In the portion devoted to the literature review, it shall be looked more closely at a study that is comparable to the one that was used in the thesis work so that the reader may gain a deeper comprehension of both its methods and its findings. In the year 2015, Becchio and Fabrizio[19] conducted this following research. The purpose of the study is to identify nzeb options that provide the best value for single-family residences in Italy. In order to arrive at the most financially advantageous solution, a variety of energy efficiency measures (EEMs) were implemented. The modifications to the energy systems were the primary focus of the study, even though it did take into account the refurbishments that were made to the building's components. The calculations involving energy were carried out with the assistance of a dynamic simulation tool known as Energy Plus. When it comes to simulating the energy generation system of a building, this tool produces very detailed findings that can be viewed and analyzed. In addition, the EN15459 standard was utilized for the computation of the total cost of a single-family dwelling that was included in this study.

Calculations always begin with the definition of a reference building at the very beginning of the procedure. An existing structure in Turin, Italy serves as the basis for the reference building. The structure is a single-family dwelling and has a net floor area of 174 square meters as well as a net floor height of 2.7 meters. The building in question satisfies the requirements of the 2015 rules in terms of its u-values. The In the following table, you can observe both the initial thermal properties of the building as well as its refurbished features.

Envelope thermal insulation	EI 0 [W/m2K]	EI 1 [W/m2K]	EI 2 [W/m2K]	E3 [W/m2K]
External Wall	0.33	0.23	0.15	0.11
Roof	0.28	0.21	0.15	0.11
Floor	0.29	0.21	0.15	0.11
Windows	Ug/Uf/Uw 1.76/2.00/1.94	Ug/Uf/Uw 1.48/1.00/1.49	Ug/Uf/Uw 1.06/1.00/1.19	Ug/Uf/Uw 0.83/1.00/0.99
Average U-value	0.55	0.41	0.30	0.25

Table 2.3-1Thermal features of the Reference Building used in the study of Becchio[19]

In this context, "EI" refers to the various refurbishment scenarios that the building components may undergo. It was clear from looking at Table 2.3.1 that the u-values for each component had a progressive decrease over time. This resulted in an increase in the building's overall energy performance while simultaneously incurring a certain expense. In order to limit the amount of energy needed for space heating, we chose four distinct shading scenarios denoted by the letters SO1, S02, S03, and S04.The next step that Becchio took was to broaden the scope of the investigation by presenting four distinct technological system possibilities for space heating, cooling Domestic Hot water, and ventilation. They refer to these events as BTS, which stands for behind the scenes. Table 2.3.2 provides a visual representation of these potential outcomes.

Denomination	BTS 0	BTS 1	BTS 2	BTS 3
Heating	Gas condensing boiler with solar integration	Gas condensing boiler and air to water heat pump	Ground to water heat pump	Air to water heat pump
Cooling	Multi split air conditioner	Air to water reversible cycle heat pump	Ground to water reversible heat pump	Multi split air conditioner

Domestic Hot water (DHW)	Solar water heater	Solar water heater with auxiliary gas condensing boiler	Solar water heater with auxiliary electric resistance	Solar water heater with auxiliary electric resistance
Ventilation	-	Mechanical ventilation	Mechanical ventilation	Mechanical ventilation

Table 2.3-2Energy efficiency measures for building technical systems from Becchio[19]

The utilization of solar power was broken up into two distinct configurations for solar thermal systems and three distinct configurations for solar photovoltaic (PV) systems. The solar system configurations varied from three to four plates, while the PV configurations ranged from 1.6 kWp to 3.2 kWp to 6.3 kWp of total installed peak output. The solar photovoltaic system with 1.6 kWp covered an area of 11.9 m2, while the system with 3.2 kWp covered 23.8 m2, and the configuration with 6.3 kWp covered 47.9 m2. The are used was sufficient for the roof.

The findings concerning energy were discussed in terms of the overall primary energy. This fundamental energy is equal to the sum of the energy used for lighting, equipment, heating and cooling, domestic hot water, and ventilation. Additionally, primary energy factors derived from the Italian standard were employed in 2015. (1.092 for natural gas and 2.174 for electricity). The calculations for the overall cost included the expenses of investment, maintenance, and replacement in addition to the costs of energy. On the x-axis, the numbers were taken from the total primary energy, and on the y-axis, the global cost was plotted. The following graph was constructed in order to arrive at the most cost-effective computation.

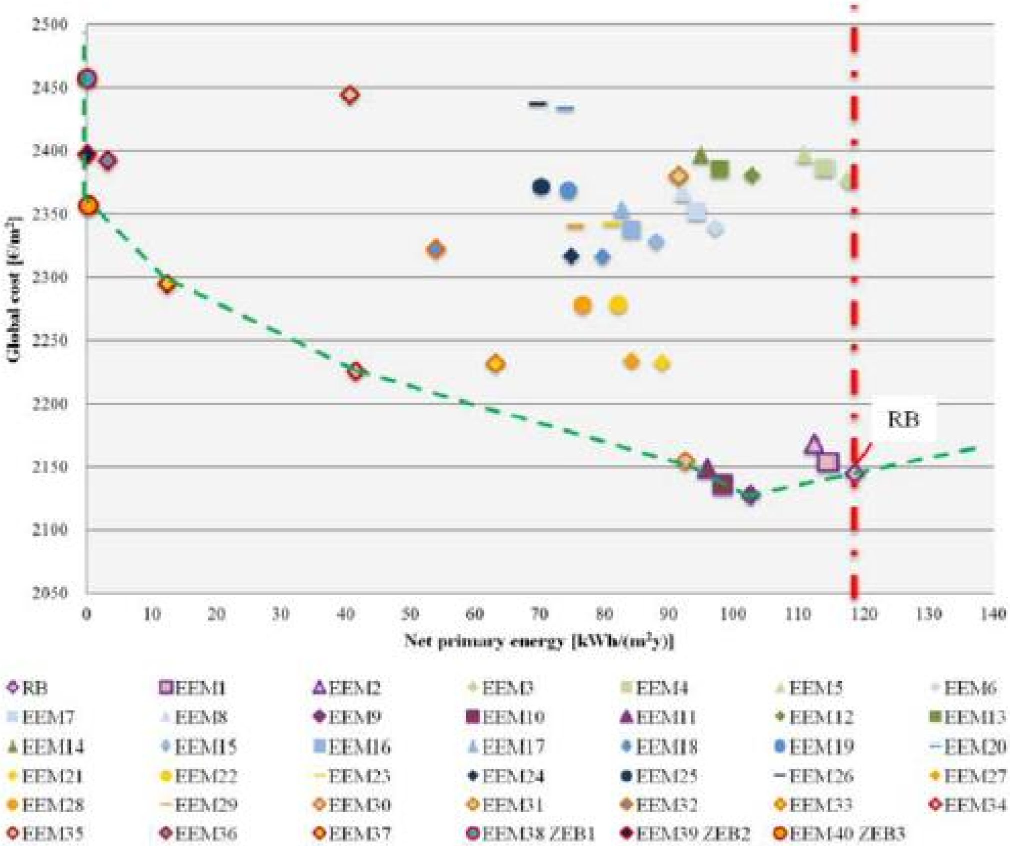

Figure 2.3.1Net primary energy vs Global Cost graph from the calculations of Becchio[19]

It is clear that the reference building, which is denoted by the letter RB, possesses the highest value for net primary energy. This demonstrates that it is the scenario with the lowest possible performance, which is very important for a cost-optimality analysis. The EEMs that are included in the purple (BTS0) and dark blue (BTS1) labels are the ones that have the worst performance in terms of the amount of primary energy that they consume. In point of fact, building systems such as BTS0, have lower global costs due to the fact that the costs of investment, maintenance, and replacement are all relatively low. On the contrary side, BTS1 options, which integrate a gas boiler and a heat pump for heating, show the highest values for global cost. In this particular scenario, it would appear that the initial investment in a hybrid heating generation system would not be profitable for either the boiler or the heat pump. The EEMs that produce light blue (SO2) and yellow (SO3) clouds have the best performance in terms of energy efficiency; however, these EEMs also have the highest values for their global cost. The initial investment cost for System BTS2, which makes use of a ground source heat pump, is rather significant, despite the fact that it has relatively low expenses associated with both energy and maintenance. The low initial investment cost of System BTS3, which only includes the ventilation system and not the water terminals, along with the low costs of maintenance and repair, makes it a potential viable alternative to conventional systems. Becchio has also brought out the advantages of the various PV configurations, which can be seen in the table below. The global cost showed some increment but the drop in primary energy is really significant.

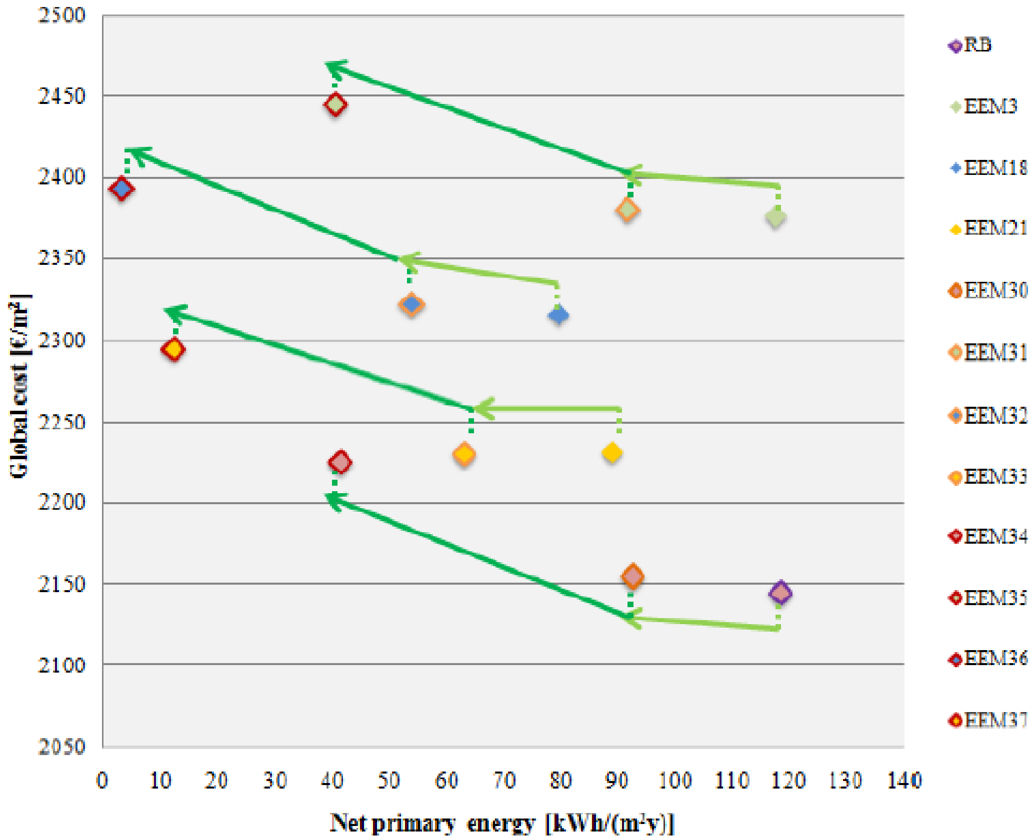

Figure 2.3.2 Effect of addition of PV to the systems[19]

Only three of Becchio's many hypothetical situations were able to arrive at a point where there was no net gain or loss. According to the findings of the study, it is feasible to reduce emissions to levels very close to zero by modifying either the technical systems or the insulation layers. Getting closer to net zero required a number of steps, one of which was installing a number of huge photovoltaic panels. However, in order to achieve net zero, one of the setups described before must have had the best possible performance. Because of the heavy use of boilers and the relatively limited amount of photovoltaics, the most cost-effective solution typically had a high primary energy consumption. The zero-energy solutions did not demonstrate any signs of being economically viable. The disparity in price is a very important consideration. The best energy solution, which is EEM40, resulted in a 10% increase in global costs when compared to the reference building. The research analyzed various potential solutions and determined which ones offered the best combination of low cost and high energy savings. It appears that bridging the gap between the two is going to be a very difficult task. The findings of the study imply that it would be possible to investigate it further in order to locate a singular answer to both problems.

2.3.2 Case study 2

The following study, which utilizes a cost-optimal analysis, is one that was conducted by Zangheri[20]. Zangheri performs an exhaustive investigation of a variety of cost-effectiveness classifications. The type of building and the area in which it is situated both have a role in determining which category a structure falls into. Zangheri's findings should be analyzed because this thesis project is centered on the influence that varying climates have, and it would be helpful to do so.

The research uses a total of four different reference buildings, each of which is a different kind of structure. These include dwellings for a single family, apartment complexes, office buildings, and a school. The study also provides a mechanism to explore the methodology of cost-optimal analysis, giving a pathway to do so in the process. It seems that the first thing that should be done is to identify the climate conditions that are representative. They have compared the severity indexes during the summer with the severity indexes during the winter in order to decide where the computations should be carried out. As a direct consequence of these decisions, the cities of Seville, Madrid, Rome, Milan, Bucharest, Vienna, Paris, Prague, Berlin, and Helsinki were chosen. The next step was to decide what kind of structure would be constructed. As was noted earlier, they were responsible for the construction of four distinct types of residential and commercial buildings. The net floor space of the single-family home was 140 m2, the apartment building had 990 m2, the office building had 2400 m2, and the educational institution had 3500 m2. The next thing that needed to be done was to specify the characteristics of the reference building components as well as the heating and cooling generator system. Due to the fact that different member states have different criteria, the initial systems and u-values are not identical to one another. For instance, as a reference building scenario, a single-family residential home in Milano had a gas boiler for heating and a chiller for cooling, but in Helsinki, the heating generator was from district heating and there was no cooling system present. In Helsinki, the heating generator was from district heating. Due to the fact that this was the case, the step of specifying the remodelling measures was also expressed in a range of values rather than in single numbers. The program EnergyPlus was used to run the simulations, and the EN 15459 standard was utilized for the cost estimations.

Several different energy system refurbishments were applied including heat pump, solar thermal systems, photovoltaics, and biomass boilers. The classic primary energy to cost graph was produced after the calculations is shown below. The graph shows the results of varying scenarios in Vienna in an apartment block. The results are categorized by BRL(Base refurbishment level), Cost optimal level and NZEB level.

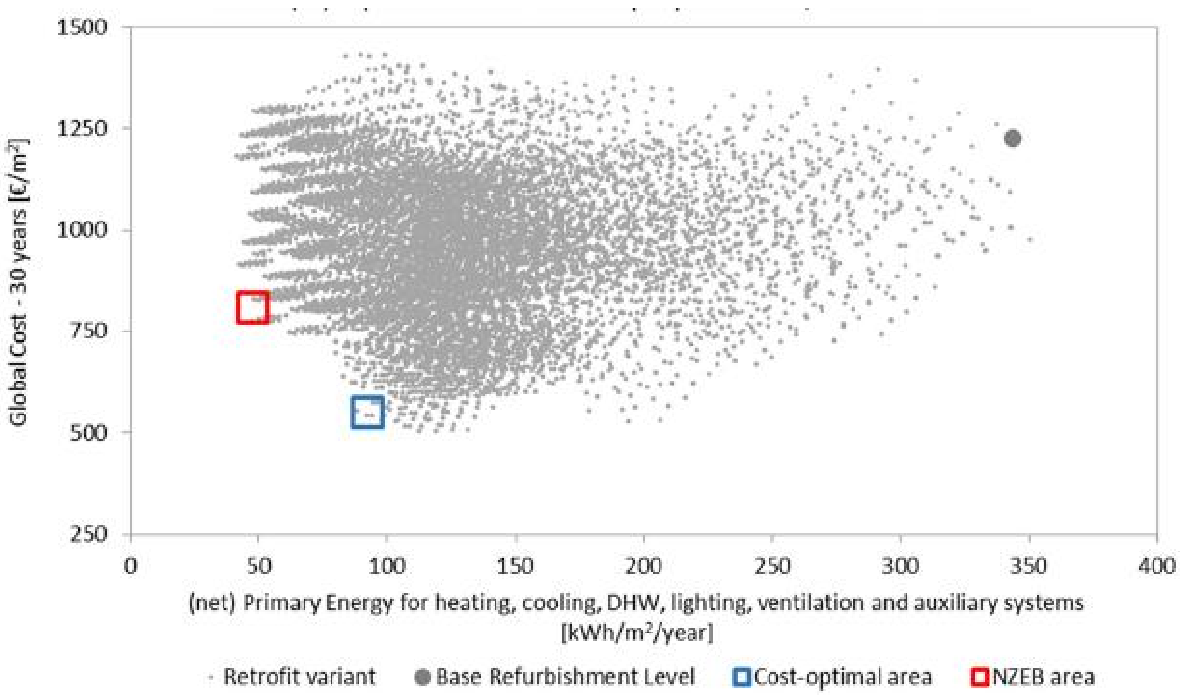

Figure 2.3.3Cost-optimality graph of an Apartment Block in Vienna from research of Zangheri[20]

The results of primary energy for all the defined were reported. Table below shows the comparison of 2 climates (Milan and Prague) with 4 distinct building typologies in terms of cost and energy. Simply by looking at the table, it was possible to observe that the amount of energy and cost changes that occurred following the necessary refurbishments increased in direct proportion to the size of the building. It was also possible to demonstrate that the net primary energy for a cost-optimal solution and a NZEB was noticeably greater in a climate with a lower average temperature, such as Prague. The decrease in prices for single-family homes in Milan is significantly more noticeable than it is for other types of housing. These findings demonstrate how much more challenging it is to find a solution that is both cost and energy optimal in locations with colder weather.

		Net primary energy [kWh/m2/year]			**Global cost difference with respect to BRL [%]**	
Climate	**Building type**	**BRL**	**C-opt**	**NZEB**	**C-opt**	**NZEB**
Milan	SFH	346	50	<20	-26	2
	AB	260	98	<40	-53	-13
	Office	400	76	<10	-20	-7
	School	357	86	<10	-17	-4
Prague	SFH	519	159	<55	-4	33
	AB	303	164	<100	-30	7
	Office	615	118	<25	-42	-34
	School	398	110	<10	-38	-12

Table 2.3-3Net primary energy and Global cost difference of scenarios depending on building typology and climate[20]

2.4 Other Articles

The following table provides a list of additional articles that have been subjected to additional examination for the purpose of gaining a deeper comprehension of the cost optimal analysis procedure and energy performance estimates.

Author	**Reference**	**Location**	**Calculation tool**	**Objective**
Patrcevic (2022)	[21]	Croatia	Dynamic and quasi-static methods	Comparing cost-optimality analysis outcomes of hourly and monthly standards
Wei (2022)	[22]	USA	Dynamic calculations with Energy Plus	Effect of a battery storage on the cost optimality analysis
Palladino (2021)	[23]	Italy	Spreadsheet calculations	Hourly and monthly calculations comparison in single family homes in Italy
Corrado (2021)	[24]	Italy	Dynamic calculations with Energy Plus	Confirmation of the hourly EN52016 method for house demand calculations
Vujnovic (2021)	[25]	Croatia	Dynamic calculations with IDA/ICE	Cost optimality analysis of a nZEB hotel building

Lorenzati (2019)	[26]	Italy	Dynamic calculations with Energy Plus	Energy refurbishments on different types of houses in northern Italy
Luthander (2018)	[27]	Sweden	Steady state calculations using Matlab	PV Load matching by using a battery in nZEB's.
Kurnitski (2018)	[28]	Estonia, Finland,Norway, Sweden	Dynamic calculations using IDA/ICE	Nzeb energy performance regulations comparison in Nordic countries
Ballarini (2017)	[29]	Italy	Quasi-steady state calculations	Cost optimality analysis by making energy refurbishments using the buildings in the Italian building stock
Ortiz (2016)	[30]	Spain	Dynamic calculations on TRNSYS	Cost optimality analysis of residential buildings in Catalonia.
Baglivo (2015)	[31]	Italy	Dynamic calculations on Procasaclima2015 and Matlab	Cost optimality analysis of standard and high performant buildings.
Aelenei (2015)	[32]	Italy, Portugal, Romania, Spain, Greece	Quasi-steady state calculations	Cost optimality analysis in different climatess

Ferrara (2015)	[33]	Italy,France	Dynamic calculations in TRNSYS	Comparing the effect of primary systems in two different climates.
Haase (2015)	[34]	Spain, Norway, Lithuania, UK	Quasi-steady state calculations on PHPP	Refurbishments done to reach to a cost optimal solution in a shopping mall
Barthelmes (2014)	[35]	Italy	Dynamic calculations on EnergyPlus	Effects of energy targets on the energy and costs of buildings
Tronchin (2014)	[36]	Italy	Quasi-steady state calculations	Cost optimality analysis in Italy
Kapsalaki (2012)	[37]	Portugal, Sweden, Greece	Quasi-steady state calculations on Matlab	Cost optimality analysis in 3 different climates
Hamdy (2012)	[38]	Finland	Dynamic calculations on TRNSYS and IDA/ICE	Cost optimality analysis that mainly focuses on the effect of cooling.
Widen (2008)	[39]	Sweden	Steady state calculations	Improving the load matching of demand and supply to reach nZEB.

3. Software Implementation

The thesis work will be done on a residential single-family home located in different climates. The house is simplified as much as possible and is considered a single-zone building.. The demand of the house consists of domestic hot water, space heating, space cooling. These demands were calculated using the Edilclima software. The software uses the UNI/TS 11300 standard which is also known as the EN 15316:2007 quasi-static monthly standard.

After the demand generation, several different systems were designed using the Edilclima software and output was generated in form of non-renewable primary energy [kWh/m2a].

The technical systems calculation is followed up with a cost calculation for building systems. The standard EN 15459:2018 is used to calculate it. The used primary energy of the desired system and the cost of the system is going to lead to an indicator of the cost-optimality performance of the house. In this section, the important inputs, and outputs of the software EDILCLIMA and the steps of calculation of the building technical systems will be discussed.

3.1 Edilclima

Edilclima is a software-house to develop calculation programs for the design of plants and their compliance with legal constraints[40].The strongest feature of Edilclima is that they do not only actively participate in the Comitato Termotecnico Italiano (CTI) and Comitato Europeo di Normazione (CEN), but they also advocate their own plans and ideas in the process. This approach led Edilclima to advance further in recent years. The main goal of the software is to offer the designer a flexible design tool that gives the freedom of simplified decision-making while concerning the legal requirements.

Edilclima software consists of different modules. The main module, the module which will be introduced in this thesis work, is called The Calculation of Energy Performance of Buildings. This module has a user-friendly interface that aids the energy performance calculation of buildings in the docility of the UNI/TS 11300-1 technical standard. The UNI/TS 11300-1 standard includes winter air conditioning, summer air conditioning, production of domestic hot water, ventilation, transport of people or things, and lighting. The latest version of the software allows the user to implement the following calculations:

- Energy performance of the building in a dynamic hourly regime, respecting the UNI EN 52016-1 standard.
- Sizing the heating system for winter respecting the UNI/TS 11300-1 standard.
- Calculating the useful energy in the winter and summer according to the UNI/TS 11300-1 technical standard.
- Primary energy for services such as space heating, production of domestic hot water, ventilation, and lighting, according to technical standards UNI/TS 11300-2 and UNI/TS 11300-4.
- Primary energy for cooling service, according to the UNI/TS 11300-3 technical specification.
- Counting of contributions provided by renewable source plants (solar thermal, solar photovoltaic) according to the technical specifications UNI/TS 11300 11300.

The software also has some additional modules for the calculation of building performance, technical systems, and some legal aspects. Edilclima also includes modules such as checking the design of the building plant, energy certification of buildings, thermal bridges, solar thermal and photovoltaic systems. Edilclima also contains a module which calculates the improvement of a refurbishment of a house in terms of non-renewable primary energy and cost. The standards that are useful for the calculation of systems are described in the section below.

3.2 The UNI/TS 11300 Standard

When it comes to computations, Edilclima relies on the technical standard known as UNI/TS11300. Italy's contribution to the European standard series is called the UNI/TS 11300 standard. In the Italian specifications, the quasi-static monthly method EN 13790 for calculating energy requirements is referred to as the UNI/TS 11300-1. And the standard EN15316, which is utilized for the generation systems in the monthly method, is represented in the Italian regulations by UNI/TS 11300-2 and UNI/TS 11300-4 respectively. Last but not least, the standard EN15243 is also referred to as UNI/TS 11300-3. This section will provide a concise explanation of the computation procedures for these four standards.

3.2.1 UNI/TS 11300-1 :"Evaluation of thermal energy need for space heating and cooling"

[41]The calculation procedure includes the following steps:

1) definition of the boundaries of all the air-conditioned and non-air-conditioned rooms of the building;

2) definition of the boundaries of the different calculation zones, if required;

3) definition of the internal calculation conditions and of the input data relating to the external climate;

4) calculation, for each month and for each area of the building, of the ideal energy needs

thermal for heating ($Q_{H,nd}$) and cooling ($Q_{c,nd}$);

5) calculation of the heating and cooling season;

6) for the extreme months of the heating and cooling season if any

recalculation of energy needs on fractions of the month respectively included

in the heating and cooling seasons;

7) possible calculation, for each month or part of a month and for each area of the building, of the

thermal energy requirements for humidification ($Q_{H,hum,nd}$) and for dehumidification

($Q_{C,dhum,nd}$);

8) aggregation of the results relating to the various months and to the various areas served by

same plants.

The optimal thermal energy requirements for heating ($Q_{H,nd}$) and cooling ($Q_{c,nd}$) are calculated in stages 4 and 6 of the technique outlined above. These calculations are performed for each zone of the building as well as for each month or part of a month and include the following examples:

$$Q_{H,nd} = Q_{H,ht} - \eta_{H,gn} * Q_{gn} = \left(Q_{H,tr} + Q_{H,ve}\right) - \eta_{H,gn} * (Q_{int} + Q_{sol,w}) \quad (1)$$

$$Q_{C,nd} = Q_{gn} - \eta_{C,ls} * Q_{C,ht} = \left(Q_{int} + Q_{sol,w}\right) - \eta_{ls} * (Q_{C,tr} + Q_{C,ve}) \quad (2)$$

$Q_{H,ht}$ is the total thermal energy exchange in the case of heating, expressed in [MJ];

$Q_{C,ht}$ is the total thermal energy exchange in the case of cooling, expressed in [MJ];

$Q_{H,tr}$ is the exchange of heat energy by transmission in the case of heating,

expressed in [MJ];

$Q_{C,tr}$ is the exchange of thermal energy by transmission in the case of cooling,

expressed in [MJ];

$Q_{H,ve}$ is the exchange of thermal energy for ventilation in the case of heating,

expressed in [MJ];

$Q_{C,ve}$ is the exchange of thermal energy for ventilation in the case of cooling, expressed in [MJ];

Q_{gn} are the total contributions of thermal energy, expressed in [MJ];

Q_{int} are the thermal energy inputs due to internal sources, expressed in [MJ];

$Q_{sol,w}$ are the thermal energy inputs due to incident solar radiation on the

glazed components, expressed in [MJ];

$\eta_{H,gn}$ is the utilization factor of the thermal energy inputs;

$\eta_{C,ls}$ is the utilization factor of thermal energy losses.

The thermal energy exchanges are estimated using the following equations for each thermal zone of the building and for each month or portion of a month is shown below.

In case of heating:

$$Q_{H,tr} = H_{tr,adj} * \left(\theta_{int,set,H} - \theta_e\right) * t + \left\{\sum_k F_{r,k}\Phi_{r,mn,k}\right\} * t + \left\{\sum_l (1 - b_{tr,l}) F_{r,l}\Phi_{r,mn,u,l}\right\} * t - Q_{sol,op} \quad (3)$$

$$Q_{H,ve} = H_{ve,adj} * \left(\theta_{int,set,H} - \theta_e\right) * t \quad (4)$$

In case of cooling:

$$Q_{C,tr} = H_{tr,adj} * (\theta_{int,set,C} - \theta_e) * t + \left\{\sum_k F_{r,k}\Phi_{r,mn,k}\right\} * t + \left\{\sum_l (1 - b_{tr,l})F_{r,l}\Phi_{r,mn,u,l}\right\} * t - Q_{sol,op} \quad (5)$$

$$Q_{C,ve} = H_{ve,adj} * (\theta_{int,set,C} - \theta_e) * t \quad (6)$$

Where:

$H_{tr,adj}$ is the global coefficient of heat transfer by transmission of the zone considered, corrected for the difference in temperature internal-external, determined with equation (X), expressed in [W/K];

$H_{ve,adj}$ is the global ventilation heat transfer coefficient of the area considered, corrected for the difference in temperature internal-external, determined with equation (X), expressed in [W/K];

$\theta_{int,set,H}$ is the internal control temperature for heating the zone considered, expressed in [°C];

$\theta_{int,set,C}$ is the internal control temperature for cooling the zone considered, expressed in [°C];

θ_e is the average external temperature of the month in question or of the fraction of the month , expressed in [°C];

$F_{r,k}$ is the shape factor between the kth building component and the celestial vault;

$F_{r,l}$ is the form factor between the l–th building component of the non
air-conditioned and the celestial vault;

$\phi_{r,mn,k}$ is the extra heat flux due to infrared radiation towards the celestial vault from
kth building component, averaged over time, expressed in [W]

$\phi_{r,mn,u,l}$ is the extra heat flux due to infrared radiation towards the celestial vault from
l–th building component of the non-conditioned environment, averaged over time,
expressed in [W];

$b_{tr,l}$ is the dispersion reduction factor for the non-air conditioned environment having the l-th component subject to infrared radiation towards the celestial vault;

t is the duration of the month considered or of the fraction of the month defined according to what is reported in point 10, expressed in [ms];

$Q_{sol,op}$are the thermal energy inputs due to incident solar radiation on the opaque components, expressed in [MJ].

The global heat transfer coefficients are calculated by the following formula:

$$H_{tr,adj} = H_D + H_g + H_U + H_A \tag{7}$$

$$H_{ve,adj} = \rho_a * c_a * \left\{ \sum_k b_{ve,k} * q_{ve,k,mn} \right\} \tag{8}$$

H_D is the direct heat transfer coefficient for transmission to the environment external, expressed in [W/K];

H_g is the stationary heat transfer coefficient for transmission to the ground, expressed in [W/K];

H_U is the heat transfer coefficient for transmission through non-ambient environments air-conditioned, expressed in W/K;

H_A is the heat transfer coefficient for transmission to other conditioned areas at different temperatures, expressed in W/K;

$\rho_a * c_a$ is the volumetric heat capacity of air, equal to 1200 J/(m3 × K);

$q_{ve,k,mn}$ is the time-averaged flow rate of the k-th air flow, expressed in m3/s;

$b_{ve,k}$ is the temperature correction factor for the k-th airflow in natural ventilation.

The UNI/TS 11300-1 standard establishes the temperature and relative humidity levels that must be maintained on the inside of residential structures during their respective heating and cooling seasons. During warmer seasons, the temperature inside is maintained at 20 degrees Celsius, and the relative humidity is maintained at 50 percent. The indoor temperature is maintained at a steady 26 degrees Celsius during the cooler seasons, while the relative humidity is managed at 50 percent. With the assistance of the European standard EN 13790:2008, the length of the heating and cooling seasons can be determined. The several climate zones that can be found in Italy make it difficult to choose between the different seasons. The calculations for the more frigid climates, such as continental and marine, were done as though the structure were located in climate zone F, which is Italy's zone with the coldest average temperatures. That puts the beginning of the heating season on October 5 and its end on April 25. While calculations for Turin were based on the conditions of climate zone E, which runs from the 15th of October to the 15th of April and has a heating season that lasts for that entire time.

3.2.2 UNI/TS 11300-2 “Evaluation of primary energy need and of system efficiencies for space heating, domestic hot water production, ventilation and lighting for non-residential buildings”

[42]The input thermal energy demand for each subsystem must be estimated using the calculation method outlined in this technical specification after determining the output thermal energy requirement. The consumption of electrical auxiliaries and thermal energy are taken into account while determining each subsystem's energy requirements (i.e. the electrical energy dissipated in the form of heat).

When calculating the heat balance of a subsystem, the thermal energy recovered by its electrical auxiliaries is subtracted from the thermal energy requirements that the subsystem upstream of the one being studied must meet.

In general, each subsystem can be distinguished from an abbreviation that defines the service to which it is dedicated (for example, distribution subsystem dedicated to the heating service or to domestic hot water production) in addition to an abbreviation that identifies it for the purpose of fully identifying and allocating between I energy needs.

When recovering thermal losses from one subsystem Y dedicated to service X in another subsystem dedicated to service Z (for example, obtaining domestic hot water from subsystem for service domestic hot water in the subsystem for heating service), this notation with two abbreviations, for example, X and Y, is helpful.

For each subsystem Y dedicated to service X, the following must be determined:

- the input energy requirement of the subsystem $Q_{X,Y,in}$;

- the total auxiliary energy required $E_{X,Y,aux,}$;

- losses $Q_{X,Y,l}$;

- losses recovered $Q_{X,Y,lrh}$.

On the base of:

- useful energy to be supplied at the output Qout,x;

- characteristics of the subsystem and operating conditions of the plant.

The following heat balance equation holds for each subsystem. It must be noted that the energy is in the form of thermal energy and not primary energy.

$$Q_{X,Y,in} = Q_{X,Y,out} + Q_{X,Y,l} - \left(Q_{X,Y,lrh} + Q_{X,Y,l,rh,Z} + Q_{X,Y,aux,rh}\right) \quad [kWh] \qquad (9)$$

$Q_{X,Y,in}$ is the thermal energy entering subsystem Y dedicated to service X;

$Q_{X,Y,out}$ is the thermal energy output to subsystem Y dedicated to service X;

$Q_{X,Y,l}$ are the thermal energy losses in subsystem Y dedicated to service X;

$Q_{X,Y,l,rh,X}$ are the losses of thermal energy recovered in subsystem Y and loaded into subsystem X;

$Q_{X,Y,aux,rh}$ is the thermal energy recovered from the electrical energy dissipated in the form of heat from subsystem Y auxiliaries;

$Q_{X,Y,l,rh,Z}$ any losses recovered to be loaded onto the generic service Z.

Starting with the subsystem's heat balance equation and taking the demands of the auxiliaries into account, one may determine the average returns of the subsystems.

The yield in terms of primary energy during the calculation period taken into consideration is equal to:

$$\eta_{Y,P} = \sum_i Q_{Y,out,i} / \left(\sum_j E_{Y,in,j} * f_{P,j} + \sum_j E_{Y,aux,j} * f_{P,el} \right) \tag{10}$$

Where:

$Q_{Y,out,i}$ represents the energy in the form of the i-th outgoing energy vector o

produced by subsystem Y;

$E_{Y,in,j}$ represents the energy in the form of the jth energy input vector o

supplied to subsystem Y;

$E_{Y,aux,j}$ is the electricity requirement of the auxiliaries of subsystem Y;

$f_{P,j}$ is the primary energy conversion factor dependent on the energy carrier

used.

$f_{P,el}$ is the primary energy conversion factor of electricity.

The yield is defined in Formula (above) as the ratio of the energy output or created to the energy input or supplied to the subsystem, expressed in primary energy.

The performance of each subsystem can be determined either in relation to the entire period of heating season activation, taking into account the sum of monthly needs in the activation period, or on a monthly basis, taking into account the input and output requirements of the subsystem, along with the needs of the auxiliaries, for each month, both on a seasonal basis.

The table below provides a summary of the subsystems' alleged efficiencies.

Description	**Space heating**	**Domestic Hot Water**	**Space cooling**
Emission system efficiency $\boldsymbol{\eta_e}$	0.95	-	0.98
Regulation efficiency $\boldsymbol{\eta_{rg}}$	0.98	-	0.90
Delivery efficiency $\boldsymbol{\eta_{er}}$	-	1	-
Distribution system efficiency $\boldsymbol{\eta_{du}}$	0.96	0.93	0.98
Accumulated efficiency $\boldsymbol{\eta_s}$	0.99	0.82	0.96

Table 3.2-1Assumed efficiencies for the subsystems

3.2.3 UNI/TS 11300-3 “Evaluation of primary energy and system efficiencies for space cooling”

[43]The standard is applicable to newly constructed, renovated, or existing systems that only have cooling systems or only use air conditioning during the summer.

The calculation is divided into the following stages:

- determination of the ideal cooling requirement $Q_{C,nd}$,

- calculation of emission, regulation, distribution and accumulation losses of the plant and calculation of any energy recovered;

- calculation of the air treatment requirement Qv

- calculation of the electricity requirement for the auxiliaries of the heating systems Q_{aux}

- calculation of the average monthly coefficient of performance η_{mm} of the refrigerating machines,

through the evaluation of reference performance data provided by manufacturers;

- calculation of the primary energy requirement for summer air conditioning $Q_{C,P}$.

The primary energy requirement for summer air conditioning is calculated with the following formula:

$$Q_{C,P} = \sum_k Q_{aux,k} * f_{p,el} + \sum_k \left[\sum_x \frac{Q_{Cr,k,x}+Q_{v,k,x}}{\eta_{mm,k,x}}\right] f_{p,x} \quad \text{[kWh]} \qquad (11)$$

Where:

Q_{aux} is the electricity requirement for air conditioning system auxiliaries

[kWh];

Q_{Cr} is the actual cooling demand [kWh];

Qv is the air treatment requirement [kW];

η_{mm} is the average monthly coefficient of performance of the energy production system refrigerator;

$f_{p,el}$is the determined conversion factor from electrical energy to primary energy;

$f_{p,x}$ is the primary energy conversion factor of the energy vector used by the generator;

k is the k-th month of the summer air conditioning season;

x is the index that indicates the different input energy sources.

The global mean seasonal efficiency is determined by:

$$\eta_{glo} = \frac{\sum_k (Q_{C,nd,k} + Q_{v.k})}{Q_{C,P}} \qquad (12)$$

Where:

$Q_{C,nd}$ is the ideal requirement for cooling [kWh];

Qv is the air treatment requirement [kWh];

k is the k-th month of the summer air conditioning season,

It must also me noted that the specific consumption of the building for summer air conditioning [kWh/(m2 -year)] is obtained from the ratio between primary energy requirement for summer air conditioning $Q_{C,P}$ and the surface area of the building considered.

3.2.4 UNI/TS11300-4 "Renewable energy and other generation systems for space heating and domestic hot water production"

3.2.4.1 The Solar Thermal System

[44]This technical standard outlines the process for applying the requirements of UNI EN 15316-4-3 in a national setting, while adhering to the overall guidelines established by UNI EN 15603. The following information is provided by this technical specification for the purpose of computing the performance of solar thermal systems: the required input, the method by which benefits are computed, and the required outcomes. The following solar thermal systems are the focus of this particular technical specification:

1) household hot water systems that are prefabricated (UNI EN 12976-1) and systems that are custom assembled (UNI CEN/TS 12977-1)

2) heating-only systems and combination heating-and-cooling systems (UNI CEN/TS 12977-1)

The primary energy requirement, considering that the primary energy conversion factor of the thermal energy produced by the solar system is equal to zero, and given by:

$$Q_{p,sol} = \sum f_{p,el} * Q_{sol,aux} \tag{13}$$

In other words, the primary energy requirement of the solar generation subsystem, which can only be determined by the energy requirement of the subsystem auxiliaries and then transformed into primary energy using the relative conversion factor.

3.2.4.2 The Solar Photovoltaics

[44]Solar radiation, installed peak power, and system efficiency all influence how much electricity photovoltaic systems produce. Regarding the estimation of the electrical energy generated by solar systems placed in buildings, the UNI/TS 11300-4 incorporates the UNI/TS 11300-2. The specification outlines how UNI EN 15316-4-6 should be applied at the national level. Monthly calculations are performed. The photovoltaic system's thermal energy output, the use of electrical auxiliaries, generating losses, or recovering those losses for space heating are not taken into account in the computation.

The monthly electrical energy is calculated by the following formula:

$$E_{el,pv,out} = (E_{pv} * W_{pv} * f_{pv})/I_{ref} \qquad (14)$$

$E_{el,pv,out}$ is the amount of electricity produced by the photovoltaics system [kWh]

E_{pv} is the the monthly solar radiation incident on the photovoltaic system [kWh/m2]

W_{pv} is the the peak power, which represents the electrical power of a photovoltaic system of a given surface, for an irradiance of 1kW/m2 on this surface [kW]

f_{pv} is the system efficiency factor which takes into account the efficiency of the photovoltaic system integrated in the building

I_{ref} is the reference solar irradiance equal to 1 kW/m2

The peak power $W_{pv}$is calculated as :

$$W_{pv} = K_{pv} * A_{pv} \quad (15)$$

Where:

K_{pv} is the peak power factor which depends on the type of photovoltaic module installed [kW/m2]

A_{pv} collection surface area of the photovoltaic system [m2]

The efficiency factor was estimated to be 0.8 since the solar panels were thought to be highly ventilated panels. The photovoltaic modules where assumed to be mono-crystalline which makes the value of peak power factor 0.150 kW/m2.

3.2.4.3 The Heat pumps

[44]The input data and calculation techniques for calculating:

1) the monthly requirement of the energy carriers of the generation subsystems with heat pumps for heating and/or domestic hot water production are defined in this technical specification.

2) of the portion of the necessary energy for distribution that is carried by integration systems, which will be determined using the relevant sections of this technical specification.

The technical specification applies to absorption heat pumps that generate heat for domestic hot water production and heating services using air and water as heat transfer fluids, as well as vapor compression heat pumps powered by electric motors and using the air, ground, or water as energy sources.

The following information forms the basis for the calculating method provided in this technical specification:

1) The supply of useful thermal power

2) Only the heating function requires input power.

3. COP or GUE (provided power or requested power, respectively: COP or GUE = supplied power/requested power)

4) The COP and GUE's partial load correction coefficients.

The producer must offer the following information for the calculations required by this technical specification:

1) Full load efficiency as established by the applicable technical standards

2) Performance for vapor compression heat pumps at climatic load factors PLR other than 1, at the same cold source and hot sink temperatures mentioned in the preceding point, in accordance with the reference climatic conditions A, W, and C specified by UNI EN 14825.

3) Different performance from one of the absorption heat pumps indicated by the manufacturer in line with UNI EN 12309-2 at climatic load factor PLR.

4. Methodology

4.1 Climate Selection

In the course of this thesis work, an investigation into the energy efficiency of a residential building and its associated technical systems will be carried out in a variety of climates across Europe. It is essential to select climates that are diverse from one another in order to achieve findings that are similar to one another. In order to continue with the selection process, it is necessary to first describe the climate zones of Europe.

At least eight completely different climates can be found across Europe. On the map that follows, the various locations of the climate are indicated by their geographical coordinates. The climates are as follows:

- Semiarid
- Subtropical Dry summer
- Marine
- Humid Continental
- Subarctic
- Tundra
- Highland

Although there are a total of eight distinct climates, Europe is primarily influenced by only three of these climates. These three regions are the subtropical dry summer, the marine, and the continental regions. The research for this thesis will concentrate on these three substantially different climates. First, because of its proximity to the Sub-tropical dry summer climate, Turin was selected. The city of Turin can be found in an area that is transitional between the Sub-tropical dry summer zone and the highland zone. When compared to the possibilities of a Continental or Marine climate, it features a weather pattern that is rather unique. The city of

Stockholm, the capital of Sweden, was selected since its climate is classified as continental. In the context of the EU, the fact that Sweden is a country that places a high priority on converting older homes into NZEBs makes the country an attractive choice. In addition to this, the weather can be difficult, which puts the NZEB through a significant ordeal. The city of Copenhagen has been selected as the venue for the Marine climate. Denmark is another nation that has fairly stringent policies regarding the shift to renewable energy sources. Which may provide a greater opportunity for the work presented in the thesis to be implemented in the actual world.

Figure 4.1.1Different climates in Europe[45]

4.2 Building modelling assumptions

Previously, a number of values that are going to be utilized in the procedure for the computations for the UNI/TS 11300 standards were assumed. These numbers are held steady across the board for every climatic condition that this study takes into account. In the case of the exterior wall, both the emissivities and the absorption factors were maintained at 0.90. While maintaining a right angle of 90 degrees with the horizon, the wall was built. It was presumed that the roof had an absorption factor of 0.6, despite the fact that it had an emissivity of 0.9. This signifies that it was presumed to have a lighter color than the walls that faced the exterior of the building.

The emissivity of the windows was measured at 0.837, and their g-value was adjusted to 0.850. In addition, it was presumed that the curtain factor was 0.15, which translates to the fact that when the curtains were closed, only 15% of the sunlight was able to flow through.

Another essential presumption is that the usable energy factor of the home was predetermined to be 0.80. This indicates that there is a 20% decrease in the demand for the heating of the home as a result of the days in which the inhabitants are not at home or choose not to use the cooling or heating systems.

4.3 The Reference Buildings

4.3.1 The Tabula Project

In each of the climates studied, a reference building was selected from among three pre-existing structures that were used for the Tabula Project. Throughout the course of the IEE project TABULA, residential building typologies for thirteen different European nations were produced. Each national typology consists of a classification scheme that categorizes buildings according to their age, size, and other factors, as well as a series of representative structures that are meant to symbolize the many types of buildings.[46] They have been distributed to the general public by the project partners in the form of national "Building Typology Brochures" that are written in each nation's native language. This section is a standard component. In addition to the reference calculation that is used for international comparison, it is planned to calibrate the estimated energy consumption to the typical levels of actual consumption. This will make it possible to conduct an accurate analysis of the amount of money that can be saved on energy and costs. The residential building types were used to generate building stock models for seven different countries. These models enable a prediction of the actual national building stock consumption as well as the energy saving potentials for the building stock.

4.3.2 The House Data

4.3.2.1 Turin

Figure 4.3.1 Image of the existing reference building in Turin [47]

The first structure in question is a single-family dwelling that was constructed in the city of Turin in Italy in the year 2006. A total of 174 m2 of reference floor space can be found over the home's two levels. Given the fact that the ratio of surface area to volume is only 0.57, the gross volume is 578.05 m3. The following table provides information on the sizes of the various building components.

Building Component	Surface area [m2]	U-value [W/m2K]
Roof	96.4	0.28
External wall	223.3	0.34
Floor	96.4	0.33
Window	21.7	2.20
Door	2.4	1.70

Table 4.3-1Building component characteristics for the reference building in Turin

4.3.2.2 Stockholm

Figure 4.3.2Image of the existing reference building in Stockholm [47]

The second building in issue is a home for a single family that was built in the year 1975 in the municipality of Stockholm, which is located in the country of Sweden. The single level of the house contains a total of 106 square meters of floor area that may be used as a reference. Given that the ratio of surface area to volume is just 0.64, the gross volume is 392.52 m3, given that the surface area is only 0.64 times the volume. The dimensions of a variety of construction components are detailed in the table that may be found below.

Building Component	Surface area [m2]	U-value [W/m2K]
Roof	125	0.21
External wall	100	0.31
Floor	125	0.32
Window	22	2.30
Door	2	2.80

Table 4.3-2Building component characteristics for the reference building in Stockholm

4.3.2.3 Copenhagen

Figure 4.3.3Image of the existing reference building in Copenhagen[47]

The third building in question is a single-family home, and it was built in the year 2011 in the city of Copenhagen, which is located in the country of Denmark. The single level of the house contains a total of 151 square meters of floor area for reference purposes. Given that the ratio of surface area to volume is just 0.61, the gross volume is calculated to be 568.23 m3, given that the ratio is so low. The dimensions of a variety of construction components are detailed in the table that may be found below.

Building Component	Surface area [m2]	U-value [W/m2K]
Roof	178	0.11
External wall	152	0.18
Floor	178	0.10
Window	33.5	1.30
Door	2	1.70

Table 4.3-3Building component characteristics for the reference building in Copenhagen

4.3.3 Technical Systems of the Reference Building

Prior to elaborating on the technical system, it is necessary to first discuss the primary energy factor, which is a highly significant idea. When determining the overall amount of primary energy that a structure requires, the primary energy factor is an essential component to take into account. In order to calculate what percentage of that energy originates from primary sources, it outlines a variety of parameters that are specific to each type of energy source. The following table provides a rundown of the key energy components that are relevant to each of the climates that were considered.

Country	Electricity	Natural Gas
Italy	2.05	1.05
Sweden	1.60	1.0
Denmark	2.50	1.0

Table 4.3-4 Primary energy factors for each source and climate

All of the reference buildings, no matter where they are located or the weather, have the same technical systems installed. The traditional boiler, which utilizes methane as its natural gas source, is responsible for providing the space heating. The burner on the boiler operates via atmospheric combustion, and it features a conventional generator. When calculating the generation of heat, Edilclima takes a straightforward approach to the problem. It necessitates the application of notional useable power, which is equal to the required amount of energy for heating the reference building. Therefore, different inputs are necessary for the boiler depending on the climate. The distribution system consists of a single pipe that runs both above and below the room that is not air-conditioned. The pipes are laid out in a horizontal distribution while the system itself is centralized. The emission system is made up of radiators that are mounted on the exterior wall and have nominal emitter powers that are equivalent to the required amount. The boiler contributes to the production of residential hot water, but it is supplemented by a solar thermal system that consists of 4 collectors. The solar thermal system comprises a thermal storage tank that is 100 liters in capacity and covers 10.32 square meters of the roof's surface area. The diagram that follows presents an illustration of the thermal integration of the solar thermal system. It is important to note that both the heating and cooling systems will be replaced while the research is being carried out, so keep this in mind. However, the solar thermal system that supplies the domestic hot water need will continue to operate in the same manner regardless of the circumstances.

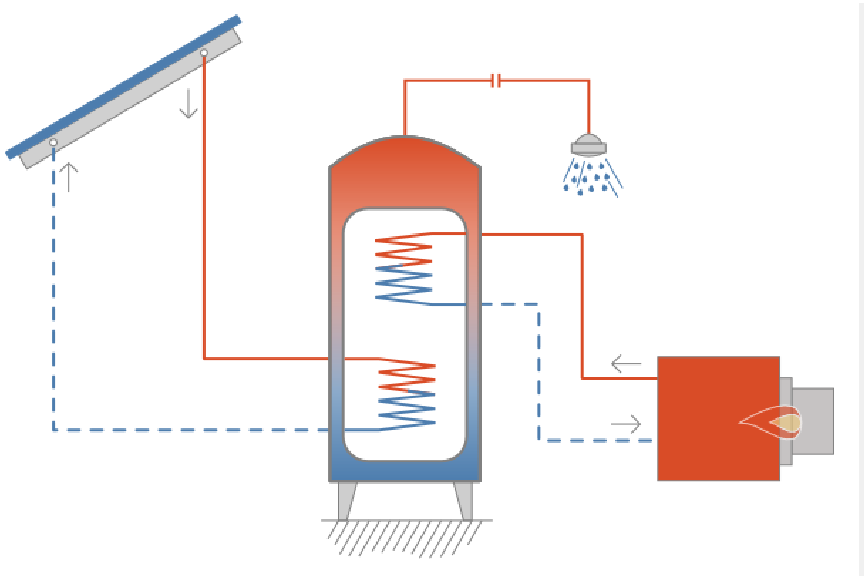

Figure 4.3.4 Scheme of the domestic hot water set-up of solar thermal system [48]

A heat pump that transfers heat from air to water is utilized in order to handle the cooling load. When it comes to the process of cooling, Edilcima opts for a more straightforward approach. The heat pump has an EER of 2.40 and a nominal power output of 4.70 kW, both of which are impressive statistics. The heat pump features a distribution network that is comprised of a basement ring and mains that rise upwards. The effectiveness of the distribution is 98%. Water fan coils, which operate at an efficiency of 98%, are used to provide the cooling.

4.4 Refurbishment scenarios of Building components

After the houses were designed, it became clear that the windows and the walls that faced the exterior were responsible for the greatest amount of heat loss. Therefore, just these two components received any attention during the restoration process.

The single pane of glass in the window was replaced with a 4+12+4+12+4 krypton triple-paned glass, and the window frame was upgraded to 90mm of laminated wood. The overall u-value of the window, which is denoted by the symbol Uw, dropped all the way down to 0.863.

When selecting the numerous scenarios for the refurbishment, a slightly different strategy was utilized. There were two distinct levels of renovation that were taken into consideration, with one being a more stringent and expensive option than the other. The first modification to the exterior walls is the installation of an additional layer of insulation consisting of fiberglass panels with a density of 20 kg/m3 each. 40 millimeters is the thickness of the layer. The thermal transmittance of the building's outside walls in the reference building in Turin is reduced from 0.34 to 0.236 as a result of this addition. In Copenhagen and Stockholm, it is reduced from 0.18 to 0.15, while in Stockholm it is reduced from 0.31 to 0.23. After this layer of insulation comes a further layer that is significantly thicker. The second step involves spraying a polyurethane coating with a thickness of 100 millimeters, which brings the u-values down to 0.15 in Turin, 0.108 in Copenhagen, and 0.144 in Stockholm.

These renovations result in the building having two separate windows and three separate external walls when the previous state of the building is also taken into account. Which, when taken collectively, yields a total of six additional potential outcomes. The various degrees of refurbishment that the building components have received are outlined in the table that follows.

Building component	Baseline	Refurbishment level 1	Refurbishment level 2
Window	Single glass window	Triple glass 4+12+4+12+4 Krypton window and laminated wod frame	-
External Wall		40 mm fiberglass panels	100 mm sprayed polyurathane

Table 4.4-1Building component refurbishment scenarios

4.5 Building system refurbishments

If the major objective is to decrease the amount of primary energy that is consumed, the reference building requires technological advancement. This objective might be accomplished by utilizing heat pumps rather than the conventional boiler. The level of contribution made by the heat pumps differs depending on the source of the heat that they receive. In order to meet both the energy and cost-optimal goals, this section provides the option of installing a heat pump that draws its heat from the earth or the air.

4.5.1 The air to water heat pump

Figure 4.5.1 Image of the air source heat pump that is installed[48]

The air-to-water heat pump is the same heat pump that was stated in the reference building case; however, it was exclusively utilized for the cooling load in this particular structure. The heat pump can now satisfy both the need for heating the interior area as well as the demand for domestic hot water. When estimating the necessary generation, the Edilclima software applies the EN15316:2007 quasi-steady state standard, which is a more precise technique for heat pumps. Lamborghini Caloreclima series IDOLA 3.2 model number 4 was chosen to be the most suitable heat pump for this operation.It serves space heating, domestic hot water and cooling demands. This was the motivation behind putting them on different tracks. The performance sheet for the heat pump is shown in the figure below for your viewing convenience. It displays the operating temperatures as well as the fluctuations in those temperatures with regard to the COP and the useful power. A condensing boiler, the details of which will be provided in a subsequent section, serves as a backup for the heat pump. The distribution and emission subsystems are precisely the same as those that were discussed earlier in relation to the cooling load.

The electrical heat pump draws its cold source from the surrounding air and has a minimum cut-off temperature of -25 degrees Celsius and a maximum cut-off temperature of 43 degrees Celsius. The hot source is water, and the operating temperatures range from 12 degrees Celsius to 65 degrees Celsius. It is equipped with a thermal storage tank with a volume of 130 L.

Performance coefficients (*) COP

θf [°C]	θc [°C]		
	35	45	55
-7	3.11	2.29	1.83
2	3.87	2.97	2.42
7	4.96	3.67	2.83
12	4.73	4.02	3.26

Useful power Pu [kW]

θf [°C]	θc [°C]		
	35	45	55
-7	4.90	4.54	4.28
2	5.28	5.25	5.26
7	6.26	5.96	5.74
12	5.94	6.11	5.67

Figure 4.5.2Performance sheet of the Air source heat pump [48]

The air source heat pump has a condensing boiler working in tandem with it as a backup. On the coldest days of winter, when the demand for heating is at its highest and there are no other options to generate power on-site, having this back-up system can be quite helpful. The method of computation for the condensing boiler system is streamlined in the same way that it is for the conventional boiler system. It considers the nominal power input from the combustion process to be the required amount for the home. The boiler that was selected has an absolute minimum combustion power of 1 kW and an electrical power of 18 W for the burner. It was determined that the losses through the chimney accounted for 5%, resulting in an overall useable efficiency of 98.2%. The gas is returned to the system at a temperature of 60 degrees Celsius and contains 6% oxygen. Methane, which has a lower calorific value of 9.940 kWh/Nm3, is the gas that is employed as the source, and this fact must not be overlooked.

4.5.2 The Ground source heat pump

A ground source heat pump might be an improvement on the air source heat pump, which was defined earlier for the purpose of heating, domestic hot water heating, and cooling loads. A ground-source heat pump will have a greater COP and EER, as well as a higher power output and less variation in the temperatures it receives as input. The cost of purchasing one of these heat pumps is going to be a drawback, which is something that will be covered in the following chapter. It was decided to go with the Weishaupt WWPS heating and cooling series, specifically the model WWP 10 IBER. It is an electrical heat pump that has a control unit with an on-off switch. The ground serves as the cold source, and the optimal working temperature ranges from -5 degrees Celsius to 25 degrees Celsius. The heat pump transfers the warmth to the water at temperatures ranging from 20 to 62 degrees Celsius. Once more, the capacity of the thermal storage tank is 130 L. The data from the condensing boiler is used to support the heat pump once more.

Performance coefficients (*) COP

θf [°C]	θc [°C]		
	35	45	55
-5	3.70	2.70	2.30
0	4.30	3.30	2.70
5	4.80	3.70	2.90
10	5.70	4.30	3.40

Useful power Pu [kW]

θf [°C]	θc [°C]		
	35	45	55
-5	8.30	7.80	7.60
0	9.70	9.30	8.90
5	10.90	10.40	9.90
10	13.00	12.10	11.50

Figure 4.5.3Performance sheet of the ground source heat pump [48]

The following table provides a concise summary of the levels of renovation completed on the heating, domestic hot water, and cooling systems.

	System 1	System 2	System 3
Heating	Traditional boiler	Air to water heat pump + Condensing boiler	Ground source heat pump + Condensing Boiler
Domestic Hot Water	Traditional boiler + Solar thermal collectors	Air to water heat pump + Solar thermal collectors	Ground source heat pump +Solar thermal collectors
Cooling	Air to water heat pump	Air to water heat pump	Ground source heat pump
Ventilation	Natural Ventilation	Natural Ventilation	Natural Ventilation

Table 4.5-1 Technical system scenarios

4.5.3 The Photovoltaics

In order for a structure to achieve low levels of primary energy that is not renewable, the installation of photovoltaics is required. It is an excellent method for producing energy on the site itself. It should not come as a surprise that a cost-optimal scenario includes photovoltaics as a component because the cost of photovoltaic panels has been steadily falling over the past few years. It is vital to have an understanding of the space that is available in order to determine the total number of photovoltaic modules that will be installed. The solar thermal system that was first introduced in the baseline scenario is present in all of the other scenarios, and it occupies a total of 10.32 square meters of roof space. The roof space of the house with the smallest footprint has this area deducted from it. Which brings the total amount of space available for photovoltaics to 86.08 m2.

The levels of photovoltaics that are employed will be determined, not by the number of modules, but rather by the total peak power that they are able to give. Becchio, who undertook extensive research on the influence of photovoltaics in single-family homes while doing a cost optimality study, used earlier research to come up with these values. He chose them from the available literature. The table that was provided below displayed the levels clearly. The modules will be oriented in such a way that they face south, and their angle of separation from the horizontal plane, denoted by the symbol B, will be 35 degrees. It turned out to be the best option. The coefficient of reflectance was set at 0.6, and the photovoltaic efficiency was calculated to be 0.80. This indicates that the module is an extremely well-ventilated one. The levels of photovoltaic power can be categorized as low, medium, or high, with low being 1600 Wp, medium being 3200 Wp, and high being 6300 Wp.

	Level 0 - PV0	**Level 1- PV1**	**Level 2- PV2**	**Level 3- PV3**
PV total peak power [Wp]	No PV installed	1600	3200	6300

Table 4.5-2Applied PV levels

When combined with the three various heating and domestic hot water generators and the four different levels of photovoltaics, the six distinct building envelope options result in a total of 72 potential scenarios per climate from which to choose a cost-optimal and NZEB solution. Due to the inclusion of three distinct climates, a total of 216 distinct cases will be investigated.

4.6 Costs of system components

It is time to move on to the cost estimates now that the estimation of the amount of primary energy from non-renewable sources that the house will require has been finished. The cost is broken down into the global cost per square meter, as was covered in part 2 of this paper. According to standard 15459:2018, the overall cost of the building is equal to the sum of four separate values.

The initial cost of the construction is referred to as the investment cost, and it represents the total amount spent on the structure before it begins to generate revenue. These include the components of the system (such as boilers and heat pumps), the components of the structure (such as insulation layers and windows), and the work (design and installation). In the following table, you will find a list of the investment charges that were employed in the work for this thesis. It is essential to make the assumption that the return on investment for both the components of the system and the components of the structure is the same across all three locations. When compared to fluctuations in the cost of electricity and gas, changes in the investment cost of the components would not bring about as significant of a change in the results.

System component	**Price [EURO]**
Traditional Boiler	800
Condensing Boiler	1100

Air to water heat pump	5000
Ground source heat pump	9600
Radiators	5600
Solar thermal collectors (4 collectors)	900

Table 4.6-1Investment costs of system components [20]

Photovoltaics is an important component of the system that varies depending on the climate. To obtain an accurate cost optimal solution, it is required to apply specific cost values for each country. This is due to the fact that the level of photovoltaics will alter and grow depending on the scenario. The following table provides an overview of the different levels of investment costs associated with photovoltaics.

	Italy	Sweden	Denmark
Cost of PV after tax [EURO/W]	3.55	3.9	3.354

Table 4.6-2Investment cost of PV per W[49]

Additionally, the capital expenditure expenditures for the building components need to be determined. Only the additional costs associated with the refurbishment of the building are taken into consideration because it is an existing structure. The expenses associated with the renovations are detailed in the table that can be found below. The costs of the design and installation were kept at a constant level of 40.000 Euros throughout all climates.

Component	**Price per unit area [EURO/m2]**
Single glass	35
Aluminium frame	200
Triple glass 4+12+4+12+4	110
Fiberglass with 4cm thickness	5.5

Sprayed polyurethane with 10cm thickness	30
Laminated oak frame 90mm	450

Table 4.6-3Investment cost of building components [48]

When determining the global cost, the EN 15459:2018 standard also takes into consideration the expenses of maintenance and replacement as separate categories of expenditures. The period of time that is used to calculate the total cost of residential constructions is fifty years. Over the course of this 50-year time period, the standard establishes values for each component that will need to be maintained or replaced at some point. In the following table, the value of the maintenance cost, its lifespan cost, and its replacement cost are shown, together with the proportion of the investment cost that each represents.

Building or system component	Maintenance Cost [%]	Lifetime [year]	Replacement Cost
Single glass	0	35	35 euro/m2
Aluminium frame	0	35	200 euro/m2
Triple glass 4+12+4+12+4	0	35	110 euro/m2
Fiberglass with 4cm thickness	0	40	5.5 euro/m2
Sprayed polyurethane with 10cm thickness	0	40	30 euro/m2
Laminated oak frame 90mm	0	35	450 euro/m2
Traditional Boiler	1.5	20	264 euro
Condensing Boiler	1.5	20	400 euro
Air to water heat pump	3	17	2000 euro

Ground source heat pump	3	17	4000 euro
Radiators	1.5	35	2000 euro
Solar thermal collectors (4 collectors)	0.5	20	300 euro
Photovoltaics	0.5	20	Total replacement, equivalent to investment cost

Table 4.6-4Additional costs for refurbishments [16]

The cost of the system's energy consumption is the very last cost that needs to be addressed. The outputs of the following table are used in the computation of the cost of the energy. Values such as real interest rate and energy prices vary from nation to country; hence, the most significant differences in cost will emerge as a direct consequence of these variations in value. In a time span of fifty years, all of the essential inputs that are required to calculate the worldwide cost have been finished. It is time to evaluate the results of using non-renewable primary energy in

Country	Price of electricity [euro/kWh]	Price of methane [euro/Sm3]	Real interest rate [%]
Italy	0.25	1.27	2.97
Sweden	0.2525	2.07	1.96
Denmark	0.4559	1.5	2.06

Table 4.6-5Financial input data for the cost calculations per climate [49]

Type of evolution	Value [%]
Price evolution rate of energy	1.00
Price evolution rate of labor	1.00
Price evolution rate of products	1.00
Price evolution rate of water	1.00
Price evolution rate of services	1.00

Table 4.6-6Price evolution rate types and values[48]

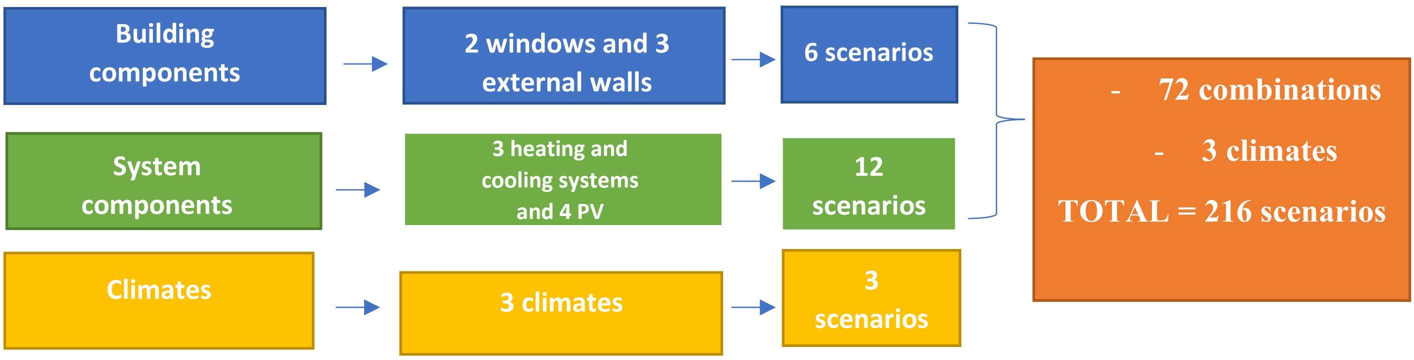

Figure 4.6.1The summary of all scenarios

5. Results and conclusion

5.1 Non-renewable primary energy results

The total energy consumption throughout the course of the year was measured in terms of primary forms of energy that are not renewable. Domestic hot water, space heating, and space cooling are all included in the calculations for the values of non-renewable primary energy. The calculations used to determine the cost-optimality of residential single-family homes do not take into account the cost of lighting, equipment, or transportation of stuff and things. The value of non-renewable primary energy was determined for each member state by applying the primary and non-renewable primary energy variables in the calculation. These principles were discussed in further detail in chapter 4 of the thesis study.

It is important to keep in mind that the reference building scenario will be abbreviated as "RB" while the other scenarios will be denoted by the letters SC. The scenario with the Number 17, for instance, will be abbreviated as SC17 from now on.

Throughout all of the estimates, significant decreases in the use of primary sources of non-renewable energy were found. In each of the three different climates, the non-renewable primary energy consumed by the reference buildings was the greatest. In the first scenario, the non-renewable primary energy consumption for the home in Turin was calculated at 66.37 kWh/m2a, whereas in the 71st scenario, this figure was calculated to be 0 kWh/m2a (SC71). While the SC71 house in Stockholm used only 2.43 kWh/m2a, the reference house in Stockholm used 65.44 kWh/m2a. And measurements taken in Copenhagen showed a drop from 62.89 kWh/m2a to 3.16 kWh/m2a in the same time period. This decline was a result of high expectations due to the fact that the performance of the construction components had grown, and scenario by scenario, higher technology had been included.

The impact that advances in technology have had on the consumption of primary sources of energy that are not renewable is outlined in the table below. It is important to note that none of the possible outcomes use photovoltaics at this time. The ground source heat pump was unequivocally the solution that delivered the best performance with regard to energy.

Building components scenarios/Heating and cooling systems	**System 1 [kWh/m2a]**	**System 2 [kWh/m2a]**	**Difference [%]**	**System 3 [kWh/m2a]**	**Difference [%]**
Turin reference refurbishments	66.37	50.12	**-24.4**	42.55	**-35.8**
Stockholm reference refurbishments	65.44	30.02	**-54.1**	21.95	**-66.5**
Copenhagen reference refurbishments	62.89	44.96	**-28.1**	33.29	**-47.1**

Table 5.1-1System refurbishments by climate

When a photovoltaic system was connected, there was a noticeable shift in the amount of primary energy that came from non-renewable sources. When natural gas was replaced by electricity as the primary source of energy for generators, these shifts took on an even greater degree of significance. For the city of Turin, for instance, it was discovered that the reduction in the amount of non-renewable primary energy value for a 1.6 kWp PV configuration with a conventional boiler was 25.3%, whereas for the same house, the reduction was 44.3% when it was equipped with a generator of a ground source heat pump. This distinction is brought about by the fact that the heat pump receives its power supply straight from the generator. Therefore, the utilization of a heat pump results in an increase in the requirement for the consumption of electrical power. This is also demonstrated when the capacity of the PV system is increased to 3.2 and 6.3 kWp, respectively. In a scenario in which a conventional boiler was used, the addition of photovoltaics had no influence on the amount of energy produced. However, the on-site renewable source was still helpful in satisfying

Heating system	PV0 [kWh/m2a]	PV1 [kWh/m2a]	Δ [%]	PV2 [kWh/m2a]	Δ [%]	PV3 [kWh/m2a]	Δ [%]
Traditional Boiler	66.37	49.57	**-25.3**	47.31	**-4.6**	47.31	**0**
Air source heat pump	50.12	30.49	**-39.2**	22.29	**-26.9**	17.0	**-23.7**
Ground source heat pump	42.55	23.69	**-44.3**	21.06	**-11.1**	18.14	**-13.9**

Table 5.1-2Effect of PV on non-renewable primary energy in Turin

When the results from Turin's climate are compared to those from the other two climates, it's possible that the photovoltaic impact will be slightly different in Turin. When the generators were swapped, there was a smaller decline in demand for primary sources of nonrenewable energy in Turin. This is due to the fact that the cooling load in Turin is considerably larger compared to that in Stockholm and Copenhagen. In addition, because the cooling load was handled by an air-source heat pump even in the conventional boiler scenarios, the additional advantage from PV was diminished when the generator was used in its place.

Heating system	PV0 [kWh/m2a]	PV1 [kWh/m2a]	Δ [%]	PV2 [kWh/m2a]	Δ [%]	PV3 [kWh/m2a]	Δ [%]
Traditional Boiler	65.44	50.45	**-22.9**	50.13	**-0.6**	50.03	**-0.2**
Air source heat pump	44.96	12.01	**-73.3**	8.84	**-26.4**	7.52	**-14.9**

Ground source heat pump	21.95	5.85	**-73.3**	5.16	**-11.8**	3.84	**-25.6**

Table 5.1-3Effect of PV on non-renewable primary energy in Stockholm

Turin's potential for the generation of power from photovoltaic cells is demonstrated by the results to be significantly higher than that of the other two cities under consideration, which is an additional point regarding the importance of the influence of PV. It is common knowledge that Turin is subjected to higher levels of irradiation from both direct and diffuse sources along the horizontal plane. The 71st scenario (SC71) in Turin was the only one that resulted in a house that was able to achieve a net-zero energy building (0 kWh/m2a). This was due to the fact that it was able to derive a greater advantage from PV within the same time frame as the refurbishment of building components.

Heating system	PV0 [kWh/m2a]	PV1 [kWh/m2a]	Δ [%]	PV2 [kWh/m2a]	Δ [%]	PV3 [kWh/m2a]	Δ [%]
Traditional Boiler	62.89	42.5	**-32.4**	40.93	**-3.7**	40.93	**0**
Air source heat pump	44.96	23.83	**-47.0**	18.51	**-22.3**	12.35	**-33.3**
Ground source heat pump	33.29	13.07	**-60.7**	9.01	**-31.1**	4.33	**-9**

Table 5.1-4Effect of PV on non-renewable primary energy in Copenhagen

5.2 Economical evaluation

The EN 15459:2018 standard was utilized throughout the process of carrying out the economic calculations. Earlier on in this thesis work, in part 2, the steps and inputs that make up this standard were broken down and discussed. Within the Edilclima program is a module known the energy diagnostics and improvement actions. This module was responsible for doing the calculations. The column charts that follow illustrate, for a selection of possible outcomes, the expenses associated with investment, maintenance, replacement, and energy use. The reference nuilding scenario is the one that should be used as a reference for developing each climatic scenario. The scenarios with the lowest cost (SC32 for Turin and SC56 for Copenhagen and Stockholm) are compared with the scenario with the lowest non renewable primary energy use (SC71 for all climates)

When compared to the other climates, the baseline scenario has the greatest energy cost but the lowest investment cost. This is something that is observed across the board. This is because the building in question has not been upgraded or given any new technology. In addition, it has been found that the NZEB solution has the highest investment and lowest energy costs.These outcomes were unsurprising and in line with expectations. It is useful to have an understanding that the expenses of the C-opt solution fell somewhere in the middle of the baseline scenario and the C-opt scenario, which ensures that the adopted scenarios are accurate enough.

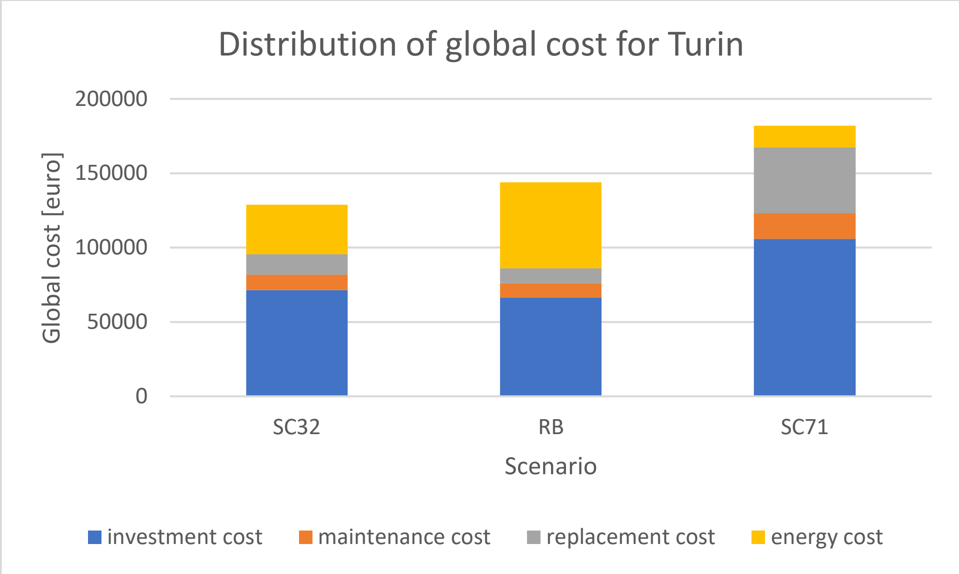

Figure 5.2.1 Column chart of the distribution of global cost for selected scenarios in Turin

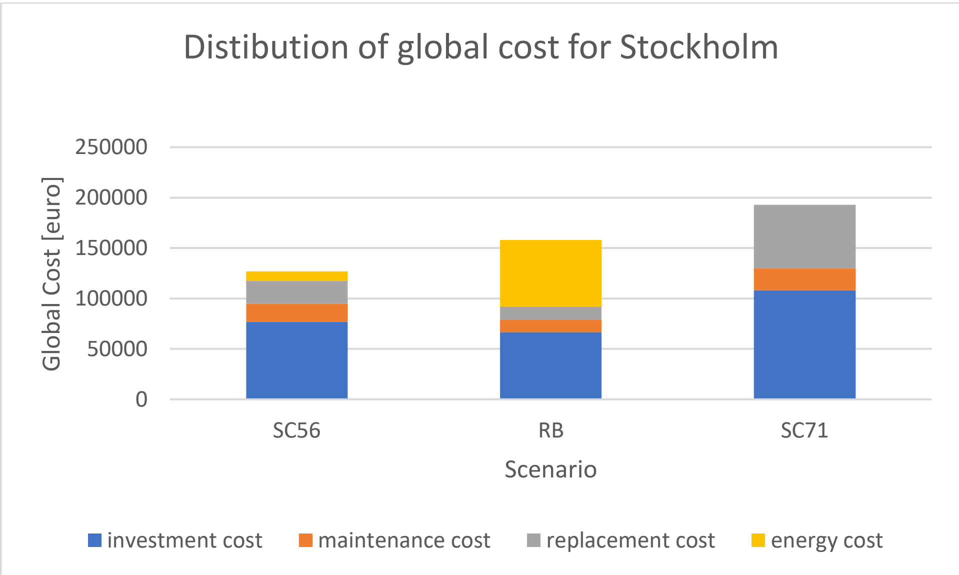

Figure 5.2.2 Column chart of the distribution of global cost for selected scenarios in Stockholm

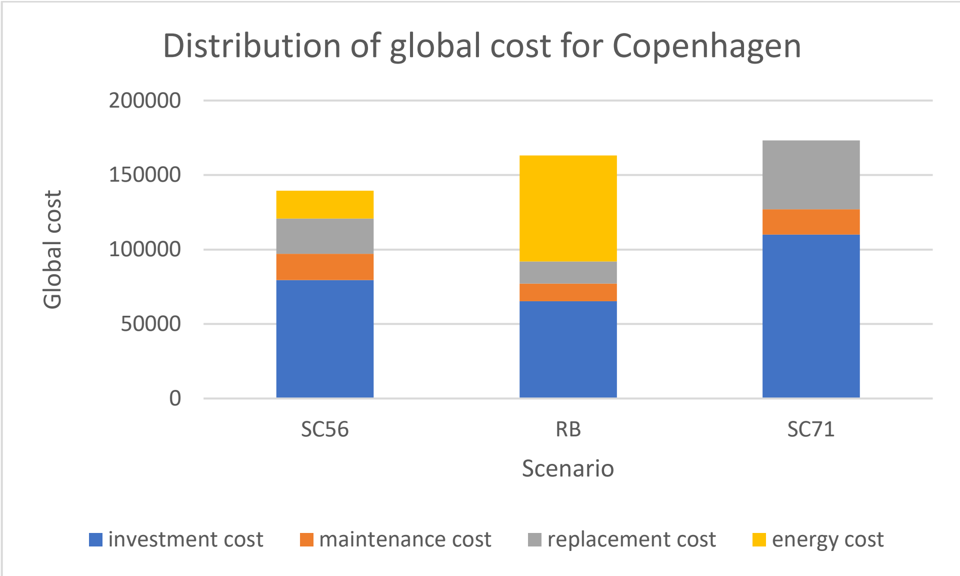

Figure 5.2.3Column chart of the distribution of global cost for selected scenarios in Copenhagen

It can also be observed that the refurbishments resulted in a reduction of 40% of the worldwide costs, which brought that number down to 8%, while the increase in investment costs brought that number up to 58% from 46%. Maintenance expenses went up from 7% to 8% as a direct result of the installation of additional equipment. Because of the identical factor, the expenses of replacement skyrocketed by an amount equal to 16%.

The replacement cost is the variable that contributes the most significantly different cost percentages between the Cost optimum scenario and the NZEB scenario. A shift from 11% to 24% of the total. Even though an attempt was made to make up for these additional costs by increasing the cost of the energy, the NZEB scenario still ended up being the most expensive scenario.

When considered in isolation, the findings concerning the expenses do not produce any conclusive findings. When contrasted with one another in the following section, the cost and energy numbers will take on a greater level of significance.

5.3 The cost optimal solution

The findings of a comparison between the utilization of non-primary energy (kWh/m2a) and the global cost per m2 are depicted in the scatter graphs that can be seen below. The quantities of energy consumption are represented along the horizontal axis, while the global cost per square meter is shown along the vertical axis (in euros per square meter). SC 71, which had a value of 0 kWh/m2a, was the lowest possible level of non-renewable primary energy use for Turin . Which is the same as a building that uses zero net energy. The building with the highest energy value, which serves as the reference structure(marked as RB), has a value of 66.37 kWh/m2a. All of the other energy values fall somewhere within this range of numbers. The prices per square meter range from 1084 euros per square meter (SC19) to 712 euros per square meter (SC32). The outcomes of the Turin competition can be seen in the scatter graph that follows. The scatter plot is equipped with a distribution plot found on the top and right sight of the figure. These distribution plots represents the density on which values of cost and energy are at. In figure 5.3.1, it could be seen that the non-renewable primary energy usage values are much higher for system 1 when its compared to system 2 and 3. While the cost values are the highest for system 1 and then system .Which makes system 2 the most cost-efficient solution.

On the graphs, the points are classified according to the heating systems that they use. The first type of heating system is the conventional boiler. The ground source heat pump is represented by heating system 3, whereas heating system 2 is the air source heat pump. The table below explains the previous description in detail.

	System 1	System 2	System 3
Heating	Traditional boiler	Air to water heat pump + Condensing boiler	Ground source heat pump + Condensing Boiler
Domestic Hot Water	Traditional boiler + Solar thermal collectors	Air to water heat pump + Solar thermal collectors	Ground source heat pump +Solar thermal collectors
Cooling	Air to water heat pump	Air to water heat pump	Ground source heat pump

Table 5.3-1Reminder of the selected systems

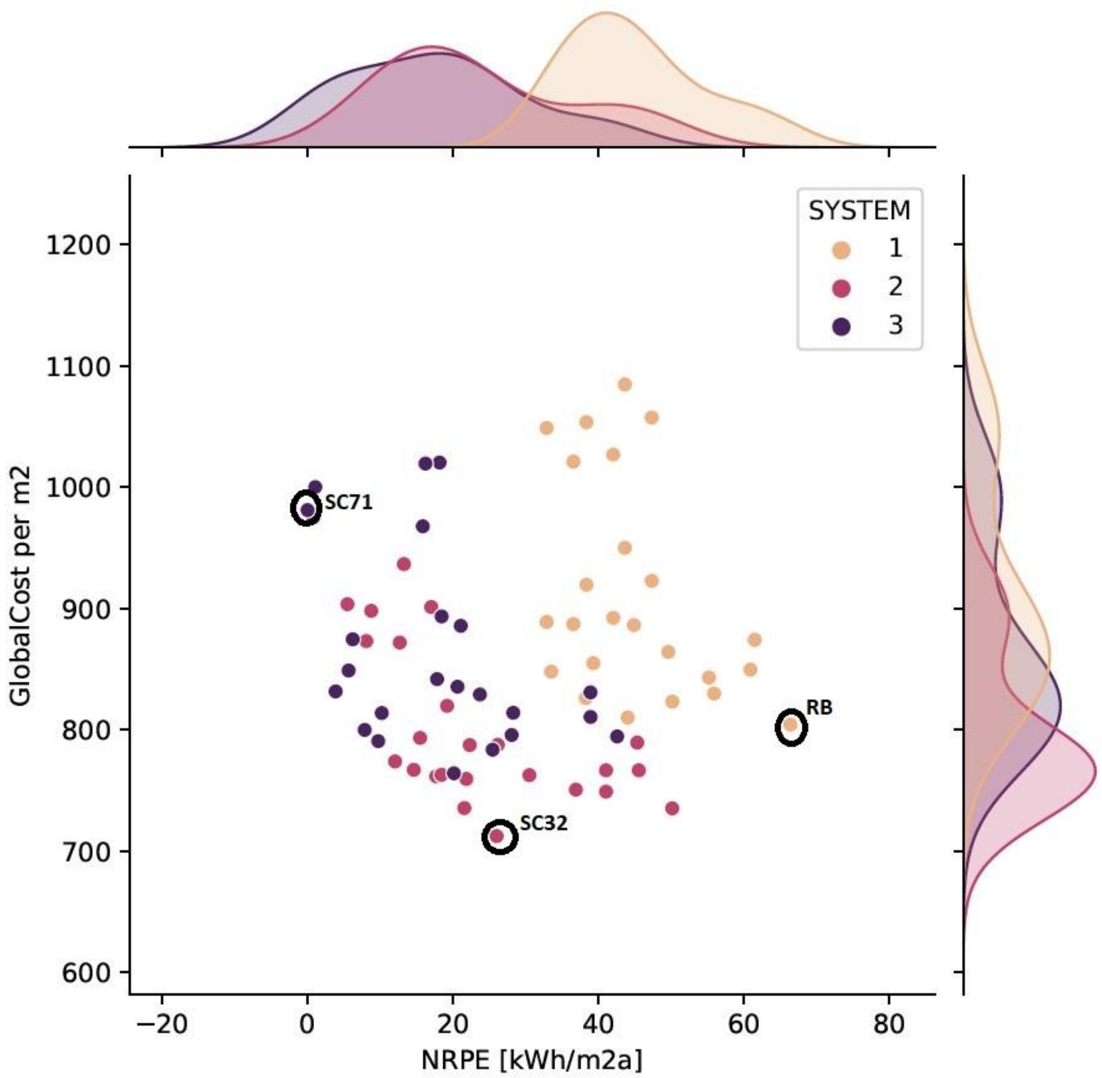

Figure 5.3.1Non-renewable primary energy vs Global cost per m2 scatter plot in Turin

In figure 5.3.2, it I seen tha tSC71 in Stockholm has the lowest non-renewable primary energy use at 2.43 kWh/m2a. The reference building has the highest energy efficiency, at 65.44 kWh/m2a. All the other energies fall inside this range. Estimated expenses range from 1893 euros per square meter in Scenario 19 to 1102 euros per square meter in Scenario SC56. The distribution plot shows the biggest a large difference in terms of primary energy and cost in system 1. While system 2 and system 3 were much closer results.

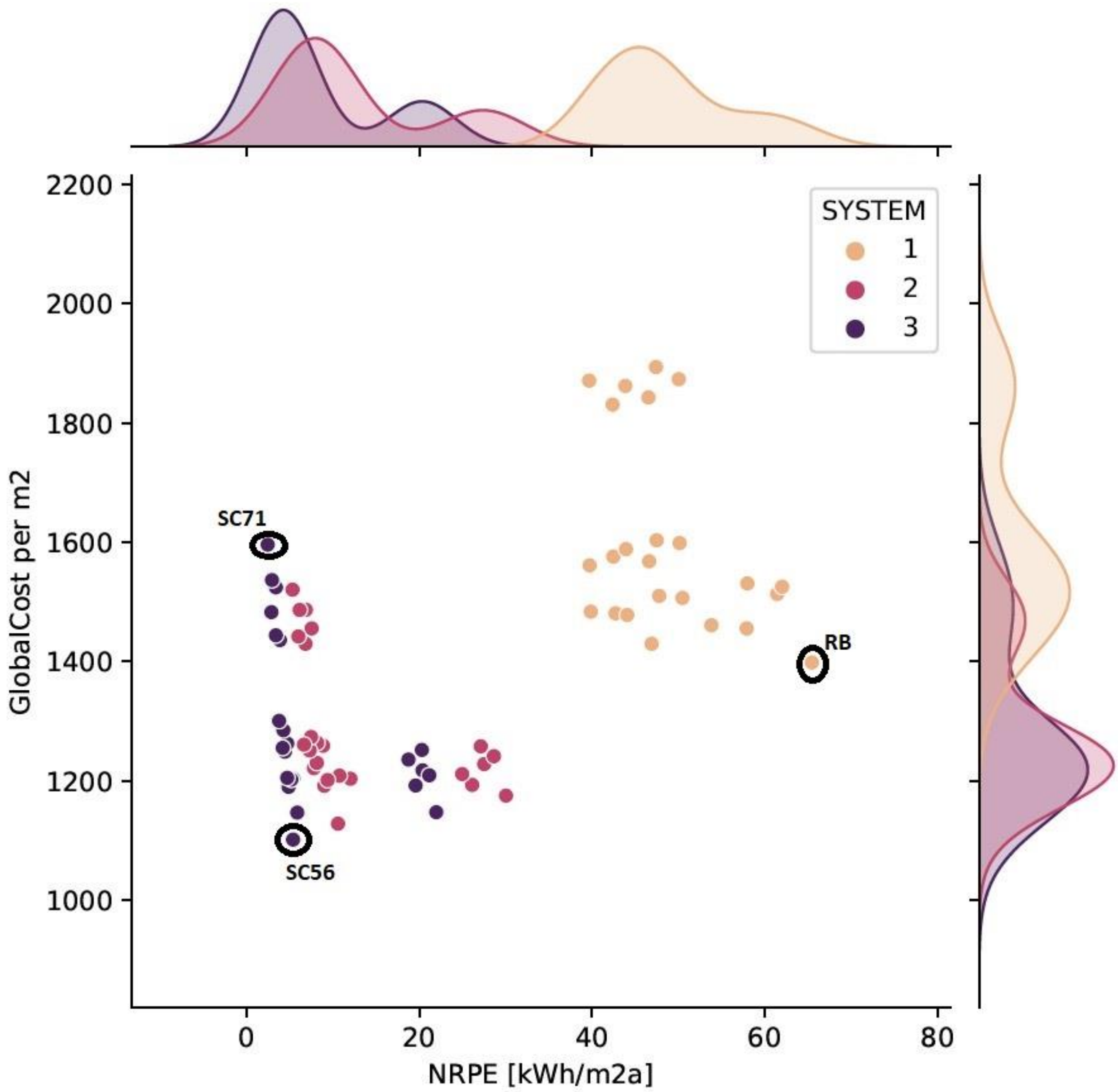

Figure 5.3.2Non-renewable primary energy vs Global cost per m2 scatter plot in Stockholm

SC71 has the lowest non-renewable primary energy use for Copenhagen at 3.16 kWh/m2a .The reference building(RB) with the highest energy value is 62.89 kWh/m2a. The remaining energy values fall within this range. The expenses per square meter range from 1,270 euros per square meter (SC22) to 866 euros per square meter (SC56). The outcomes of Copenhagen are depicted in figure 5.3.3.The difference in non-renewable primary energy between systems 1 against 2 and 3 is quite clear in Denmark as well.

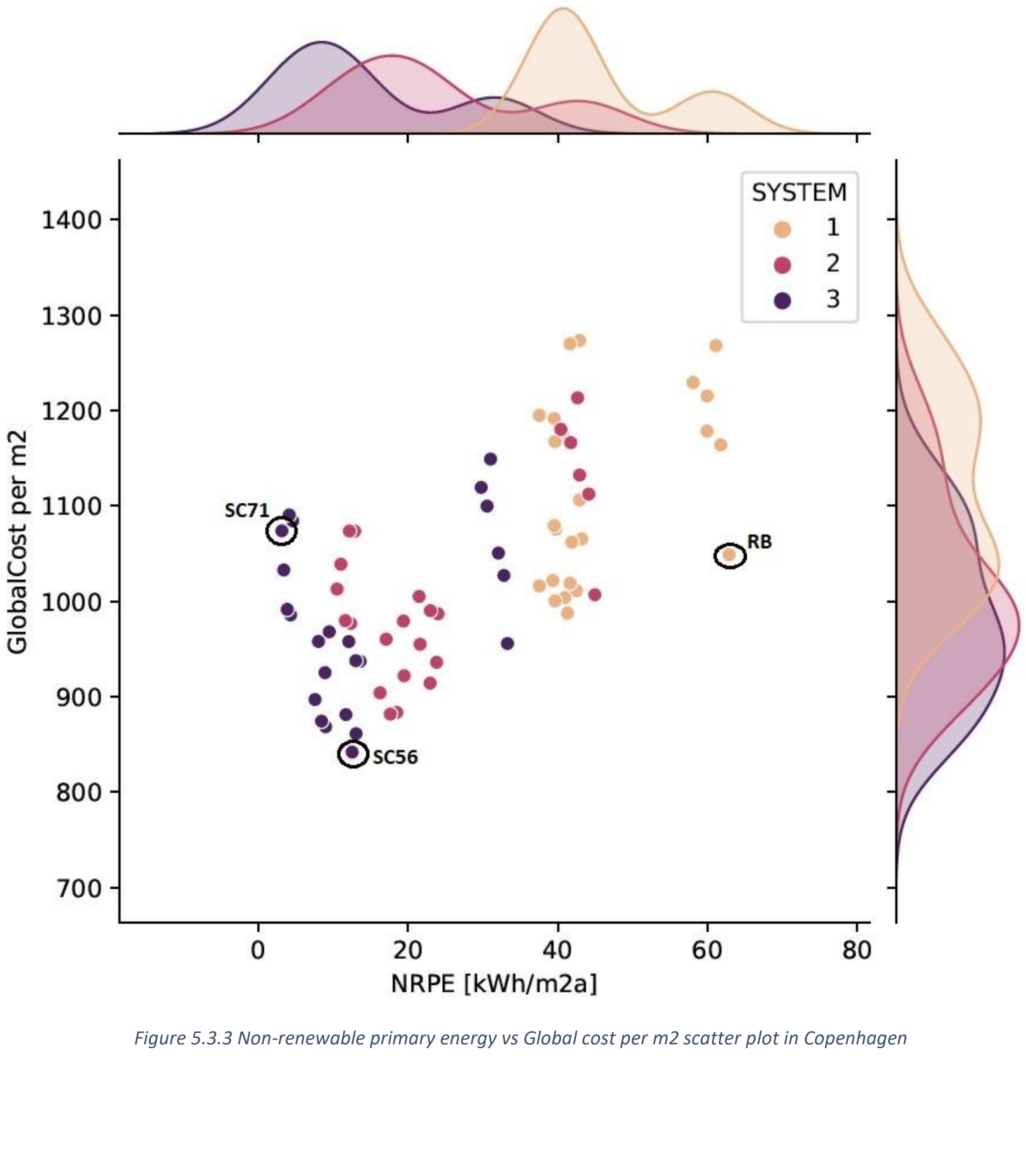

Figure 5.3.3 Non-renewable primary energy vs Global cost per m2 scatter plot in Copenhagen

These infographics make it simple to identify the cost-effective solutions that are most suited for each climate. The appendix section allowed for the examination of the precise values of each piece of data. SC32 was determined to be the most financially beneficial option for Turin. Window 1, which is the window that is used as the standard in the reference building, is included in Scenario 32. Wall 2 of the exterior, which indicates that an additional layer of fiberglass insulation was installed for protection. The air source heat pump was used for both the heating and cooling systems, and the total peak output of the PV systems that were installed was 1.6 kWp. Because of this setup, the initial consumption of non-renewable energy increased by 11.4% in 50 years.

SC56 was the best option from a financial perspective for both Stockholm and Copenhagen. Window 1 is the one that is really opened in SC56, which has this window installed. Wall 2 of the exterior, which indicates that an additional layer of fiberglass insulation was installed for protection. The ground source heat pump was used for both the heating and cooling systems, and the total peak output of the PV systems that were installed was 1.6 kWp. Following the completion of the renovations, the overall amount of non-renewable energy consumed decreased by 91.8% in Stockholm and by 80% in Copenhagen. The reduction in worldwide costs was 41.8%, and the reduction in local costs was 31.8%.

The reduction in non-renewable primary energy and overall expenses associated with the C-opt and NZEB scenarios are broken down and summarized in the table below.

	NRPE [kWh/m2a]			**Global cost difference from RB [%]**	
Climate	RB	Cost optimal scenario	SC71	Cost Optimal Scenario	NZEB
Turin	68.12	25.99	0	-11.4	21.9
Stockholm	65.44	5.37	2.43	-21.2	14.1
Copenhagen	62.89	12.55	3.16	-18.26	1.3

Table 5.3-2 Change of primary energy and costs by each climate for specific scenarios

5.4 The effect of Photovoltaics

Each new level of photovoltaic panels installed automatically results in a higher installment cost; nevertheless, certain levels of PV have resulted in a lower global cost for heat pump operations. The utilization of solar photovoltaic output is helped by the rising demand for electricity. The scatter plots that follow will show you how the non-renewable primary energy used and the costs have changed over time. The direction of the arrows indicates the progression of PV. Therefore, the scenario on the far right is a scenario with no PV system installed while the scenario on the far left if a scenario with the highest configuration of PV(6.3 kWp). It is possible to see that PV raises costs while simultaneously lowering the need for primary energy derived from non-renewable sources, however there is a value of total peak power that is ideal somewhere around PV1 and PV2.This is observed in all three climates. As a result of this, the option with the lowest cost was determined to be 1.6 kWp, although the solution with 3.2 kWp was not too far behind. Table below re-explains the details on the PV configurations.

	Level 0 - PV0	**Level 1- PV1**	**Level 2- PV2**	**Level 3- PV3**
PV total peak power [Wp]	No PV installed	1600	3200	6300

Figure 5.4.1Summary of PV configurations

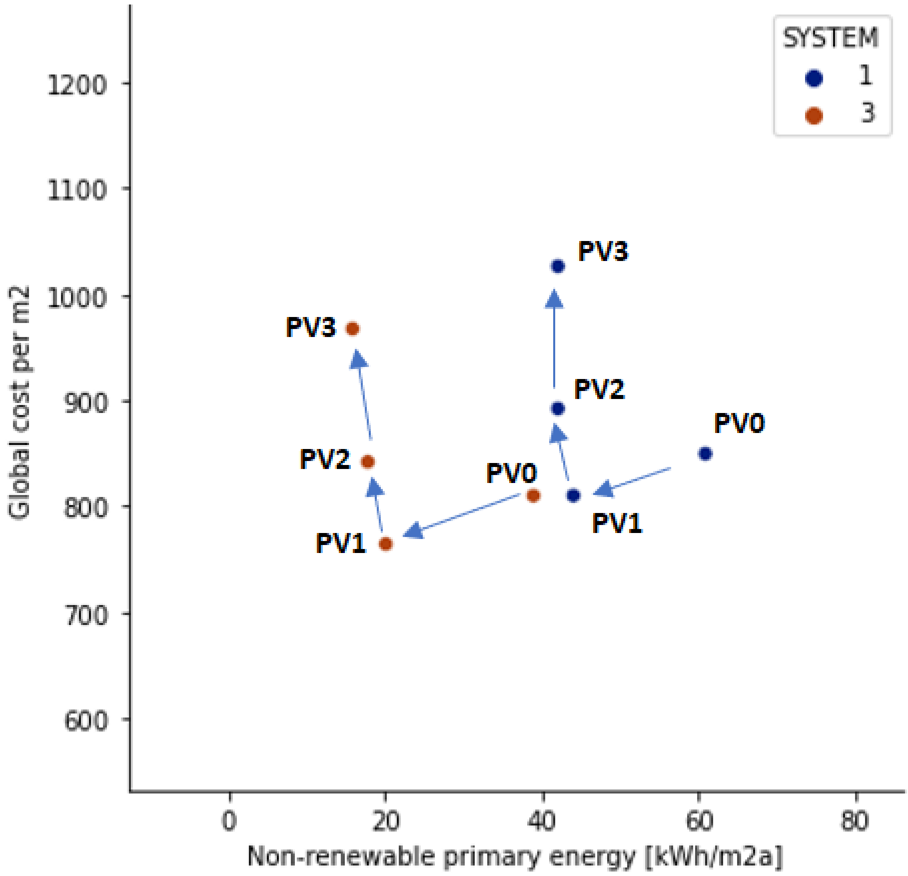

Figure 5.4.2Effect of PV in Turin

The arrows are evidence that there is a best-case scenario for the layout of photovoltaic systems. In spite of the fact that the use of non-renewable primary energy continued to reduce in each of the scenarios as a result of the addition of PV modules, the overall cost reached an extremely high level. The steepness of the arrows illustrates how challenging it is, from an economic standpoint, to incorporate photovoltaics.It must also be observed that the additional cost versus the energy gains were much less in system 1 compared to system 3. This is because the increased electricity demand when a heat pump is in operation.

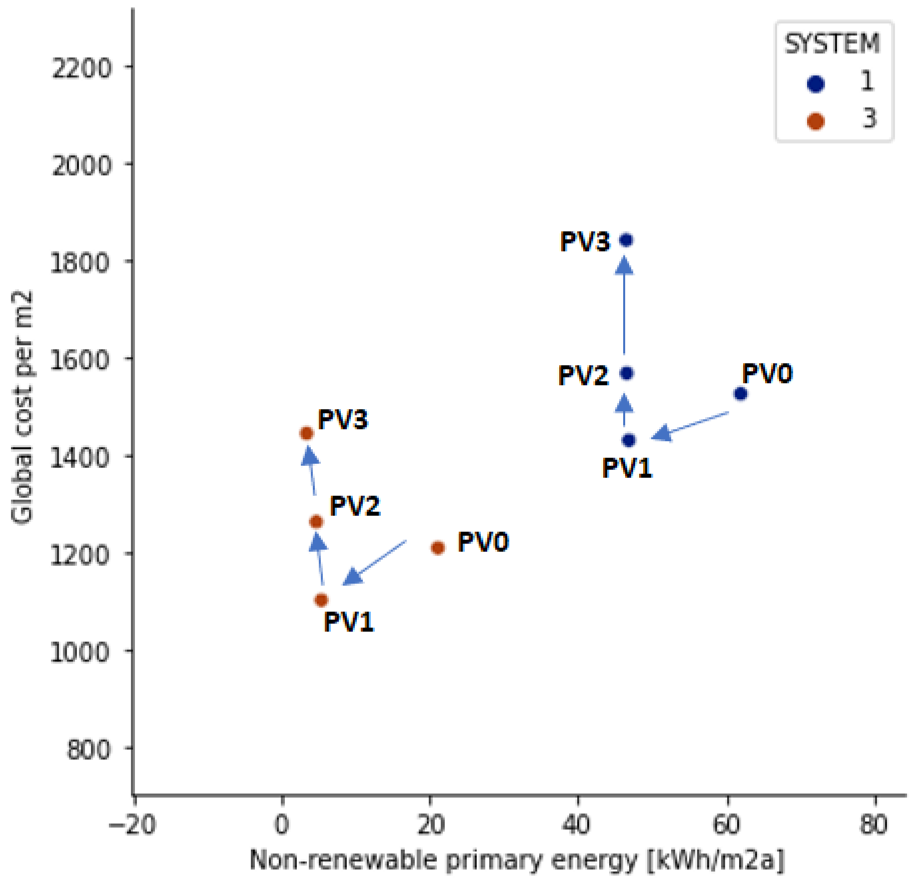

Figure 5.4.3Effect of PV in Stockholm

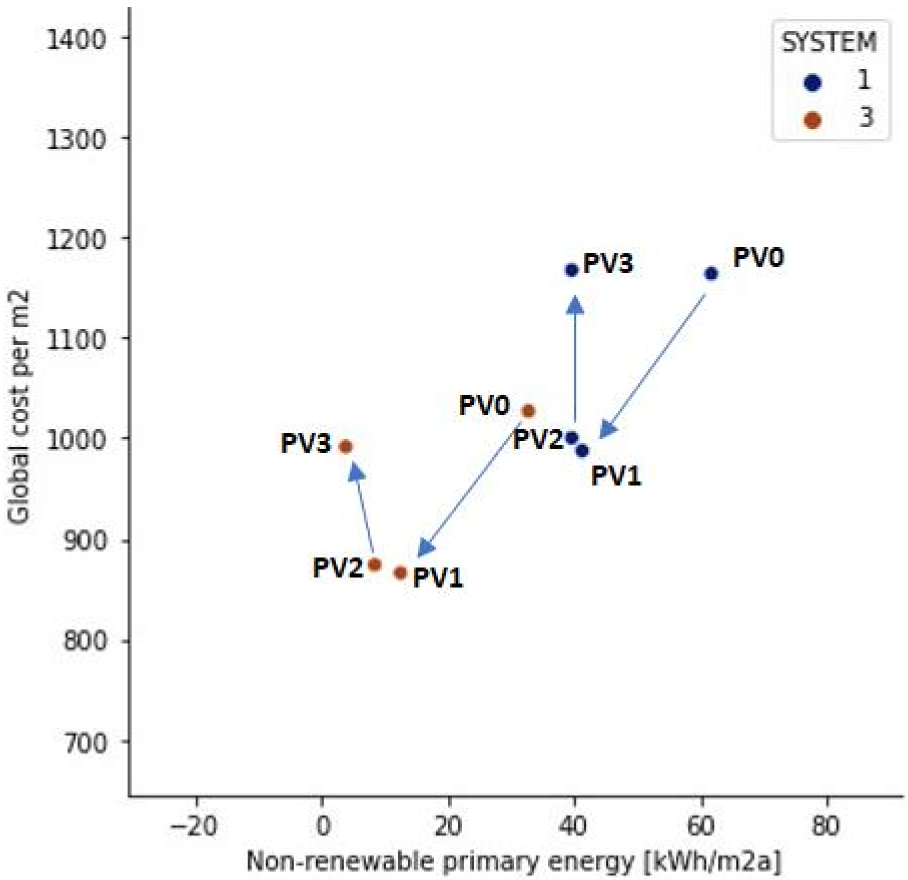

Figure 5.4.4Effect of PV in Copenhagen

5.5 Conclusion

The cost-effectiveness of different building component refurbishments and system refurbishments of a single-family home in three different climates were analyzed. The climate in Turin is subtropical with dry summers and Mediterranean, the climate in Copenhagen is humid oceanic, and the climate in Stockholm is humid continental. Refurbishment of the building's components, including the windows and the external walls, was carried out in accordance with the EPBD 2018/844 requirements for existing buildings. Various ways of measurement for technical systems were implemented. There were a total of 72 different climate-specific scenarios that were used. This indicates that 216 different actions were executed.

The findings of the study demonstrate that it is possible, regardless of climate, to achieve low energy usage while also reducing global prices. By utilizing innovative technological systems such as heat pumps and photovoltaics, it is possible to achieve low levels of energy consumption. The cost optimal solution for Turin had a overall reduction of cost by 11.4% while Stockholm and Copenhagen did 21.2% and 18.26% respectively. The reduction of costs were higher in the Baltic countries due to the high natural gas prices. The shift towards using electricity as the primary source made a larger impact. Due of the prohibitively high costs of external wall refurbishments and photovoltaics, the most energy-optimal alternatives did not offer the best method of saving from the cost. There was also a large difference across countries in terms of the non-renewable primary energy. The cost for the best energy performant scenario for Turin increased by 21.9% while the increase was 14.1% in Stockholm and 1.3% in Copenhagen. The increase in Copenhagen was not too high due to its high minimum requirements of Denmark while the building process was taking place. Meaning, the building was already high performant before refurbishments were applied.

The scenarios in the study showed that it was much easier to reach cost-optimal values by differentiating the heating and cooling system measures rather than building components. The shift toward heat pumps may arrive at nearly positive buildings, but in order to obtain net zero values, a high installation of photovoltaics in conjunction with a stringent building envelope was also required.

It is also observed that, within the proposed scenarios, only one case in Turin made it possible to reach a 0 kWh/m2a non-renewable primary energy consumption value. This was because Turin had much higher efficiencies while generating electricity from the photovoltaics due to its advantage of capturing higher solar irradiation. More amount of PV was necessary for Denmark and Sweden cases to reach a net-zero energy building by definition.Which would not be feasible in terms of cost.

One important difference comparing the results in Turin and the results in the Baltic countries is that the main heating source of cost-optimal solution for Turin was an air source heat pump. While the main heating source of the cost optimal solutions in the other countries was a ground source heat pump. This was because air source heat pumps usually perform in outside air temperatures that are not as cold as in Sweden or Denmark. Where since the ground source heat pumps extracts heat from the ground, the temperature doesn't drop below freezing which makes it more efficient in colder climates.

The lowest non-renewable primary energy value reached in the cost optimal scenarios was in Sweden. This was because Sweden had the lowest non-renewable primary energy factor for electricity among the three countries. The more electricity was used the lower energy values Sweden had compared to the other climates. This also shows that the goals set by a country could be reached either easier or harder by manipulating the primary energy factors. Regardless of changing the systems or building configurations.

5.6 Future works and improvement

The work for the thesis could be strengthened by a number of alterations and additions. The effects of these modifications would produce more precise results regarding the building's energy consumption as well as its energy generation. In accordance with the monthly UNI/TS 11300 standard described in section 3, the calculations were carried out. However, the majority of current research has been on performing the calculations on an hourly time scale. hourly demand estimates according to EN 52016:2018 and hourly generation profile calculations according to EN15316:2017 Even if these standards are not currently mandated by the legislation, adopting them will undoubtedly lead to more precise outcomes. These findings were more significant when analyzed in terms of cooling loads as opposed to heating loads. However, these computations are significantly more complicated and need a great deal of time for computations. These technologies are utilized in an efficient manner by pricey software such as EnergyPlus, IDA ICE, and TRNSYS. Although Edilclima has not yet implemented the hourly generation profiles, the hourly EN 52016 dynamic hourly approach is included in the software.

Including lighting and the transportation of things is one way to add more detail to the possible scenarios. On the other hand, as was said earlier, the incorporation of them is not mandated by the standard for single-family dwellings.

The topic could be expanded to include additional climates in order to get to nearly zero values. It would be more difficult, but it would also give rise to a wider variety of new possibilities if there were more arctic, temperate, arid, or tropical climates.

Buildings could benefit from the installation of mechanical ventilation in order to enhance the flow of air and promote occupant comfort. It would be possible to install more technological advancements for shadings and demand side management of the amount of heating and cooling the property requires.

Utilizing a battery as a storage mechanism is another fantastic technique to increase the results, particularly the effect of photovoltaics on the system. Although this has proven to be an effective strategy for reaching a net-zero energy building, it is not yet an alternative that can be considered economically viable.

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Appendix

A) RESULTS OF TURIN

Scenario	W	EW	SYS	PV	NRPE [kWh/m2a]	Global Cost per m2 [Euro/m2]
RB	1	1	1	0	66.37	804.3384483
SC01	2	1	1	0	61.46	874.1132184
SC02	1	2	1	0	60.87	849.5701724
SC03	1	3	1	0	55.17	843.0961494
SC04	2	2	1	0	55.87	829.8794828
SC05	2	3	1	0	50.14	823.2235057
SC06	1	1	1	1	49.57	864.1827586
SC07	2	1	1	1	44.86	886.2801149
SC08	1	2	1	1	44.01	810.1050575
SC09	1	3	1	1	38.25	826.1726437
SC10	2	2	1	1	39.27	854.8191379
SC11	2	3	1	1	33.49	847.9198276
SC12	1	1	1	2	47.31	922.7163218
SC13	2	1	1	2	43.61	949.953908
SC14	1	2	1	2	42.02	892.2458621
SC15	1	3	1	2	36.54	887.0956897
SC16	2	2	1	2	38.32	919.4981034
SC17	2	3	1	2	32.86	888.8476437
SC18	1	1	1	3	47.31	1057.304885
SC19	2	1	1	3	43.61	1084.524483
SC20	1	2	1	3	42.02	1026.789023
SC21	1	3	1	3	36.54	1021.007816
SC22	2	2	1	3	38.32	1053.47569
SC23	2	3	1	3	32.86	1048.723103
SC24	1	1	2	0	50.12	735.3063793
SC25	2	1	2	0	45.31	789.5027586
SC26	1	2	2	0	45.53	766.6291954
SC27	1	3	2	0	41.02	766.6275287
SC28	2	2	2	0	41.02	749.0605747
SC29	2	3	2	0	36.88	750.6717241
SC30	1	1	2	1	30.49	762.6241954
SC31	2	1	2	1	26.15	787.6673563
SC32	1	2	2	1	25.99	712.3741954
SC33	1	3	2	1	21.54	735.5279885
SC34	2	2	2	1	21.82	759.5020115
SC35	2	3	2	1	17.68	761.656092

SC36	1	1	2	2	22.29	787.4228161
SC37	2	1	2	2	19.18	819.7227011
SC38	1	2	2	2	18.4	762.9072414
SC39	1	3	2	2	14.6	767.0170115
SC40	2	2	2	2	15.47	793.3101149
SC41	2	3	2	2	12.02	773.9121264
SC42	1	1	2	3	17	901.1677586
SC43	2	1	2	3	13.24	936.5702299
SC44	1	2	2	3	12.67	871.8922414
SC45	1	3	2	3	8.07	873.0994253
SC46	2	2	2	3	8.75	898.025
SC47	2	3	2	3	5.48	903.5197701
SC48	1	1	3	0	42.55	794.5255172
SC49	2	1	3	0	38.89	830.8294828
SC50	1	2	3	0	38.9	810.605
SC51	1	3	3	0	28.27	814.0371264
SC52	2	2	3	0	28.05	795.7547126
SC53	2	3	3	0	25.44	783.6124713
SC54	1	1	3	1	23.69	829.1164943
SC55	2	1	3	1	20.61	835.504023
SC56	1	2	3	1	20.11	764.1725287
SC57	1	3	3	1	9.71	790.6792529
SC58	2	2	3	1	10.2	813.8051724
SC59	2	3	3	1	7.85	799.9114368
SC60	1	1	3	2	21.06	885.6801149
SC61	2	1	3	2	18.43	893.4358621
SC62	1	2	3	2	17.8	841.7726437
SC63	1	3	3	2	5.64	848.8387931
SC64	2	2	3	2	6.21	874.5743103
SC65	2	3	3	2	3.86	831.6427011
SC66	1	1	3	3	18.14	1020.25069
SC67	2	1	3	3	16.2	1019.394253
SC68	1	2	3	3	15.84	967.7036207
SC69	1	3	3	3	0.78	975.102931
SC70	2	2	3	3	1.06	1000.034713
SC71	2	3	3	3	0	981.0413218

B)RESULTS OF STOCKHOLM

Scenario	W	EW	SYS	PV	NRPE [kWh/m2a]	GlobalCost per m2 [Euro/m2]
RB	1	1	1	0	65.44	1398.684953
SC01	2	1	1	0	61.43	1513.544019
SC02	1	2	1	0	62	1525.524299
SC03	1	3	1	0	57.97	1530.993832
SC04	2	2	1	0	57.89	1455.711869
SC05	2	3	1	0	53.81	1461.044766
SC06	1	1	1	1	50.45	1506.793458
SC07	2	1	1	1	47.76	1510.171028
SC08	1	2	1	1	46.89	1430.045234
SC09	1	3	1	1	42.7	1481.033178
SC10	2	2	1	1	44.06	1478.235607
SC11	2	3	1	1	39.84	1483.826542
SC12	1	1	1	2	50.13	1598.726729
SC13	2	1	1	2	47.47	1603.29
SC14	1	2	1	2	46.6	1568.163178
SC15	1	3	1	2	42.45	1576.025888
SC16	2	2	1	2	43.91	1588.480841
SC17	2	3	1	2	39.71	1561.272523
SC18	1	1	1	3	50.03	1873.115701
SC19	2	1	1	3	47.39	1893.517383
SC20	1	2	1	3	46.52	1842.514766
SC21	1	3	1	3	42.37	1830.581215
SC22	2	2	1	3	43.84	1861.876729
SC23	2	3	1	3	39.65	1870.734953
SC24	1	1	2	0	30.02	1175.721495
SC25	2	1	2	0	27.5	1228.507944
SC26	1	2	2	0	28.62	1241.706168
SC27	1	3	2	0	27.1	1258.295794
SC28	2	2	2	0	26.11	1193.642056
SC29	2	3	2	0	24.95	1211.779907
SC30	1	1	2	1	12.01	1203.928037
SC31	2	1	2	1	10.74	1209.131402
SC32	1	2	2	1	10.57	1128.681215
SC33	1	3	2	1	8.98	1192.228598
SC34	2	2	2	1	9.37	1201.775234
SC35	2	3	2	1	7.78	1221.807477
SC36	1	1	2	2	8.84	1259.261589
SC37	2	1	2	2	8.16	1264.084299

SC38	1	2	2	2	8.12	1230.551121
SC39	1	3	2	2	7.29	1251.438972
SC40	2	2	2	2	7.45	1273.854299
SC41	2	3	2	2	6.63	1261.087383
SC42	1	1	2	3	7.52	1455.73486
SC43	2	1	2	3	6.85	1486.892056
SC44	1	2	2	3	6.81	1429.948598
SC45	1	3	2	3	5.98	1442.250841
SC46	2	2	2	3	6.13	1486.729626
SC47	2	3	2	3	5.31	1520.673084
SC48	1	1	3	0	21.95	1147.893738
SC49	2	1	3	0	20.36	1218.063178
SC50	1	2	3	0	21.14	1209.709439
SC51	1	3	3	0	20.28	1252.241682
SC52	2	2	3	0	19.56	1192.640374
SC53	2	3	3	0	18.73	1236.130561
SC54	1	1	3	1	5.85	1147.245047
SC55	2	1	3	1	5.37	1204.162243
SC56	1	2	3	1	5.37	1102.068785
SC57	1	3	3	1	4.85	1190.286729
SC58	2	2	3	1	4.92	1205.163551
SC59	2	3	3	1	4.42	1249.275888
SC60	1	1	3	2	5.16	1202.578598
SC61	2	1	3	2	4.69	1263.064766
SC62	1	2	3	2	4.69	1205.46514
SC63	1	3	3	2	4.17	1255.653551
SC64	2	2	3	2	4.25	1285.18028
SC65	2	3	3	2	3.75	1300.845514
SC66	1	1	3	3	3.84	1436.167009
SC67	2	1	3	3	3.38	1524.518598
SC68	1	2	3	3	3.38	1444.172804
SC69	1	3	3	3	2.86	1482.969907
SC70	2	2	3	3	2.93	1536.66972
SC71	2	3	3	3	2.43	1596.010935

C)RESULTS OF COPENHAGEN

Scenario	W	EW	SYS	PV	NRPE [kWh/m2a]	GlobalCost per m2 [Euro/m2]
RB	1	1	1	0	62.89	1059.617219
SC01	2	1	1	0	61.12	1268.002119
SC02	1	2	1	0	61.76	1164.012517
SC03	1	3	1	0	59.94	1178.454371
SC04	2	2	1	0	59.95	1215.36404
SC05	2	3	1	0	58.07	1229.419603
SC06	1	1	1	1	42.5	1011.074967
SC07	2	1	1	1	43.19	1065.340596
SC08	1	2	1	1	41.3	987.5658278
SC09	1	3	1	1	39.35	1021.730331
SC10	2	2	1	1	41.89	1062.087881
SC11	2	3	1	1	39.74	1075.676623
SC12	1	1	1	2	40.93	1003.736358
SC13	2	1	1	2	42.92	1106.237086
SC14	1	2	1	2	39.65	1000.399338
SC15	1	3	1	2	37.55	1016.112715
SC16	2	2	1	2	41.65	1018.914305
SC17	2	3	1	2	39.54	1079.381987
SC18	1	1	1	3	40.93	1170.915695
SC19	2	1	1	3	42.92	1273.416358
SC20	1	2	1	3	39.65	1167.578675
SC21	1	3	1	3	37.55	1194.900728
SC22	2	2	1	3	41.65	1270.030331
SC23	2	3	1	3	39.54	1191.510331
SC24	1	1	2	0	44.96	1006.862848
SC25	2	1	2	0	42.66	1213.348675
SC26	1	2	2	0	44.15	1112.400861
SC27	1	3	2	0	42.93	1132.361523
SC28	2	2	2	0	41.74	1166.317417
SC29	2	3	2	0	40.42	1180.258212
SC30	1	1	2	1	23.83	936.0211921
SC31	2	1	2	1	24.01	986.8639735
SC32	1	2	2	1	22.96	914.1281457
SC33	1	3	2	1	21.63	954.8931788
SC34	2	2	2	1	23	990.1327152
SC35	2	3	2	1	21.5	1005.053974

SC36	1	1	2	2	18.51	883.4428477
SC37	2	1	2	2	19.4	979.2260927
SC38	1	2	2	2	17.64	881.7219205
SC39	1	3	2	2	16.28	904.0356954
SC40	2	2	2	2	19.49	921.9229801
SC41	2	3	2	2	17.09	960.2249007
SC42	1	1	2	3	12.35	976.7750331
SC43	2	1	2	3	12.89	1073.567417
SC44	1	2	2	3	11.64	979.7295364
SC45	1	3	2	3	10.54	1012.815629
SC46	2	2	2	3	12.18	1073.681722
SC47	2	3	2	3	11.04	1038.873444
SC48	1	1	3	0	33.29	955.7133775
SC49	2	1	3	0	31.03	1149.122649
SC50	1	2	3	0	32.81	1027.085298
SC51	1	3	3	0	32.08	1050.561854
SC52	2	2	3	0	30.57	1099.781722
SC53	2	3	3	0	29.78	1119.420265
SC54	1	1	3	1	13.07	867.602649
SC55	2	1	3	1	13.62	937.0729801
SC56	1	2	3	1	12.55	866.2649007
SC57	1	3	3	1	11.72	881.1380132
SC58	2	2	3	1	13.04	937.6781457
SC59	2	3	3	1	12.1	957.7203974
SC60	1	1	3	2	9.01	868.3958278
SC61	2	1	3	2	9.49	967.9974172
SC62	1	2	3	2	8.46	874.2740397
SC63	1	3	3	2	7.59	897.0001325
SC64	2	2	3	2	8.93	925.2243046
SC65	2	3	3	2	8.05	957.8684106
SC66	1	1	3	3	4.33	985.6562252
SC67	2	1	3	3	4.61	1084.268278
SC68	1	2	3	3	3.88	991.4968874
SC69	1	3	3	3	3.42	1032.824636
SC70	2	2	3	3	4.15	1090.563974
SC71	2	3	3	3	3.16	1073.848411

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