MCCXXII

VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

Università degli studi di Padova

DIPARTIMENTO DI INGEGNERIA INDUSTRIALE
Corso di Laurea Magistrale in Ingegneria Meccanica

TESI DI LAUREA MAGISTRALE

Energy efficient glazed office building envelope solutions for different European climates

Laureando:
Marco Scanferla
Matricola 1129506

Relatore:
Prof. Ing. Michele De Carli
Correlatrice:
Prof.ssa Violeta Motuziene

ANNO ACCADEMICO 2016-2017

ENERGY EFFICIENT GLAZED OFFICE BUILDING ENVELOPE SOLUTIONS FOR DIFFERENT EUROPEAN CLIMATES

Scanferla Marco

Abstract

The aim of this study is to show the critical aspects of a completely glazed high rise office building from an energy efficiency point of view in different European climates. The achievable consumptions and the most influential parameters such as glazing U-value, VT/SHGC and shading and their optimal values were investigated. The study has been carried out for a theoretical office building in Italy and Lithuania, representatively of a southern and northern EU climate. The building chosen is representative of all the glazed-simple shape buildings and the analysis of the entirety of the building enables a clear and immediate outcome of global consumptions. Number of DesignBuilder simulations were performed and the annual consumptions are summed with the primary energy criteria. Results show the critical aspects of 100% WWR buildings: in the coldest climate the main problem is the huge surface of relatively high glass U-value compared with standard walls, while in the warmer one the main efforts need to be done to avoid the summer overheating caused by incoming solar radiation. Finally, it is shown that it is difficult to lower the overall primary energy consumptions below 130 and 140 kWh/m^{2}a for North-Italy and Lithuania locations respectively. The analysis is focused only in the envelope parameter, thus it is not included renewable energy systems, which can generate higher energy efficiencies.

This document is to be considered the extended report which collects the entire scientific literature involved in the pertinent Paper, which was published with the same title in the “Science - Future of Lithuania” on September 2017.

Sommario

Il principale scopo di questa ricerca è di evidenziare, da un punto di vista dell'efficienza energetica gli aspetti più critici di un alto edificio del terziario con involucro completamente vetrato, considerando diversi climi europei. Sono stati studiati i consumi minimi raggiungibili e i valori ottimali dei parametri più influenti come Trasmittanza del vetro, VT/SHGC, e ombreggiamento. Lo studio è stato eseguito su un edificio teorico posizionato in Italia e Lituania, rappresentativi come climi caldo e freddo rispettivamente. L'edificio è stato appositamente scelto per essere rappresentativo per tutti gli edifici vetrati a semplice forma. Le analisi nell'interezza energetica dell'edificio permettono un rapido e immediato impatto dei consumi globali. Sono state eseguite un esteso numero di simulazioni con il software DesignBuilder e i consumi annuali sono stati sommati col criterio dell'energia primaria. I risultati mettono in mostra gli aspetti critici dell'edificio completamente vetrato: nei climi più freddi il problema dominante è l'eccessiva area finestrata che costringe un valore di trasmittanza più elevato rispetto ad una canonica muratura, mentre nel più caldo il principale consumo energetico è dato dalla necessità di raffreddare gli elevati carichi solari entranti. In conclusione, si dimostra che risulta teoricamente difficile abbassare i consumi di energia primaria sotto i 130 e 140 kWh/m^2 per Nord-Italia e Lituania rispettivamente. L'analisi è focalizzata solo sui parametri dell'involucro, quindi non sono inclusi sistemi ad energia rinnovabile, i quali possono generare efficienze superiori.

Questo documento è da considerarsi la versione estesa che raccoglie tutta la letteratura scientifica utilizzata nella stesura del relativo Articolo, il quale è stato pubblicato nel giornale "Science - Future of Lithuania" in Settembre 2017.

Index

Chapter 1

1. Totally glazed buildings

1.1. Introduction and Curtain Wall

Building energy demand is about 35% of the global energy requirement.(IEA, Transition to suistainable buildings, 2013) and up to 40% of the total European energy consumption (BPIE, Principles for Nearly Zero-Energy Buildings, 2011). In the last two decades, the scientific community promoted the use of passive strategies for buildings, all over the world, in order to achieve global annual energy consumption lower and lower.

In Europe, the recast of Energy Performance of Buildings Directive (2010/31/EU) requires that:

''Member States shall ensure that by 31 December 2020, all new buildings are nearly zero-energy buildings and after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings".

To face these requirements many European company head to innovative concepts: tiny volumes, quick to build and easy to dismantle and transport, thick layers of isolation, usage of waste materials and modularity are just some of the new characteristics of many standing out start-ups as Koda House by Kodasema (Es) and Wikkelhouse (Ne). (Fig.1.1) *(Source: http://www.kodasema.com/)*

Figure 1.1: Sample of KODA by Kodasema (Es) Source: http://www.kodasema.com/

The small amount of floor and lateral surface enables low consumptions, the easiness to adapt to different climate make these residences easily suit in every location. These ideas are not close only to residence buildings, but offices spaces are designed with same criteria.

On the other hand, ideas and realizations of skyscrapers are facing the overpopulation’s issues. One of the world-famous recently completed skyscraper is “The Shard” design by Italian architect Renzo piano (Fig. 1.2).

Figure 1.2: The Shard designed by Italian Architect Renzo Piano (London). Source: RPBW - http://www.rpbw.com/project/the-shard

His construction was completed in London city centre in 2012. No parking space was designed for this building: this choice tells the story of a different and totally innovative concept. People are living closer and closer in the city space, and the idea of sharing spaces and transports is a must. In the building residences, one hospital, restaurants and offices take place.

The building is also known as “The Glass Shard” due to the particular shape with which the glass envelope is made of. It can be asserted that the majority of these high-rise building are mostly covered by glass.

Excluding this singular and innovative shape in the glass architecture of the Shard, in medium and big city, people are used to see high skyscrapers supported by steel and enveloped by glass known also as “Glazed curtain wall”. Looking at each medium city it is easy to see more than one high modern building standing out, all covered by glass. (Figure 1.3)

Figure 1.3: Oslo (Norway), Milan (Italy), and below Vilnius (Lithuania), Madrid (Spain).

A curtain wall system is an outer covering of a building in which the outer walls are non-structural and so it is usually made of a lightweight material, reducing construction costs. Usually glass is used as the curtain wall, and the great advantage is that natural light can penetrate deeper within the building.

The building weight is supported by the internal pillars and so the curtain wall has no structural function, but supported his own weight.

Anyway, curtain walls, mainly made of glass, are the most important used way to cover the modern building facades. This solution is one of the most loved by the architects, in fact the Free Façade is the fifth of the "Five points toward a new architecture".(Le Corbusier, 1926)

"[..] the whole façade is extended beyond the supporting construction. It thereby loses its supportive quality and the windows may be extended to any length at will, without any direct relationship to the interior division"

Many modern architects as Renzo Piano and Pelli designed high rise buildings with an envelope mainly covered by glass.

1.1.1. Why did glazed facades become so popular?

It is indisputable that in the last century and much more in the last decades a trend for the use of glass has taken place in the society; despite many structural techniques exist, all these buildings can be included in the big group of 100% or nearly 100% WWR buildings.
In literature some reasons why this tendency extended so broadly are found:

- First at all is the **Daylighting**, as a matter of fact it is one of the leading drivers today on architectural design-green. Daylighting is to bring natural light into buildings and provide a better indoor light environment than artificial lighting. During the early years of office working, and until around the mid seventies, it was believed that artificial light was far superior to daylight, but nowadays, many studies confirm that natural daylighting can not only reduce the lighting electricity, but also create a dynamic indoor environment, and a healthy and excited working environment will be produced as follows (Liu C. and Wang X., 2000). Artificial lighting not only consumes a large amount of electricity but also dissipates waste heat into indoor space, which causes the increase of cooling load. Daylighting design cannot only save energy but also lead to an airy architecture of great beauty. In the last modern buildings with high glazed surface, there are frequently atriums (Fig 1.4); and these open spaces have become a major topic in energy saving, given that natural lighting design is related to passive solar heating and cooling. The use of daylighting can reduce overall energy consumption up to 20% and also reduce the sensible heat load on air conditioning (Chen & Wei, 2012).

Figure 1.4: Atrium Of Belgrade Business Building Designed by Kohlbauer Martin

Another secondary reason is due to the contemporary society: **the transparent corporate culture**. Companies who want to create a distinctive image for themselves (e.g. transparency or openness) often like the idea of being located in a glazed office building, as if they say, "See, we're in here, doing something for you; we're not hiding anything". Furthermore, companies like to give the impression of a democratic working environment, open-plan and with floor-to-ceiling windows, so that all employees, not just the boss, benefit from the view. (Poirazis, 2005) *(Treehugger journal – July, 6th, 2010 -Lloyd Alter)* .

- **The connection to the outdoors**: closely related to daylighting is the visual connection to the outdoors that can be provided by a transparent façade. This connection, given by high WWR values, brings advantages not only in energy savings, but even gives long-term positive effects for workers. According to a “the Work Intelligent Unit” journal article, there are benefits in several areas. Firstly, regarding human health: the exposure to natural light stimulates the production of vitamine D, which is connected to the human immune system and influences the circadian rhythm. Then, human vision under daylight conditions is normally better than under artificial light, as it enables us to see colours and perspective more clearly. Finally, the link between light and mood, and mood and productivity is complex, and not easy to prove scientifically due to the number of other contributory factors. However, studies have made links between improvement in workplace daylighting and productivity.

1.1.2. Green tendencies against all-glass buildings

Despite this success, focusing on the energy savings aspect, many experts assert that the glazed façade is not one of the best solutions; thus, since global warming have become more widespread, the glass structure has come under scrutiny.

Two different ideas are grown in the present society: some architects and engineers continue to improve the contemporary art, creating more and more complex building shape, mainly covered by glass. On the other hand, some tendencies concerning green environment and energy savings, are against the use of the glass façade, supporting more classical way of building such as concrete brick walls.

Here, a brief list of the experts joining the ideas against glass is reported after a research on the web.

In an article by Straube it is asserted that each high rise building with glazed façades is an energy-consuming nightmare because it requires an high amount of heating and cooling energy at the perimeter just to maintain comfort (Straube, 2008). Again, results of his studies bring bad news from the comfort point of view: on a cold winter day it happens that offices exposed to the sun require cooling, while those in the shade need heating.

Another expert who is not supporting the totally glazed facades is Alex Wilson, founder of Environmental Building News, in which he looks at the issue of “Rethinking the All-Glass Building”. He writes *(Building Green Journal – June, 29, 2010 – Alex Wilson)*:

“Some of the world's most prominent "green" skyscrapers, including New York City's One Bryant Park (the LEED Platinum Bank of America skyscraper) and the New York Times Tower, wear the mantle of green with transparent façades. But there is a high environmental cost to all that glitter: increased energy consumption. Until new glazing technologies make technical solutions more affordable, many experts suggest that we should collectively end our infatuation with heavily glazed, all-glass buildings.”

This idea is carried on by the Treehugger, a journal with the aim of rethinking about science with a simple point of view. Although, it is not so technical, in an article, Lloyd Alter deals with the problem of this “glazed boxes” as he defines not the main skyscrapers, but the most of the all-glass buildings located in the industrial area. He proposed a new architects generation, able to consider the sustainable problem next to the aesthetic issues. Furthermore, the next step for a good development of building architecture should be the overtaking of all-glass facades *(Treehugger journal – July, 6th, 2010 -Lloyd Alter).*

In London skyline, “The Shard”, “Walkie Talkie” and “The Gherkin” are the three most important glazed buildings which boast a wide world knowledge.

The 20 Fenchurch Street (Fig. 1.5), nicknamed “Walkie Talkie” because of his singular shape, is a 34-storey skyscraper located in the financial district of London, mainly covered by glass. One of the reason why the Rafael Viñoly’s building is famous is completely unexpected: the building was accused of melting cars parked below it, plus some damage caused by the heat, due to the concentration of sunlight reflection *(BBC news - September, 2, 2013).* As it can be seen the curve of the facade of the building allows the sunlight to be concentrated. The effect was not predicted, but for sure it is not a good introduction for a new generation building.

Figure 1.5: 20 Fenchurch Street nicknamed “Walkie Talkie” in London

The 30 St. Mary Axe building (Fig. 1.6), called “The Gherkin” because of what his shape reminds, was designed by Norman Foster and Arup Group and completed in 2004. Ken Shuttleworth, one of the father of the building, after leaving the Norman Foster studio architect became one of the key voice in the fight against the glass, claiming that the building was a mistake *(BBC News – May, 27th, 2014)*.

He was one of the main architect who gave shape to “The Gherkin”, and after his completion he regretted to have designed it:

“Everything I’ve done for the past 40 years I’m rethinking now and I think it’s important to grasp that to meet the new building regulations, and to meet zero carbon by 2019, we have to reduce the amount of windows in buildings — or the glass industry will have to come up with new products.”

(Glass and Glazing journal – June, 3rd, 2014)

Figure 1.6: The 30 St. Mary Axe building nicknamed “The Gherkin” in London

Shuttleworth claims there is no way to reach low energy consumptions and zero carbon emissions' regulations with a totally glazed skyscraper. He started an intense struggle against glass, strange profile, silly shape and double curves, as he defined. Ken criticizes many architects and asserts that the most of his colleagues are egoistical and they just aim to leave their own impact icon in the society. His struggle hits the Renzo Piano's London building too: He says that he cannot understand how it is possible to make it work from an energetic point of view.

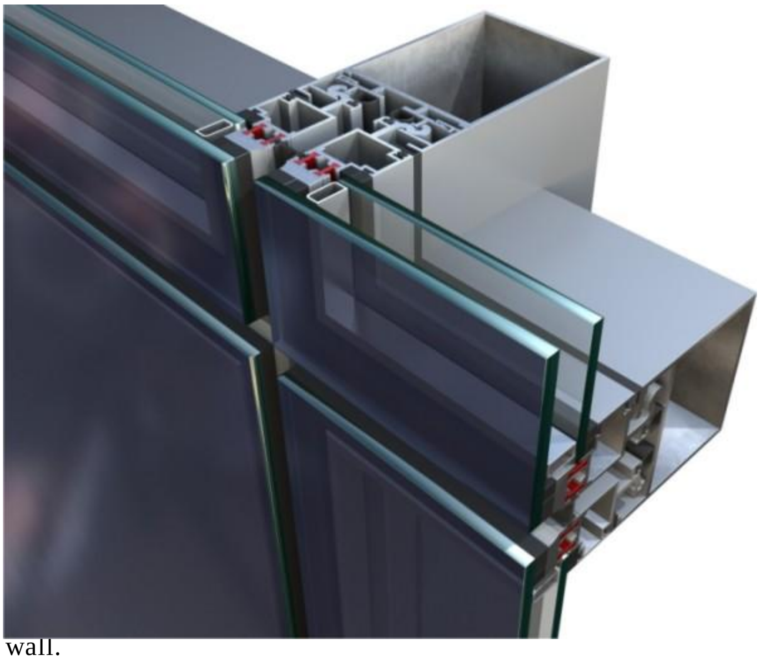
In an interview Shuttleworth highlights that we have been designed glass boxes for more than 30 years and now we are try to make them green and low consumptions *(The Telegraph – June, 26th, 2011)*. Anyway, we should realize we are in the era of efficiency, that nowadays, the fascinating is represented by the green and the sustainable, and fashion is headed to a combination of efficiency and aesthetics.

1.1.3. Negative thermal aspects in totally glazed buildings

Reasons why building completely covered by glass are criticized are here reported.

- First at all, the **U-value** issues: Although new technologies concerning the windows are improving the glass parameters, it is impossible to reach the same U-values of an opaque surface. Using the best windows solutions in commerce, as for example a quadruple pane, very low-E, Krypton filled, the glass U-value will be around 0.6 - 0.7 W/m^{2}K *(Autodesk Sustainability Workshop – Glazing properties)*. A modern standard brick well-insulated wall, instead, with a good thickness can easily achieve U-value up to 0.1 W/m^{2}K. Therefore, the losses through caused by the envelope transmittance in a building with 100% glazing will always be many times higher than in a building with traditional walls. Furthermore, the best state-of-art windows need to be connected, and the junctions are a much more difficult problem in a curtain wall than in a brick self standing wall. Many scientists focused their study particularly in the junctions between the panels in a curtain wall, because it is a weak point of the facade (Bae et al. 2015). The optimization of the frame is very important because it has to combine both the structural and the thermal functions. The best way to optimize the thermal aspect of the frame is the focalization on the reduction of thermal bridges. (Fig 1.7)

In conclusion, it is clear how the energy required for heating is generally higher in a glazed building than in a traditional one, furthermore, the colder is the climate the higher the heating loads are.



wall.

- The second problem is the enormous amount of surface covered by glass in a skyscraper. There are several types of glazing, but anyway, one of the week points of high glass surface is that a large amount of solar radiation is allowed to income in the building and to contribute, positively or negatively, in the loads balance. The coefficient that measures the solar gain incoming based on how much solar radiation is arriving at the outer part of the windows is called Solar Heat Gain Coefficient (**SHGC**). Since the glass is opaque at the infrared radiation, the sunlight transmitted by the glass can create a sort of greenhouse effect inside the building. This effect could be positive in winter, or in climate in which heating is required, but devastating in warmer climate because the cooling loads can increase of more than one time the value they would have in a traditional building. (Poirazis et al. 2008)

At this point it can be imagined that a bad designed glazed building located in a cold climate in winter and hot in summer is a nightmare from an efficiency point of view.

This is because in winter the high windows U-value requires high heating loads, while in summer the high solar gain implies an high cooling load.

- Of course, there are other types of negative aspects of the glass facades such as the glaring when the daylight is to intense. The daylight is positive for the office workers, but the direct sunlight create strong discomfort *(A workplace intelligent unit Journal – Daylight in the office)*. Anyway, this study is mainly focalized in the reduction of energy consumptions, thus the first two reasons mentioned above are the most important.

Experts such as Straube and Wilson define the high glazed façades as a modern trend by which we were infatuated. Furthermore, they both assert that with the current materials and glass properties, is not green to build glass façades and it implies high energy requirements during the operational time of the building.
Anyway, buildings covered with a glazed curtain walls, with good energy requirements were built even if is difficult to find some data. This means that is possible to build NZEB totally glazed, but extremely difficult. Such buildings need to be extreme accurately studied about the HVAC system combined with the activity office planning.

1.2. Curtain wall - State of art

In paragraph 1.1 a brief introduction of curtain wall was already given. This research deals with glass curtain walls, and the general expression “Curtin wall” will always be used referring to a complete façade made of glass. The definition of glazed curtain wall is unique and it can briefly summarized as: a technique to envelope the facades of a building with glass, in which the glass has not the structural function. After this characterization two main typologies of curtain walls can be listed, but mainly dividing by the technique used to fix the glass.

The traditional way to fix the glass it is called the “Stick system” (Fig. 1.8), in which glass panes are sustained by a studding system. The vertical and horizontal members are usually made of steel or better in aluminum. The thermal weak point of this system is the junctions: thermal breaks are required if good U-value of the façade want to be achieved.

Figure 1.8: Stick System with thermal break. Sample of Somec S.p.a.

Another type of system that was later developed is the “Structural Glazing” (Fig. 1.9). Structural glazing system, in their simplest form, consists of glass that is bonded or anchored back to a structure without the use of continuously gasketed aluminum pressure plates or caps. The back-up structure may use horizontal and/or vertical aluminum mullions or be a glass mullion, steel blade, cable or stainless steel rod. The interior and exterior may use extruded silicone/EPDM gaskets, or a wet sealed silicone depending on the system. This system creates a completely clean, flush exterior appearance while the interior members have many different options depending on design and budget.

Figure 1.9: Example of Structural grazing in a glass façade.

The technologies of the supporting system are widely developed and thousand of solutions are proposed from authors and companies to improve the structural aspect of it. In the following literature research a detailed study is carried on only from the thermal point of views.

1.2.1. Single skin

The distinction between single and double skin is a division under the topic of glazed curtain wall. In the case of single skin, the envelope of the building is one unique single façade, in which the glass panes are supported with one of the formerly described system.

It is clear that the energy consumption of buildings with curtain walls, is more sensitive to the climatic conditions and the variation of façade design compared to buildings with opaque insulated façade. (Poirazis et al., 2008)

The advancement of technologies in the thermal and optical properties of glazing helps improve the overall performance of curtain walls. The efficiency performance of many curtain wall systems can be achieved by integrating advanced glazing units, better insulated mullion, shading, cooling strategies (Gratia & De Herde, 2003), daylight control strategies (Jelle et al., 2012) and particular dynamic windows strategies (Dussault et al. 2012).

However, to achieve a high energy efficiency thanks to the envelope parameters, it is important to take into account the interaction among façade design parameters, climatic conditions and building operation parameters.

The main parameters which can influence a single skin curtain wall are nine (Lam, Ge, & Fazio, 2015):

- glazing U-value (U_{gl});
- solar heat gain coefficient (SHGC);
- visible transmittance (VT);
- U-value of the spandrel panel (U_{sp});
- U-value of frame (U_{fr});
- window wall ratio (WWR);
- infiltration rate
- depth and inclination of overhang

In the article which this list is taken from, thousands of energy plus simulations were carried out, with the purpose of finding out, through the energy consumptions, which ones of them are the most influencing and in which manner.

Although a small office building was considered in the article, the results showed that the most influencing parameter is the WWR.

WWR should be accurately chosen to have the highest energy savings potential. To fix the WWR at 100%, as in each totally glazed building, implies higher energy demands and further studies have to be carried out in the other parameter to achieve low energy building.

Excluding the high influence on the energy savings given from the optimal WWR (See later), the results of Lam's study show that the most important parameters involved in the heating and cooling requirements are:

- the windows **U-value**: low thermal transmittance of windows is a good choice since it decreases the heating demand, while the cooling is not influenced much. (This behavior will be highlighted in the conclusion)

- **SHGC** is calculated as the ratio between the transmitted and the total incoming solar radiation on the windows. Low SHGC values have a great impact on the cooling demand (Poirazis et al., 2008). Thus in cooling dominated climate, the choice of the windows has to be focused on SHGC, and cooling strategies are compulsory (Gratia & De Herde, 2003).

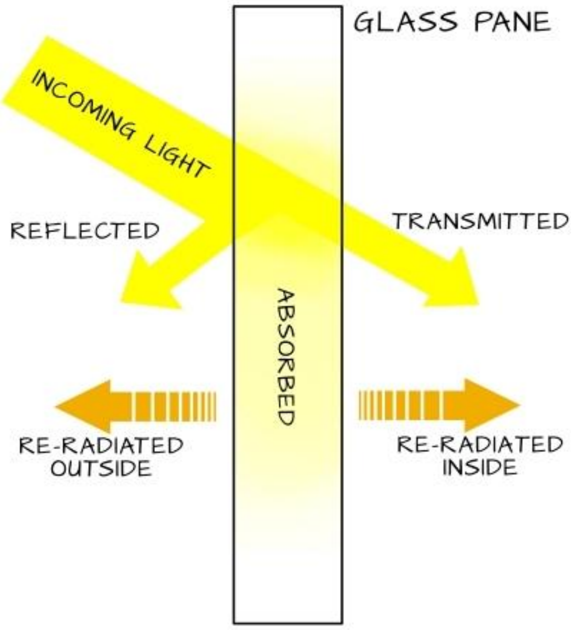


Figure 1.10: Scheme of how the glass reacts with incoming light is

- **Shading** is an alternative way to face the solar radiation incoming through the high fenestration surface. A good balance between SHGC and shading needs to be done, to enables a good daylight incoming trying to keep low the value of solar gain.

A traditional glazed façade increases the risk for unsatisfying thermal comfort close to the façade and glare problems further inside the building. Glazed buildings have less tolerance for design and construction errors and therefore require more careful planning.

Many articles showed that 100% glazed building has always higher energy demand than standard isolated building. Moreover, with accurate adjustments in all the other façade parameters, it was possible to lower the energy demand of a total glazed building to 15% higher than a reference building (30% WWR) (Poirazis et al., 2008).

Despite this virtual constrain given by Poirazis the problems of the single skin façade listed in the paragraph 1.1.3 can be solved improving the u-value of the windows, adjusting the values of SHGC in the windows and applying new shading systems; understand how to improve those parameter is the exact aim of this thesis.

In any case, it is interesting have a brief review at one of the modern solution which has grown in Europe in the last decades: the double skin glazed facades. This technology seems add more variables and thus, if well managed, to allow more possibilities to control efficiency performance.

Therefore, there has been a growing interest among clients to build and among architects to design glazed double skin façades. Improvements, which can be provided are: energy savings, wind protection with open windows, fire protection, aesthetics, solar preheating of ventilation air, sound protection, night cooling and a site for the incorporation of PV cells. Commercial buildings with integrated double skin façades can be very energy efficient buildings with all the good qualities listed above. However, far from all double skin façades built in recent years perform well. (Eriksson, 2009)

In many cases the energy consumption badly exceeds the intended heating energy performance. Therefore the European Commission partially (50%) financed a project, BESTFACADE, to promote the concept of well-performing double skin façades. One of the outputs is a best practice guideline for double skin façades (Blomstemberg, 2007). The guidelines include predicted performance. Due to the difficulties of determining the influence of a double skin façade on the energy and indoor climate performance from energy monitoring and lack of monitored data for real buildings this performance was predicted for a typical cell office.

1.2.2. Double skin

A double glazed façade, consisting of a normal façade, an air cavity and an additional external skin of glass, drastically modifies the surrounding environment (air temperature, solar radiation and air velocity) of the normal façade (Figg 1.11 and 1.12).

Although the DGF increases the temperature of air cavity (up to 10-20°C more than outdoor temperature) it reduces the solar radiation reaching the building envelope: in fact, a portion is absorbed in the DGF glazing, and usually a blind shading system is located inside the cavity. Moreover, the air velocity near the façade is modified depending on the cavity's geometry and on the air temperature.

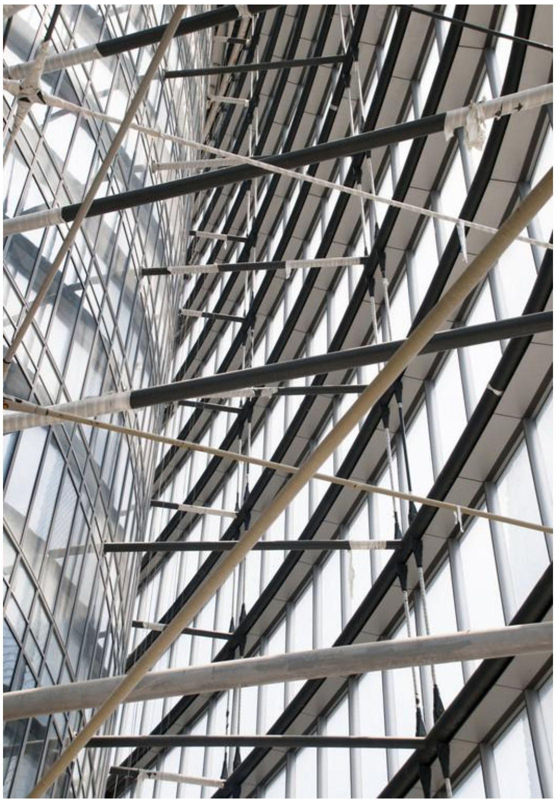


Figure 1.11: Picture of the cavity of double skin Façade of Shangai Tower in China.

The classification of DGF could be made by different types and categories: here it is made a completely review of the all state-of-art DGF classifications articles. (Poirazis, 2007)

It is not the purpose of this article to make a list of all the double-glazed façades types, thus only some helpful examples are reported.

In an article the double skin façades are divided in two categories (Magali et al. 2001): A) Double Skinned Façade on several floors and B) Double skinned façade per floor.

As she mentions, “The difference between the categories (A) and (B) is that there is a horizontal partitioning into the air cavity, at each floor”. According to the author, each of these categories is divided into subcategories. The distinction has been made between airtight or non-airtight façades “the tightness of the façade is related with the possibility to open the windows”.

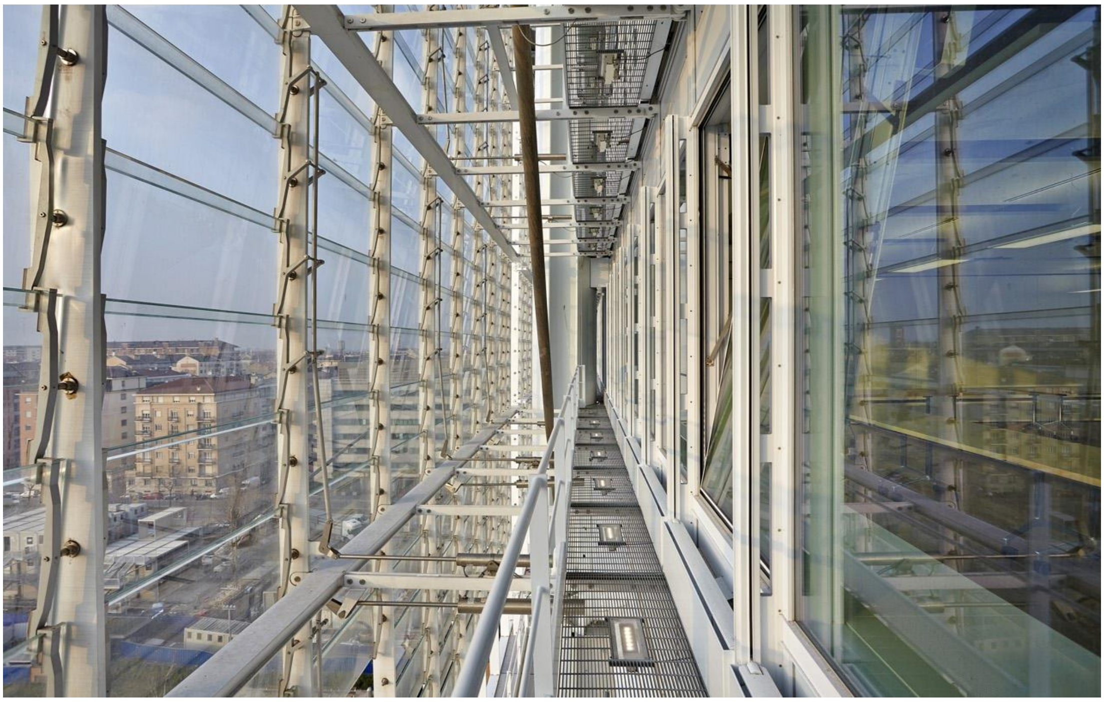


Figure 1.12: Picture of the cavity of the double skin façade in Intesa San Paolo Building in Turin, Italy.

Another categorization of the Double Skin Facades according to the ventilation type of the cavity is made in three types (Kragh, 2000):

- Natural ventilated wall (Fig 1.13): In periods with no solar radiation, the extra skin provides additional thermal insulation. In periods with solar irradiation, the skin is naturally ventilated from/to the outside by buoyancy (stack) effects: the air in the cavity rises when heated by the sun (Fig) and the solar radiation must be absorbed by blinds in the cavity. Solar heat gains are reduced as the warm air is expelled to the outside. The temperature difference between the outside air and the heated air in the cavity must be significant for the system to work. Thus, this type of façade cannot be recommended for hot climates".

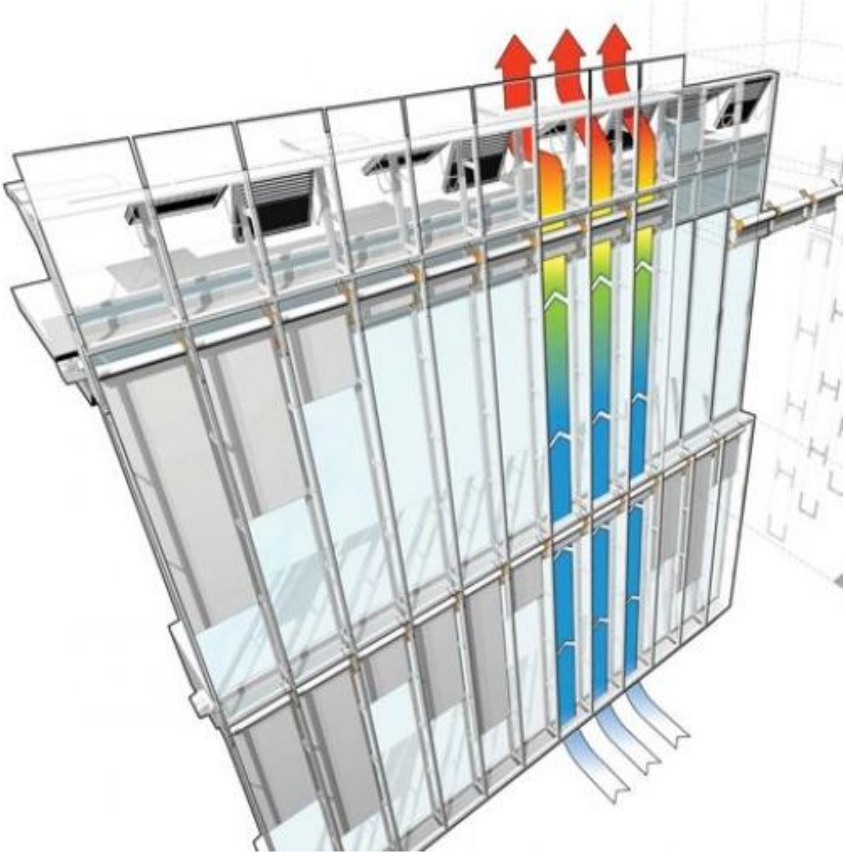


Figure 1.13: Representation of the natural raising of the air heated by the sun inside the DSF cavity.

- Active wall: inside return air is passing through the cavity of the façade and returning to the ventilation system. In periods with solar radiation the energy, which is absorbed by the blinds, is removed by ventilation. In periods with heating loads, solar energy can be recovered by means of heat exchangers. Both during cold periods with no or little solar irradiation and during periods with solar gains or cooling loads, the surface temperature of the inner glass is kept close to room temperature, leading to increased occupant comfort in the perimeter zone, near the façade. This type of façade is recommended for cold climates, because of the increased comfort during the cold season and the possible recovery of solar energy”.

- Interactive wall: “The principle of the interactive is much like that of the naturally ventilated wall with the significant difference that the ventilation is forced. This means that the system works in situations with high ambient temperatures, as it does not depend on the stack effect alone. The system is thus ideal for hot climates with high cooling loads. During cold periods with no solar irradiation as night time the ventilation can be minimized for increased thermal insulation. Apart from the advantages in terms of solar and thermal performance the system allows the use of operable windows for natural ventilation, even in high-rise buildings”.

Lastly, the most adopted **materials** as glass pane types used for Double Skin Facades are common throughout all the literature:

- For the internal skin (façade): Usually, it consists of a thermal insulating double or triple pane with the lowest window U-values in commerce (around 1.0 W/m^{2}K). The gaps between the panes are filled with air, argon or krypton.
- For the external skin (façade): Usually it is a toughened single pane, chosen without too attention at the transmittance. U-values could be around 4-6 W/m^{2}K.

It is clear how difficult could be the control and the maintenance of a DGF: the technical managing is extremely difficult. Many parameters are involved:

- the geometry of the cavity,
- the height of the cavity (1 per floor, several floor) but there are lack of literature publications on suggested height values.
- The ventilation: mechanical ventilation or natural ventilation.
- Type of shading devices

- The internal openings: they can be chosen to allow an internal ventilation in each floor. Jager presented in 2003 different design configurations of the air inlet and outlet. He gave results of different opening types of the interior façade and their relative air change efficiency related to the visible area of the opening sash.
- The external openings: It is possible to have more than two openings (one at the bottom and one at the top) in the outer façade, in order to improve the ventilation and to avoid vortexes. In this case, CFD simulations are required to achieve the best solutions.

1.2.3. Advantages and disadvantages of a double skin glazed facades

Acoustic insulation

Some authors claim that this could be the most important reason to use a Double skin façade. Anyway, the type of the DSF and the number of openings can be really critical for the sound insulation concerning the internal and external noise pollution.

Thermal insulation

Many authors asserted how DSF system can provide greater thermal insulation due to outer skin both in cooling and heating dominated climate.

In colder climates the double skin façade improve insulation lowering the envelope U-values. The values improve particularly if the cavity is kept closed in order to reduce the ventilation. In any case, a heat exchange recovery is usually located at the top of the cavity, in order to reuse the heat removed by the air flow.

In an a paper that deals with the preheating aspects of Double Skin Facades it was asserted that the highest value of heat recovery efficiency are found for thinner cavities (Stec & Paassen, 2003)

In warmer climates the heat collected inside the cavity is extracted. Some authors published some studies concerning how to reuse that heat even in summer (i.g. using solar water collectors as shading devices (Palmero-Marrero & Oliveira, 2006)). For proper ventilation of the cavity it is important to select carefully the combination of the type of the panes, the type of the shading devices and the width and height of the cavity in order to avoid overheating issues inside itself.

Natural ventilation

One of the main advantages of Double skin Façade systems is that they can allow natural (or fan supported) ventilation. Different types can be applied in different climates, orientations, locations and building types in order to provide fresh air before and during the working hours. If designed well, the natural ventilation can lead to reduction of energy consumption during the occupation stage and improve the comfort of the occupants (Lee, 2002).

Night time ventilation

During some hot days when the external temperature is higher than 26°C, offices risk to overheat beyond the comfort air temperature. So, during the first hours of the morning it can be possible to pre-cool the offices, using the internal walls and the furniture as a thermal storage (Lee, 2002).

Better protection of the shading or lighting devices: Since the shading or lighting devices are placed inside the intermediate cavity of the Double Skin Facades they are protected both from the wind and the rain. (Gratia & De Herde, 2007) (Fig. 1.14)

Figure 1.14: Example of shading inside the DSF cavity. Horizo Company, Australia.

Reduction of the wind pressure effects

The double skin facades around high-rise buildings can serve to reduce the effects of wind pressure. A constant pressure on the façade into the intermediate space, contribute to reduce discomfort issues (Oesterle et al. 2001).

Thermal comfort- temperatures of the internal wall

Since in winter the air in the cavity is warmer (compared with the outside one), the interior part of the façade can maintain temperatures that are more close to the thermal comfort levels. On the other hand, during the summer it is really important that the system is well designed so as the temperatures inside the cavity will not increase dramatically.

Low U-value and SHGC

In an article it was even said that the two many advantages of the DSF in the reduction of the glazing U-value and the SHGC. (Kragh, 2000)

This is evidently true, but if those were the only advantages, it would be sufficient to improve the U-value and the SHGC in the single skin façade, avoiding the cost of another layer of glass.

Construction cost

Compared to a conventional façade is definitely more expensive. The complexity of the system is elevate and so the prices. As the time passes the prices of this technology and its development will imply lower and lower prices. Anyway in this article a business plan is not included, and the buildings are analyzed only from a energy savings point of views.

Fire protection

It is not yet clear whether the Double Skin Facades can be positive or not. Some research mention possible problems cause by the room to room transmission of smoke in case of fire (De Carli & De Giuli, 2008)

Reduction of rentable office space

As mentioned above the width of the intermediate cavity of a Double Skin Façade can vary from 20 cm to several meters. Thus, it is quite important to find the optimum depth of the façade in order to be narrow enough so as not to lose space.

Additional maintenance and operational costs

Comparing the Double Skin and the Single Skin type of façade, one can easily see that the Double Skin type has higher cost regarding construction, cleaning, operating, inspection, servicing, and maintenance (Oesterle et al. 2001).

Overheating problems

As mentioned above, is Double Skin Façade system is not properly designed it is possible that the temperature of the air in the cavity is going to increase overheating the interior space (De Carli & De Giuli, 2008).

Different air flow velocity

Inside the cavity, mostly in multi storey-high types. Possible important pressure differences are mentioned between offices in case of natural ventilation via the cavity.

Increased weight of the structure

As it is expected the additional skin increases the weight of the construction which increases the cost.

Daylight

The daylight properties of DSF are similar to other types of glazed facades, thus there is no significant advantages by adding an outer layer of glass.

In conclusion

DSF is a system more complex than the single glazed skin system. All those variables, especially the air flow through the cavity make the double skin façade really difficult to be controlled. If perfectly controlled it can be true that the DSF has an higher efficiency than SSF (Poirazis, 2007), even if in warm climate (Mediterranean (Flores Larsen, Rengifo, & Filippín, 2015) but it is not so easy to design and control it properly. For instance, an article comparing 15 SSF building with 13 DSF building around Germany asserts that on average, the total primary energy consumption of DSF buildings is 27% higher than SSF buildings (Leão & Straub, 2016).

1.3. Examples of energy consumptions of all glass buildings

Here is a list of energetically unsuccessful and successful building from an energetic point of views. The chosen parameter to evaluate whether a building is successful or not is the overall primary energy consumption: the same value used in the development of this research. It is better to refer to the specific energy, and thus it is expressed either in kWh/m^{2}a or less often in kWh/m^{3}a for the office building only. Sometime, when the overall energy consumption data are not clear, the heating annual consumption is taken as a reference value. The research of the following example was extremely hard because of the difficulty faced for finding exact results and measures about the overall annual energy consumptions. Even in the famous certified buildings, the exposition of the certification institution was secret or rarely clear, or better, plenty of parameters and data are included in the data sheets, making the research of the interested value much more difficult.

1.3.1. Energetically unsuccessful buildings

Some successful and unsuccessful glazed buildings were analysed in an article (De Carli & De Giuli, 2007). Here it is asserted that one of the gravest mistake is to focus the designing on the aesthetic, omitting the research for the human well-being. The research of impressiveness can imply inefficient energy buildings. And, it is too late to solve this problem after the construction, when the mistake is already done.

The **Dental clinic centre of the University of Zurich** (Fig 1.15). It was designed by the architect Theo Hotz, and built in 1998; it is characterized by a double façade, in which there are blinds. In the space between the two façade it is reached an air temperature of 34°C with 500 W/m^2 of solar radiation, and up to 80°C with 800 W/m^2. At this temperature the blinds engines stopped.

During winter period, a different temperature of 4°C has been measured between the medium air temperature in the offices and the inner surface temperature of the windows; thus the offices temperature has been increased from 20 to 23°C during the day and from 18 to21°C during the night. In the library at the upper floor, annoying air temperatures up to 50°C have been registered because of non-shaded skylight.

Intense discomforts owing to cold air flow in winter were founded and finally, a 59 kWh/ m^2 a value of thermal energy consumption was estimated, while a value of **78 kWh/ m^2 a** was measured.

In conclusion, because of its wrong design, its awful internal climate and comfort, it is only usable during spring and autumn.

Figure 1.15: Dental clinic centre of the University of Zurich (1998)

The headquarters of the **Commerzbank** in Frankfurt (Fig. 1.16), designed by Norman and Forster and completed in 1997, is one of the biggest administrative building in Europe with its height of 259m. The envelope of the building is composed of a doubles skin facade of glass with ventilated cavity. One of the characteristic of the palace is the presence of some green balcony in which a garden takes place.

The problem of these sky gardens is that they interrupt the uniformity of the glass envelope. In the preliminary stage of the project the overall consumption was assessed around 520 kWh/m^{2}a, a very high value for an office building *(GPH, May, 2005, "Glasfassaden – die modernen Energieschleudern,") (Issuu, June, 2, 2014, Commerzbank tower, DAV analysis).* Despite some critics, the official measured consumptions values were never published: only the percentage for each area was. 13 % for heating, 42% for lighting and 45% for cooling, but these data don't give useful information about the energetic requirements of the building.

Figure 1.16: Commerzbank Building in Frankfurt, completed in 1998.

Even if the **Intesa San Paolo Building** (Fig 1.17) completed in Turin in 2006 which was certified in 2015 with LEED Platinum Award, has been criticized for its consumptions.

Figure 1.17: Intesa San Paolo building, Turin, Italy.

The building is provided of 1600 m^2 of PV panels in one of its facade, while the East and the West one are composed by a Double Skin System. The critics was carried out by the local journal “Eco delle città” about the high energy requirement for heating, and not only *(Eco dalle città journal, October 06-2009, Giuseppe Iasparra).*

In the official document of environmental impact evaluation it is asserted that the energy requirements during the operating period of the building will be around 1875 MJ/m^{2}K, which corresponds to **520 kWh/m^{2}a** *(SisTer s.r.l. – Intesa San Paolo, Verifica di assoggettabilità, June 2009)*. It is necessary to say that firstly, in the study it is analysis it is asserted that the 30 % of the consumptions will be provided by renewable energies. Secondly, it is not said how this value was calculated, plus, that the energy consumptions data sheet was not published and there are no measured published data.

1.3.2. Energetically successful buildings

In the last decades many efforts were carried out to improve the all glass buildings and to obtain a building with low energy demand anyway. An example is the study by the "Glass for Europe Journal" in which are collected all the glazed successful buildings in Europe. The article extends beyond the interests of this research because many small and residential buildings are mentioned *(Glass for Europe Journal, The smart use of glass in sustainable buildings, November, 12th, 2013).*

In any case it is one of the symbol of how the glass trade and trend want to have a place in the modern skyscrapers. Furthermore, architects and engineers are intensively pushing the glazed building to be more and more sustainable and green, and the results don't wait to come. Indeed, in the last years many of these buildings were classified as low energy ones.

Many associations of green certifications were born such as: LEED (Leadership in Environmental and Energy Design) in U.S.A. and BREEAM (Building Research Establishment Environmental Assessment Method) in U.K, and many of the positive targets of these associations are modern buildings enveloped of glass.

Completed in 2015 and located in the centre of administrative district of Amsterdam, "**The Edge"** has been defined the smartest building ever (Fig.1.18). It was designed by PLP architecture to Deloitte group and it won the best building BREEAM award in 2016 achieving the highest green building score ever. It is easy to understand that the building was designed in every particular. Everything is optimized aiming to the green impact of the building.

Figure 1.18: Northern façade of “The Edge”, Amsterdam, Netherlands.

The building is oriented to the sun path and the 15 storey atrium lights the whole building with northern light, while he south façade is partially covered by PV panels which contributes to the reduction of the energy requirements.

The smart-planned natural ventilation system through the atrium contributes to reduce the energy consumption, which, are astonishingly low. According to BuildUp European Journal, The level of final energy consumption of the building will vary between -0.3 and 40.7 kWh/m2.year depending on the availability of the renewable energy supply by the PV production.

Administrative Leonardo Building in Zurich (Fig. 1.19). This building, certified by Minergie, is characterized by double skin glazed façade. The cavity between the two glazed layers enables a natural ventilation: in the lower part there is an opening, while in the upper one some valves control the ventilation according to air temperature and humidity.

The outer glazed skin is characterized by a 5.6 W/m^{2}K U-value, while in the inner one the triple panes windows enable a U-value of 1.1 W/m^{2}K.

In between the two facades blinds are located. They are controlled by the same automatic system which control the cavity valves.

Air, incoming from the ground floor goes up through the cavity, and replaces the air inside the two roof’s layers: so even the roof itself is natural ventilated.

The 6 storey building has 8 different climate zones in each plan. The heating system is with standard radiators if the outside air temperature is below 0 °C, otherwise thermo active floors are activated. These one enables the cooling during the summer period.

Finally, during the summer, the night ventilation contributes to reduce the cooling loads.

Figure 1.19: South-west facade of administrative Leonardo building in Zurich.

European Investment Bank building in Luxemburg completed in 2008 (Fig. 1.20). The building was the first in Europe to obtain the new BREEAM International BESPOKE certification. The certification means that the building exceeds legislative requirements and/or compliance with best practice guidance in the country of origin (*Glass for Europe – 12 November 2013 - The smart use of glass in sustainable buildings).*

Figure 1.20: European Investment Bank Building completed in 2008 (Luxemburg).

An outstanding feature of the new building is the use of natural and centrally monitored climatic control zones. Large atria and winter gardens act as the building's lungs and are situated under the building's tubular glass shell which protects against adverse weather conditions. In hot summer months a natural ventilation system creates airflow from the gardens' lower areas to upper vents. In the south-oriented atria, heat and ventilation is carefully controlled. Radiant floor heating, induction unit and solar protection sails ensure constant temperatures.

The East building also benefits from a cooling system which pumps night air around the structure and passes cold water through the concrete floor slabs.

Energy efficiency is a top priority for the EIB's lending activities and the Bank put this policy into practice with lighting which minimizes energy consumption. Modern lighting technology reduces brightness in office areas, while staff can use individual desk lamps. In a document of EIB group the preliminary calculated consumption of the East building were: **29 kWh/m^{2}a** for the heating, 21 kWh/m^{2}a for the cooling and still 21 kWh/m^{2}a for the internal equipment such as computers and appliance. *(Source: EIB building – Project and environmental management)*

Chapter 2

2. Definition of NZEB and Passive house and Italian/Lithuanian Standards

After the choice of the overall primary energy consumption used as indicator for energy requirements in buildings, it is important to give some reference values of it, in order to understand when a building is defined with high or low consumptions. Which are the reference values which should be taken into account?

One of the last concept that appears in the building efficiency scenario is the Nearly (or Net) Zero Energy Building or shortly NZEB.

The definition of NZEB (Nearly Zero Energy Building) is not unique across the EU. The EBPD recast of 2010 (Directive 2010/31/UE) gives strictly directive about deadline, but no clear requirements about building consumption, letting each EU country decide for itself. Therefore, differences across the EU for the non-residential NZEB primary energy requirements vary from 25 kWh/m^{2}a (Denmark) to 270 kWh/m^{2}a (Estonia) and these are numbers taking into account renewable energy usage in the building (as required by EPBD).

In the European directive a **NZEB** is defined as:

- Building with an high energy efficiency,

- The low/zero energy requirement should be powered by renewable energies, included renewable energy produced in places close to the site.

Then each EU county gives it own shades, for instance Italy added that all the renewable energy should be produced around the building location.

It is easy to understand how ambiguous the NZEB definition could be.

Since it is an elder concept, the **passive house** definition is much more easy to give: To be a passive house a building must fulfil different conditions *(IEA-Energy efficiency requirement in buildings codes, 2008)*:

- The building must not use **15 kWh/m²a** or less in heating energy.
- Total primary energy consumption (primary energy for heating, hot water and electricity) must not be more than **120 kWh/(m²a)**.
- The specific heat load for heating source at design temperature must be less than 10 W/m².
- With the building pressurised to 50Pa by a blower door, the building must not leak more air than 0.6 times the house volume per hour (n50 ≤ 0.6/h).

Furthermore, about the NZEB the IEA writes:

“Compared to the passive house standards there is no exact definition for the way to construct or obtain a zero energy building. In principle this can be a traditional building, which is supplied with very large solar collector and solar photo voltage systems. If these systems deliver more energy over a year than the use in the building it is a zero net energy building.
[...] A Zero Energy Building can be a passive house where the remainder of energy is supplied from solar collectors, PVH and other renewable energy.”

Focusing on the total primary energy consumption, a building needs to have requirements below 120 kWh/m²a for having a passive house, while for the NZEB it is not specified: anyway, it often happens that a passive house is a NZEB as well. To have a general idea of how much the energy consumption of a NZEB are it is suggested the consultation of the following article by European Directive, in which are presented many examples of NZEBs and their clear consumptions *(EPBD – September 2014, Selected examples of NZEBs – detailed report).*

In any case, it is interested to enter in the details of how the NZEB building are defined in the two countries in which the simulations will be performed. It is interested to see how much requirements there are in these definitions, and that the total primary energy consumption is just a small face of the world of the national and international standards.

2.1. Italian standards to n-ZEB

The classification of a building as n-ZEB in Italy is reported in the "minimum requirements decree". *(Decreto Ministeriale dei requisiti minimi, 2015)*

The values of the parameters that define a n-ZEB depend on the climate zone. In fact, Italy is divided in 6 different climate zones (A, B, C, D, E, F), according to the measure of degree days, from the warmest (A) up to the coldest (F).

The first two parameters which define a n-ZEB are referred to the envelope and the most important is the average global heat transfer coefficient. (H'_T)

Depending on the climate zone and on the shape factor (S/V), the average global heat transfer coefficient has to be equal or minor than the value in Table 2.1.

ShapeFactor (S/V)	Climate Zone				
	A and B	C	D	E	F
$S/V \geq 0.7$	0.58	0.55	0.53	0.50	0.48
$0.4 \leq S/V \leq 0.7$	0.63	0.60	0.58	0.55	0.53
$S/V \leq 0.4$	0.80	0.80	0.80	0.75	0.70

Table 2.1: H'_T limite values for a n-ZEB. [W/m^2 K]

The second parameter necessary is the ratio between the equivalent summer solar surface ($A_{sol,est}$) and the floor area (A_{utile}). Where the $A_{sol,est}$ is calculated as:

$$A_{sol,est} = \Sigma k\ F_{sh,ob} \times g_{gl+sh} \times (1 - FF) \times A_{w,p} \times F_{sol,est} \qquad [m2]$$

Where:

-$F_{sh,ob}$ is the reduction factor for external shading, referred on July.

-g_{gl+sh} is the solar heat gain coefficient,

-F_F is the frame surface fraction,

-$A_{w,p}$ is the window's surface,

-$F_{sol,est}$ is the corrective factor for the solar irradiation incident angle.

The ratio $A_{sol,est}/A_{utile}$ must conform to the values in table 2.2.

Building category	Each climate zone
Residential	≤0.030
Other buildings	≤0.040

Table 2.2: $A_{sol,est}/ A_{utile}$ values for n-ZEB

The next indications for a n-ZEB concern the heating, cooling and domestic hot water demand.

The decree indicates that the heating, cooling and DHW energy demand in kWh/m^2 year (calculated with the Italian directive UNI/TS 11300) has to be converted in primary energy with the specific conversion factors provided by the decree.

Anyway the primary energy demand for heating, cooling and the global primary energy demand (EP_H, EP_C, EP_{gl}) must be minor than the limit values calculated for the "Target building" ($EP_{H,lim}$, $EP_{C,lim}$, $EP_{gl,lim}$).

The "target building" is an ideal building, identical to the real one for geometry sizes, orientation, location, and boundary conditions, but with technical characteristic predetermined. (es. Windows, walls, and roof U-values, systems efficiency)

In figure 2.1 is reported the U-values for a “Target building” in the different Italian climate zones.

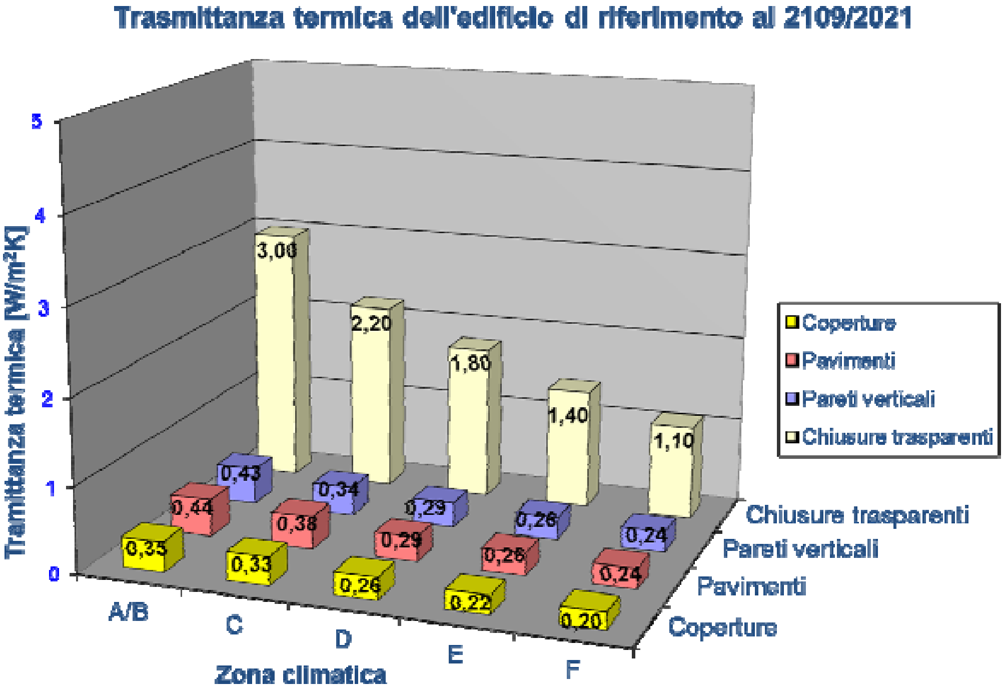


Figure 2.1: (Chiusure trasparenti=windows, Pareti verticali=walls, Pavimenti=floor, Coperture=roof)

The medium seasonal efficiency for heating, cooling and DHW (η_H, η_c and η_W) must be lower than the limit values in the “target building”.

In Table 2.3 these limit values are reported, depending on the medium of distribution.

Medium seasonal efficiency	η_H	η_c	η_W
Water distribution	0.81	0.81	0.70
Air distribution	0.83	0.83	-
Mixed distribution	0.82	0.82	-

Table 2.3: Medium seasonal efficiency for the Target building

Finally the last indications concern the use of renewable energies to cover the demand in n-ZEB. The decree establishes that it is compulsory to cover 50% of

DHW energy consumption and the 50% of the sum of heating, cooling and DHW consumptions with systems powered by renewable energies. Furthermore, it is specified that the renewable energy has to be generated in situ.

In line with European Performance Building Directive, Italian directives obligate to build only NZEB starting from 31/12/2018 for public institutions buildings while starting from 01/01/2021 for all types of buildings.

2.2. Lithuanian Standards to n-ZEB

Here the Lithuanian directive about a A++ building requirements. It is reported only the U-value requirements in table 2.4.

Type of element	Residential Buildings	Non-residential buildings	
		Public Buildings	Industrial Buildings
Roofs	0.080	0.090	0.12
Overlap			
Heated indoor partitions	0.10	0.12	0.12
Ceiling above unheated basements and cellars			
Walls	0.10	0.11	0.14
Windows, roof windows, skylights	0.70	0.85	1.1
Doors, gates	0.70	0.85	1.1

Table 2.4: Building envelope heat transfer coefficients U (A ++) (W / (m2·K)) the value of A ++ energy efficiency class of buildings regulations of specific heat loss and energy performance indicators calculation

Chapter 3

3. Literature review on envelope parameters

After the introduction to the National and European standards it is interested to go deep in the scientific literature in order to understand which are the parameters mainly responsible of reducing the energy consumptions, according to authors and researchers, and furthermore, which are their optimal values depending on the building locations.

In this literature review solutions, to reduce more and more intensively global energy demand in buildings, are investigated. Moreover, the study is focused on the different solutions chosen by the European countries, depending on the climate. To define the different climate typologies is considered as guide the Koppen-Geiger climate classification (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006). It will be noticed how, depending on different climate zones, the EU countries have adopted different solutions, and for each solution, different passive energy efficiency measures to reach the goal of n-ZEB design.

Both classical and innovative parameter as WWR (window-to-wall ratio), glazing characteristics (g-value, etc.), presence of shading system, type and strategies of shading, envelope U-value and composition, Phase Change Material, will be compared between northern and southern climates. All this literature review is not only focused in building completely covered by glass in order not to give any constraints. Furthermore, this choice allows to understand which are the advantages or disadvantages brought by choosing a glazed curtain wall in the preliminary stage of the project.

3.1. WWR (Glazing)

Window is a weak part of the building in terms of heat loss, because its U-value will be always few times higher compared to opaque parts of the envelope. Therefore, it is important optimize glazing areas (window-to-wall ratios).

Window-to-wall ratio is the ratio between the glazed surface and the opaque surface of a facade. Many studies have been conducted about the optimal WWR but with different results.

The first records (Arumi, 1977; Johnson et al., 1985,1984) concerning dedicated investigations into the impact of the WWR on the energy balance of a building showed that selecting an optimal WWR value would have halved the energy use. In general, the early research showed that for each climate and orientation it was possible to find an optimum WWR that minimized the annual energy use.

Anyway, optimum WWR that minimized the annual energy use is ambiguous, or better, it is necessary to take into account many variables to define one unique solution. For instance the study developed by (Ghisi & Tinker, 2005) assesses the value of energy savings in two different climates (Leeds, UK and Florianopolis, Brazil) using an optimal WWR in each facade of the buildings. The result showed how in a warmer climate (Florianopolis) the energy savings for the artificial lighting using an optimal WWR were higher than in the colder one (Leeds). The article considered many parameters; an example table is reported: the values of Room Index (horizontal surface/vertical surface) and WWR are both fixed as 1, while they are varied in all the article simulations.

Façade orientation	Florianopolis (Brazil)	Leeds (UK)
N	**60.6**	**33.3**
E	**66.2**	**28.9**
S	**74.8**	**19.3**
W	**42.0**	**11.9**

Table 3.1: Potential for energy savings (%) on artificial lighting when using the Ideal Window Area concept in Leeds and in Florianopolis with an outdoor illuminance of 5000 lux and 10000 lux respectively.

Generally, it was summarized that in Leeds the potential energy savings ranged from 10.8-44%, while in Florianapolis between 20.6-86.2%.

Unfortunately, the saving potential for different WWR was only calculated for artificial lighting use without taking into account heat loss and heat gains.

In any case it is clear that is not possible to consider the optimal WWR value that minimizes the artificial lighting energy demand. As a matter of fact, a facade with more glazed surface allows the entrance of more solar radiation and the heat transfer losses are usually higher through a window than through the wall.

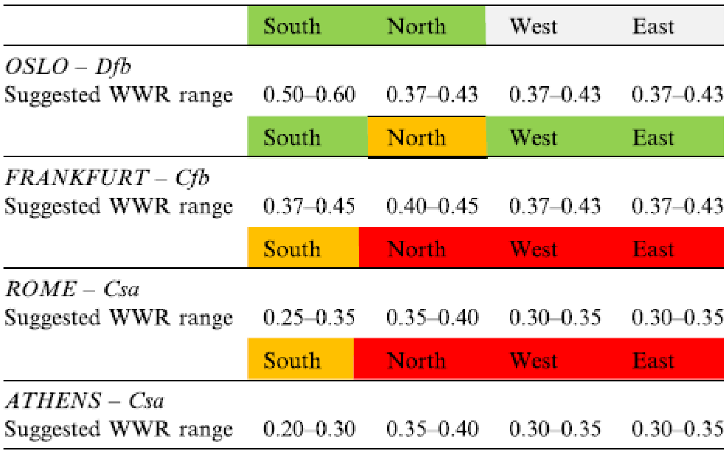
Therefore, WWR is related to the heating and cooling energy demand too.In an article (Özkan & Onan, 2011), it has been investigated the mutual influence between insulation and WWR in 4 different Degree Days zone in Turkey. Although the range of latitude is narrow, the four different regions chosen are characterized by different climates. The result of the study showed that insulation is more effective in buildings with a smaller windows area, regardless of the climate. Here there is a contrast between the previous articles and this one in which it is asserted that the WWR isn't influenced by the climate, nevertheless, it is worth to notice that the range of latitude considered is very narrow but above all the research only focused on heating energy use.

The impact of WWR for south and north facing facades in five Turkey locations with different climates (Csa, Dsa and Dfb) was investigated(Inanici & Demirbilek, 2000). The result asserted that different climates require different windows size: with values of WWR from 0,25 in Csa climate up to 0,70 in Dsa and Dfa climates. In any case, also in this study only thermal simulations were carried out, excluding the lighting ones.

It is evident that WWR can depend on the different climate, and could influences the heating, the cooling and the lighting energy demand.

More recently Kheri (2013) analyzed the relationship between windows area and climate, considering four different cities around the world (Miami, Las Vegas, Sheffield and St. Petersburg) with very different climate:Am,Bwh, Cfb, Dfb.

The analyses were wider because they took into account the energy used for heating, cooling and lighting too, and the result showed that, slightly depending on the climate, the optimum WWR was in a range between 0,2 and 0,32, while a higher value of WWR would have implicated a nonlinear increase of the thermal loads. Anyway, it is worth mentioning that were used properties of the facade (both opaque and window parts) not suitable with a low- energy building: with U-values above 2 W/m2 K the technologies used were far from the ones available at the present state of art.



	South	North	West	East
OSLO – Dfb				
Suggested WWR range	0.50–0.60	0.37–0.43	0.37–0.43	0.37–0.43
	South	North	West	East
FRANKFURT – Cfb				
Suggested WWR range	0.37–0.45	0.40–0.45	0.37–0.43	0.37–0.43
	South	North	West	East
ROME – Csa				
Suggested WWR range	0.25–0.35	0.35–0.40	0.30–0.35	0.30–0.35
	South	North	West	East
ATHENS – Csa				
Suggested WWR range	0.20–0.30	0.35–0.40	0.30–0.35	0.30–0.35

In (Susorova, Tabibzadeh, Rahman, Clack, & Elnimeiri, 2013)was investigated how the WWR could be influenced by the different climate. Six different locations in the USA were considered, including Cfa, Csb, Dfa and Dfb climates. The study showed that energy use can be affected by the WWR in hot climates and cold climates, but only marginally in temperate climates. However, energy savings from optimal configurations were somehow limited (on average 3% and 6%, reaching a maximum of 10% and 14%) in hot climates, and almost negligible (on average 1%) in temperate and cold climates. In hot climates, the main energy use reductions were found with a WWR of 0,3, while in temperate climate were found with a WWR of 0,4; in very cold locations, the best energy performance was achieved with small windows for the north-facing facade and with a WWR of 0,80 for the south-facing facade.

Anyway, the boundary conditions for these articles were:

-it wasn't investigated the entire office building itself, but only a single room and its size as the ratio between the width and the depth of the room were taken into account. These variables strongly influence the optimal WWR depending on the climate too, and here only average value of optimum WWR are reported.

-the absence of a shading system

-the thermal resistance of glazing systems especially was quite low and not in line with best practice for very low-energy buildings.

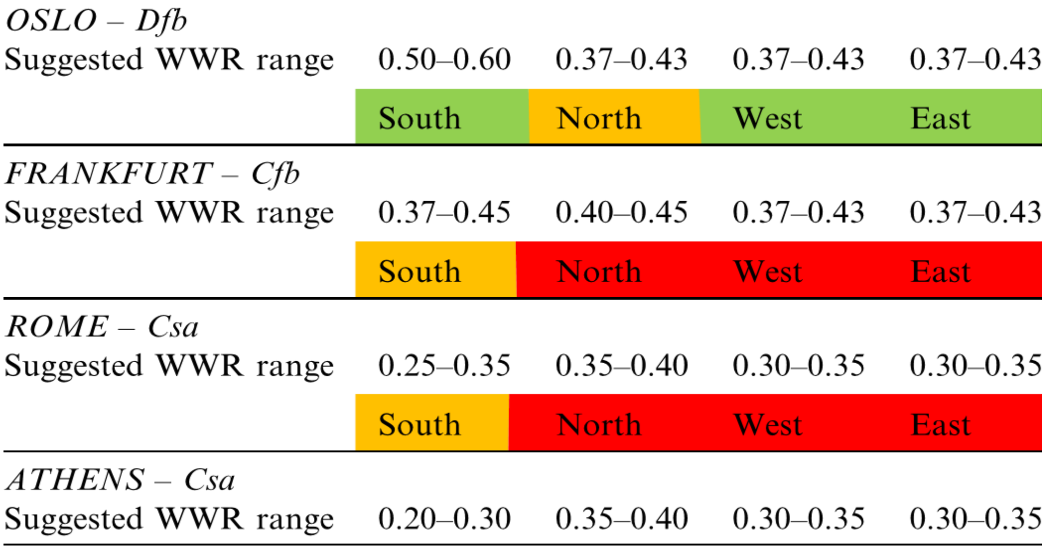
In the last year, another variable, influencing the WWR, appears: the presence of a facade shading system, especially for building with a high presence of glazed surface in the envelope. As it can be imagined, a high value of WWR, in winter allows to the solar radiation to enter and thus to contribute with the heating load; on the other hand, in summer, it implies an overheating and thus a higher cooling energy demand is required. Therefore, the presence of a shading system is a variable that strongly influences the optimal WWR value depending on the climate. Anyway, the shading system technology is discussed in the next paragraph.

An articles by (Goia, 2016) tried to explain the variability of optimal WWR basing on its own definition: the Optimal Window-to-wall ratio value is the one that minimizes, on annual basis, the sum of the energy use for heating, cooling and lighting.

By means of both thermal and lighting simulation, the optimal WWR for each main orientation was found in four different locations in Europe from temperate to continental climate, considering the presence of a shading system too. The reliability of this study is also confirmed because many variables were involved such as the efficiency of the building HVAC system, the efficacy of the artificial lighting and the compactness of the building.

The result showed that the optimal WWR is mainly the same for East-, North- and West- facing facade, while it changes in the South- facing facade, and obviously the optimal WWR value changes depending on the climate.

Values of optimal WWR of 0,4 for E,N,W- facing facades and 0,56 for S-facing facade were found in Dwb climate (Oslo) and 0,35 for the E,N,W facades and 0,27 for the S-facing facade were found in Csa climate (Rome).



OSLO – Dfb				
Suggested WWR range	0.50–0.60	0.37–0.43	0.37–0.43	0.37–0.43
	🟩 South	🟧 North	🟩 West	🟩 East
FRANKFURT – Cfb				
Suggested WWR range	0.37–0.45	0.40–0.45	0.37–0.43	0.37–0.43
	🟧 South	🟥 North	🟥 West	🟥 East
ROME – Csa				
Suggested WWR range	0.25–0.35	0.35–0.40	0.30–0.35	0.30–0.35
	🟧 South	🟥 North	🟥 West	🟥 East
ATHENS – Csa				
Suggested WWR range	0.20–0.30	0.35–0.40	0.30–0.35	0.30–0.35

Table 3.2: Suggested WWR range values for different climates and orientations that can be used in the preliminary stage of design. Information is also visually communicated using a scale of background color (light gray: very small increase, i.e. 65%; green: small increase, i.e. 6–10%; orange: medium increase, i.e. 11–15%; red: large increase, i.e. >16%).

This study shows how by moving towards colder climates it is better to have more transparent building envelopes, opposed to the "Rule of thumb" which asserted that when the climate is colder it is better to have smaller windows. Lastly, the article proposes that the "rule of thumb" is overtaken because of the use of windows with the highest performances, such as the use of triple glazed with low emissivity windows. It is normal to think, in fact, that with worse U-values windows, a high WWR implicates higher transmittance losses.

Excluding Susurova et al. (2013) article which has different boundary conditions, it is worth comparing the result of the last two articles and noticing the difference between them. This difference could be justified by considering that Kheri (2013) used windows and envelope with low performances, while Goia used the best technology in commerce to contrast the heat transfer losses. Moreover, Goia's analysis considers the presence of a shading system.

Since the purpose of this paper is to highlight the differences used in n-ZEB buildings it appears clear how it is better to refer to the optimal WWR values suggested by Goia.

The influence of the windows and walls U-values on the WWR was confirmedin a study (Kontoleon & Bikas, 2002) about the optimal WWR minimizing the thermal energy demand in summer and in winter in a building located in Greece (Mediterranean climate).

The research showed that while in winter the optimal WWR value is around 70%, in summer it dropped to 40% with double glazed windows, but it stayed on higher value (55%) with more performing windows (double glazed windows with reflective film).

Moreover, in this article it is shown that in a southern EU climate the most critical season for a high value of WWR is summer: in fact, to face the overheating it is compulsory to keep the glazed surface low.

On the other hand, in the norther EU climates, summer overheating can verify especially when the glazed surface is high. (Motuziene & Juodis, 2010)

In this article an optimal WWR of an office building in Lithuania(Dfb), for different façade orientations, was investigated.

Simulations' results shown that energy efficient WWR for conditioned office building is 20% for the south, east and west oriented façade and 20 to 40 % for the north oriented one.

It was specified that the most efficient fenestration does not satisfy standard requirements for daylighting; but on the other hand, for high values of WWR, cooling demand is even 2 to 3 times higher than that for heating (except for north orientated).

Finally, in a study by (Méndez Echenagucia, Capozzoli, Cascone, & Sassone, 2015) with many objectives, it was proposed to search for the optimal WWR to minimize the use of heating, cooling, and lighting energy demand in different climate regions (Csa, Cfa, Cfb and Dfb). However, the results showed that the optimal solution was a small window-to-wall ratio (WWR) value, regardless of the location. It is necessary to say that, in the simulation, a shading system wasn't considered.
(Liu, Wittchen, & Heiselberg, 2015) statedinstead that the optimal WWR in a Cfb climate is around 0,4, but the article deeply focused in the presence of a shading system, asserting that a correct strategy of an intelligent glazed facade shading system can decrease the energy demand up to 60%.

In conclusion, many articles about the optimal WWR value depending on the climate were considered, but it is difficult to establish a single value of optimal WWR depending only on the climate. In fact, in every article there are different boundary conditions that make the results difficult to be compared. Anyway, it is often proposed a WWR value that is higher in colder climate. This solution could be explained by the fact that in a heating dominated climate, the radiation can mainly be considered as a helpful contribution of thermal energy. In a Mediterranean climate, as southern Europe, in summer the incoming solar radiation has a negative effect since it forces to have higher cooling energy demand. It is worth highlighting that the presence of external shading system can strongly influence the WWR value in warm climate.

In table 3.3 are reported the optimum WWR values proposed by different literature articles. It is evident how much the optimal values can vary even in the same climate. That is owing to many factors such as the different envelope U-values used, the presence of a shading system, the exclusion of the lighting energy demand.
The optimal value obviously depend on the façade orientation (south orientated facades have optimal WWR values different from the north orientated ones).

In conclusion it becomes difficult to establish one unique optimum WWR for each climate, but it can be asserted that for all the European climate it stays in a range between 20-50%.

For what concern the warmer climates an optimal WWR value is in the range of 30-40%, noticing that the south oriented façade requires lower values.

In the colder climates, instead, the optimal WWR value is between 20-40%, with higher values (up to 56%) for the south oriented façade.

	Northern Climate		Southern Climate	
(Susorova et al., 2013)	**0.8**	S	**0.4**	
	Low	N		
(Goia, 2016)	**0.56**	S	**0.27**	S
	0.4	E,N,W	**0.35**	E,N,W
(Liu et al., 2015)			**0.4**	
(Motuziene & Judis, 2010)	**0.2**	S,E,W		
	0.2-0.4	N		
(Inanici & Demirbilek, 2000)	**0.5-0.7**	S	**0.25**	S

Table 3.3: Optimum WWR values, related to the article in which they were proposed. The two different columns indicate the location in which the value of optimal WWR was simulated. Usually the values were different depending on the façade orientation and or on the season (Kontoleon & Bikas, 2002).

3.2. Shading

In the article by (Goia, 2016)in which an optimal WWR value in different climate is analyzed, it is asserted that in a n-ZEB the presence of a shading system is a must, and it is highlighted that there is a lack of analysis that included the shading in the buildings.

In a study (Etzion & Erell, 2000), in which the influence of a shading system in a building in warm climate was investigated, the analyses showed how the Mediterranean climates are the ones that strongly need a shading system to increase the performance of the buildings.

In fact, in cold dominated and hot dominated climates, the variables, such as the air temperature and the solar radiation, don’t change dramatically. Thus, a design that follows the needs of the buildings for the whole year is allowed.

On the other hand, in climates with cold winter and hot summer, as the Mediterranean, different WWR values depending on the season are required: for example, by applying the winter WWR values, in summer an intense overheating verifies. Many studies confirm that the best solution for overheating issue is a shading system. In fact, many original solutions have been proposed, as Etzion and Erell (2000) proposed an intelligent glazing shading system, in which a natural air ventilation prevents summer overheating in warm climates.

Other articles pointed out the total need of a shading system in warm and hot climates and how it can reduce the global annual energy demand.

In (Bellia, De Falco, & Minichiello, 2013),it is investigated the amount of potential Energy savings in a stand-alone office building in three different Italian climates. The energy demand of the main technical systems (heating, cooling and lighting) and the energy saving related to the use of solar shading devices have been evaluated.

The result showed that the solar shading system decreases the global annual energy demand in warmer climate. For instance, the annual global energy savings in Palermo (Csa) are around 20% while only 8% in Milan (Cfb).

It is worth noticing that these are average value of energy savings owing to shading system. In fact, different values of insulation thickness or WWR strongly influence the energy savings.

Focusing on the influence of WWR, it is shown that both for Palermo and Milan, the global energy requirements of the building with WWR = 30% without shadings are about equal to those of the building with WWR = 60% and the shadings. This result not only confirms that highly glazed building require more energy, but also shows that the use of suitable shading devices can eliminate or significantly reduce this increase.

(Ascione, De Masi, de Rossi, Ruggiero, & Vanoli, 2016) proposed an extended study with dynamic simulation tool and multi-objective optimization algorithm in which design criteria for residential n-ZEB in Mediterranean climate are discussed. Every possible solution to increase the building performance were analyzed such as PCM, cool roof, different walls and window technologies, shading systems. The study was extended to almost all the Mediterranean area in four different cities: (Madrid, Nice, Naples, Athens).

For what concerns the shading system the result showed that, to achieve n-ZEB objective in Mediterranean climates, windows with triple selective systems and both external and internal shading systems (more in detail, shade roll) are required.

An article about life cycle energy implication for office building with directionally selective shading devices in sub-tropical and temperate climate was published by (Bunning & Crawford, 2016). Although the research was conducted in the south hemisphere, the temperate climates are comparable with the southern European ones. The results established that in 25 years, 25% of energy was saved thanks to the presence of a directionally selected shading system.

As in this study, other articles highlight that the best efficiency from a shading system is obtained when the devices are dynamics and with specific strategy of shading. (Nielsen, Svendsen, & Jensen, 2011) compared the performances of three types of facade: without shading system, with fixed shading system and with dynamic solar shading. Their performance was evaluated on the basis of the building’s total energy demand, its energy demand for heating, cooling and lighting, and also its daylight factors. Simulation results comparing the three facade alternatives show potential for significant energy reduction. Moreover, the use of dynamic solar shading dramatically improved the amount of daylight available compared to fixed solar shading.

Consequently, it’s clear and evident that in the southern climate of EU a good energy saving solution is represented by an external dynamical shading devices.

(Palmero-Marrero & Oliveira, 2006) proposed an even more efficient system for the building shading: the integration of collectors into the external louvres of buildings offers a means of reducing system cost as well as providing architects with more freedom to integrate the technology into their designs. The research concerns the modification of existing louvre designs to integrate a solar collector in the shading device. The evaluation of a thermal solar system for water heating is assessed in the article from an environmental and economic point of view, too. The simulations were carried out for the climatic conditions of Lisboa (Portugal) and Tenerife (Spain).

Therefore, many studies confirm the wholly reasonable presence of the shading system in the southern climates of Europe. It is reasonable to suppose that in the northern climates, being heating dominated, the presence of a shading device is not so necessary because of the low solar radiation.

Nevertheless, many researches confirmed the opposite. In the already mentioned article by (Nielsen et al., 2011) it is asserted that even in the relatively cold and northern European climates, where heating often dominates the total energy consumption, energy demand for cooling and for artificial lighting is also important, especially in very low energy building. The study was carried out in Denmark (Dwb) and compared the performances of a non-shading facade, with a fixed shaded one and with a dynamic shaded one. Results showed that with the dynamic shading devices, energy saving values up to 16% were obtained.

(Tzempelikos & Athienitis, 2007) developed a research about the impact of shading design and control on cooling and lighting energy demand. Both thermal and lighting simulations were carried out considering the glazing area of the facade, the building orientation and the shading devices type and its control. The results have shown that even in heating-dominated climates, cooling is important for perimeter spaces with high solar gains. Shading provision is necessary, hence the properties and control of shading should be considered from the early design stage, since they have a significant impact on peak thermal loads, energy consumption for heating, cooling and lighting.

The influence of shading system and its control was investigated by (Grynning, Time, & Matusiak, 2014) in the cold continental climate of Oslo, Norway (Dfb). In all modern buildings, more and more glazed surfaces are required for the facades. Previous studies have shown that a large part of the net energy demand of an office building is related to window heat loss and to cooling demands. It was found that even in the continental climate of Oslo, Norway, that is a heating dominated one, cooling demands are considerably present in the annual global energy requirement. Thus, it is shown that it is recommended to use a shading system to reduce cooling demand, especially in a low energy building as mentioned by (Tzempelikos & Athienitis, 2007).

In this study simulations of a certain number of shading strategies have been performed for south- and north-facing office cubicles with varying floor areas, window sizes and window parameters. Peculiarity of this article is its analyses depending on the shading strategies, where each one is a combination of the sizes of the rooms, the WWR, and the windows performances in terms of U-values. Simulation results showed that depending on strategy, the energy demand can either increase or decrease compared to an unshaded one- or two-person office cubicle. It’s evident the need of taking account of dynamic shading system since the first stages of design. In any case, values of energy savings were found thanks to the shading system of 9 % with a 0,4 WWR value and up to 16% with 0,6 WWR for what concerns the south-facing facade.

Instead it is not worth the presence of a shading system on north-facing, small office cubicles.

In conclusion is not true that in the northern European climate there is no need of a shading system: in fact, regarding southern European climates the use of a shading system is a must, and it is more efficient if the devices are dynamic and automatically controlled. Moreover, the presence of both internal and external shading system could be an optimal solution. On the other hand, in the northern climates, the energy savings obtained thanks to the installation of a shading devices appear lower than in the southern climate; nevertheless, if the purpose is achieving an n-ZEB, shading systems should be installed in the northern climate office buildings too. But they should not be installed without an accurate investigation of each single case and strategy.

Anyway, in the review was found the important result that both in warmer and colder climates, a shading system is necessary to reduce the cooling energy demand. This is true especially in building which requires low energy demand, or nearly Zero Energy Buildings.

It was found that with an automatic shading system with the appropriate strategy, global annual energy savings can be estimated between 9-16 % in the colder climates, up to 20% in the warmer ones.

	Northern climates		Southern climates	
(Bellia et al., 2013)			**8-20%**	Milan-Palermo
(Nielsen et al., 2011)	**16%**	Denmark		
(Tzempelikos & Athienitis, 2007)	**9-16%**	Montreal		

Table 3.4: Percentage values of energy savings thanks to a shading system. Values are reported with the locations in which the simulations/measures were carried out. Each value is related to the author who proposed it.

3.3. Windows U-value, walls U-value, roof U-value and thickness of isolation

In an research (Ascione et al., 2016), optimization techniques, coupled with building performance simulation tools, are used to study the best trade-off among transparent envelope solutions, thermal mass of the building and radiative characteristics of roof. The case study is a small residential building located in four different cities typical of the Mediterranean climate: Madrid (Spain), Nice (France), Naples (Italy) and Athens (Greece).

To evaluate the optimized solutions, heating and cooling loads minimization has been considered as objective function. In Mediterranean climate, global annual heating and cooling demand is minimized with walls of bricks, in which the holes are filled with expanded polystyrene (EPS) and insulation with rock wool of 10 cm (U=0,18 W/m^2 K), moreover walls should have M=250 kg/m^2. For what concern the roof, brick concrete roof slab with 20 cm of EPS external insulation (U =0,16 W/m^2 K and M=500 kg/m^2) and cool membrane as external covering (α_{solar} =0.2,$\varepsilon_{\text{infrared}}$=0.9) should be installed.

Windows should be triple selective systems and both external and internal shading systems are required.

In any case, this research has been carried out for a small residential building; other articles (Buonomano, De Luca, Montanaro, & Palombo, 2016) proponed other values of envelope parameters in a simulation of non-residential n-ZEB.

In this article a computer model was used to assess the energy demand of a prototype of a n-ZEB office located in Naples (Italy). Several simulations were carried out to search for the optimal solution of the envelope, the thickness of the insulation, the position of the layers in the wall, WWR, and windows type, presence of PCM and their optimal melting temperature, BIPV integrated with thermal collectors.

For what concern the envelope, results showed that optimal values of wall thickness insulation are around 9 cm with U-values of 0,23 W/m^2 K in the best layers' configurations.

Roof thickness value of 11 cm is required to achieve the optimal U-values of 0,23 W/m^2 K and the best solution for the windows is to have triple glazing with low emissivity (U=0,9 W/m^2 K).

The presence and the design of PCM is considered in this study but it will be analyzed in the next paragraph.

To find similar articles that analyze so deeply the optimization of a n-ZEB in the cold regions of EU was very difficult. Anyway, many articles from Chinese researches which aim to the reduction of global annual energy demand in building optimizing the envelope parameters have been published. An analysis about how the envelope's influence on building energy consumption was carried out by (Feng, Sha, & Xu, 2016) in a cold Chinese climate (Shenyang: Dwa, comparable with the northern EU climates).

The study focused in two main factors: the shape factor and the heat transfer coefficient.

The shape factor is most often calculated as the ratio between the outside surface area of the thermal insulation in the building envelope (A) and the heated volume (V).

The result showed how the shape factor can influence the heating load in a building.

When the using area, the number of layers and the height of the building are fixed, a nearly circular building bottom shape is recommended. Instead when the building bottom shape is already determined the building shape factor decrease with the increase of the height of the building. From the consideration of energy save it is better to have building with lower shape factor. Anyway, the article suggest that a middle-rise-high building should be chosen.

In conclusion, it is highlighted that, especially in the cold climates, such as Shenyang ones, the most influential parameter is the heat transfer coefficient. In fact, the insulation is dominant in these climates and it is clearly asserted that the smaller the heat transfer coefficient the higher the decrease of energy demand.

Anyway, the thickness of the walls cannot be unlimited but the heat transfer coefficient should be at least less than 0,5 W/m^2 K in this climate.

Many article comparing the envelope's influence on the energy saving between different climate of the world were found. Although these articles don't refer precisely to cold and hot European climate, it is possible to acquire information about envelope parameters depending on different climate of the world.

A study to prove that a n-ZEB could be built in every type of climate in the world, was published taking into account several cities: Yekaterinburg, Tokyo, Shanghai, Las Vegas, Abu Dhabi, and Singapore.(Schnieders, Feist, & Rongen, 2015)

Yekaterinburg (Russia, Dfc) was considered as representative for the cold climate, as the matter of fact the climate is even more extreme than the coldest European ones. The results showed that insulation is the only way to face extreme cold winter with temperature even under the -30°C. Thickness of insulation values of 50 cm were suggested in this climate and the presence of thermal bridges must be totally avoided.

Moving towards warmer climates the thickness of insulation was suggested lower and lower, as for instance in Tokyo, was asserted that a thickness of 15-20 cm is sufficient. Anyway, in the article is enunciated that lower value of thickness of insulation are required in Tokyo than in Europe, because of the higher solar radiation in the Japanese city.

In hotter climates like Abu Dhabi and Las Vegas ones, a good but not extreme insulation is required, above all cool colours in opaque component are required to contrast the very high solar radiation.

It was analyzed the influence of the envelope in three different regions in China(Yu, Tian, Xu, & Wang, 2015): Shenyang (Dwa, comparable to the cold EU climate, with an almost heating dominated-climate), Wuhan (Cfa, comparable with the temperate EU climate, with cold winter and hot summer), and Guangzhou (Cwa, a humid subtropical climate, cooling-dominated but not comparable with any EU climates).

The study was based on a new index of envelope performances: EEPTO. Anyway, it is important to focus on the roof and walls U-values, found to minimize the heat transfer losses. The result showed that for the roof 0.4, 0.7, 0.9 W/m^2 K are the maximum U-value admitted for the cold, medium and hot region respectively.

For what concern the walls, the maximum U-value admitted are respectively 0.45, 1, 1.5 W/m^2 K.

In conclusion, there are some parameters, that characterize the envelope performance, which cannot be optimized with the same value both in Continental and Mediterranean climate.
As suggested by (Bruno, Arcuri, & Carpino, 2015) in a research for the optimization of a passive house in Mediterranean climate, there are some main differences between the two climate:

-Large transparent surfaces with low solar gain coefficients south facing are penalizing for the excessive cooling requirements in warm climates; thus, in continental climate is important to reduce the windows U-value to contrast the heat transfer losses and to increase the WWR to allow more solar radiation in the building. On the other hand, in Mediterranean climates, is better not to have high WWR value, especially in south facade, because of the cooling demand, although windows SHGC is low. Anyway, the best solution is represented by the windows with lowest U-value regardless of the climate.

-Different insulation thicknesses are required for continental and Mediterranean climate.
in the first one to reduce the heating energy demand, even more than 20 cm of insulation is required. While in the second climate, thickness of isolation of 10 cm could be sufficient to compensate the reduction of solar heat gain during winter.
In any case to achieve n-ZEB objective very low U-value for the walls are required. For the colder climates, it was established that walls U-value above 0,5 W/m^2 K aren’t accepted, anyway, in the optimization of a n-ZEB in Naples, walls U-values of 0,23 W/m^2 K are required.

In table 3.5 some suggestions from literature are reported. Since they can be much different because of building shape, walls materials and layers, orientations, and so on, in table 3.6 U-value national standards are reported for the two involved locations.

	References	Northern Climate	Southern Climate
Walls U-value	(Ascione et al., 2016)		**0,18**
	(Buonomano et al., 2016)		**0,23**
	(Yu et al., 2015)	**≤ 0,40**	**≤ 1,0**
Roofs	(Ascione et al., 2016)		**0,16**
	(Buonomano et al., 2016)		**0,23**
	(Yu et al., 2015)	**≤ 0,45**	**≤ 0,7**

Table 3.5: Suggested envelope value corresponding with the related source.

Standards	LT(Northern climate)	ITA (Southern climate)
Walls U-value	**0,1 - 0,14**	**0,24 – 0,43**
Windows U-value	**0,7 – 1,1**	**1,10 – 3,00**
Slabs	**0,08 – 0,12**	**0,24 – 0,44**
Roofs	**0,08 – 0,12**	**0,20 – 0,35**

Table 3.6: National U-value Standards for each building part.

3.4. SHGC and VT

An important characteristic of the window is not just its U-value, but also solar heat gain coefficient (SHGC), responsible for solar heat gains and light transmittance coefficient (VT), responsible for daylighting in the room. There is no linear correlation between these two parameters, but as a rule, when SHGC is decreasing, VT is decreasing as well. Depending on the window construction, this negative effect differs.

SHGC is not one of the most important parameter when a building with standard WWR is analyzed, but in this case is different. This ratio (SHGC/VT) has a strong impact on the cooling requirements, because less solar gain means less cooling energy, on the heating, because more solar gain means less heating energy, and finally in the lighting, because higher values of VT mean that less artificial lighting is necessary (Poirazis et al., 2008). Optimal values of SHGC for a non-glazed high performance building located in the north of Italy is around 0.69 (Bruno et al., 2015). Moving towards 100% WWR values, things change dramatically: in a research based on a Sweden totally glazed building the optimal value is around 0.27. The ideal case is to have as high as possible VT coefficient and as small as possible SHGC value.The energy and daylighting efficiency of glazing is characterized by $\tau 1/g$.When this relation is less than 1, glazing does not ensure sufficient daylighting and if relation is more than 1.55, such glazing is considered as very efficient (Motuzienė & Juodis, 2010). The high-performance glazing products available today, when combined with effective daylighting strategies, have the potential to deliver high-performance façades, which maintain the glazed area while improving energy performance and occupant comfort.

3.5. Phase Change Material (PCM)

One of the last technologies proposed to decrease the building energy demand and to increase the indoor environmental comfort is PCM. In this technology, the latent heat storage potential of the transition between solid and liquid state of a material is utilized as thermal mass.

It was found that the PCM technology could be the solution of many problems: for instance, PCM could be used as a thermal storage in some thermal collectors to compensate the peak of solar radiation (Zhou & Zhang, 2015).

In any case, this paper is focused in the building integrated using of PCM: in fact, in many studies this material are considered part of the walls, usually as the last layer, to reduce cooling or heating loads.

It was found that the PCM usage can be intensively different between cold and warm climates.

For what concern the warmer climates, two article already mentioned in the envelope optimization included in them the study of PCM as a layer of the walls in the Mediterranean climates.

(Buonomano et al., 2016) analyzed the optimal melting temperature, thickness and position in the layers' walls. Moreover, these parameters were analyzed both in winter and in summer period and their influence on both heating and cooling demand was analyzed.

The result showed that in a Mediterranean climate the PCM using could decrease the cooling and the heating energy demand; the study focused on how to reduce the cooling demand since the building is in a cooling-dominated climate.

Anyway, the best range values for the melting temperature in Mediterranean climates are between 18-22°C during winter period and between 24-32 °C for the summer period.

Moreover, in the article was found that the optimal thickness of the PCM layer depends on the type, and on its parameters such as the latent fusion heat and the conductivity. Anyway, for the type used in the simulations (gypsum mixed with paraffin microcapsules) the optimal thickness was found around 30mm.

(Ascione et al., 2016) in the article in which the optimization of the envelope of 4 different cities in Mediterranean climate are discussed, an extended paragraph analyzes the optimization of PCM integrated in the building envelope.

Like the previous one, also this study focused on the optimization of PCM as a thermal mass to reduce the cooling demand, since is the higher requirement of energy in Mediterranean climate. In fact, simulations were carried out analyzing above all a PCM integrated in the walls as inner layer and the research of an optimal melting temperature was limited between the range of 25 and 29 °C.

Anyway, simulation of PCM as outer layer of the walls were developed, but result showed that with this configuration there is no energy reduction concerning the cooling demand. Nevertheless, the use of a PCM as outer layer of the walls brought positive results for the decreasing of heating energy demand. Then by assuming best inner and outer melting temperature, the last simulations carried out considered the effect of contemporary applications of both PCM layers.

Simulations' results suggest that the adoption of melting temperature of 25 °C on the inner

side allows, in each city, reduction of cooling demand (from 2%in Madrid to 13% in Naples). The outdoor forcing cause in Mediterranean climate can determine the fusion of PCM also during the winter period, thus the choice of a low melting temperature induces a PCM extra-utilization in the coldest months. By combining this solution with the application of another PCM layer with high melting temperature, on the external side, the cooling energy saving is maximized. In this case, the optimal melting temperature depends greatly by the outdoor conditions of temperature and solar radiation.

In conclusion, the use of PCM in southern climate of Europe is mainly focused on the cooling energy savings, so the presence of PCM inner layer with a melting temperature around 25-26 °C in the walls can save until 15 % of cooling demand and thus is a strong prevention against overheating.

In the colder climate, the use of PCM walls integrated is different.

In an article it was studied the presence in the wall of a thermal storage in cold climates (Guarino, Athienitis, Cellura, & Bastien, 2017): a wall opposing a glazed surface (south orientated) serves as phase change materials thermal storage.

The location of the building is Montreal (Canada, Dfb, the same climate of North-Europe); the purpose of the PCM embedded in the walls is of thermal storage, collecting energy from solar radiation.

Result showed how the thermal storage system is effective during the whole year in cold climate, the energy stored is released up to 6-8 hours after solar radiation. It was found that the heating decrease of energy demand was up to 17 % during the whole year.

Anyway, a problem of this system is that during mid-season and summer, it would be better to couple the PCM with a ventilation system, with the purpose of prevent overheating and improve the PCM charge-discharge cycles.

PCM used in that application had a melting range between 18-24°C, optimum for a heating energy demand reduction, in fact to have a bigger reduction of the cooling load, melting temperatures should be higher. In fact, since the building is in a heating-dominated climate, the reduction of heating load is much more important. Anyway, although the melting temperature are below typical summer temperatures levels in solaria, the increase of thermal capacity can reduce annual cooling requirements up to 50%.

The research is conducted only in a room of the building, so the value of melting temperature for a whole building may vary. Anyway, this article permits to compare the different use of the PCM between cold and warm climate. The great advantage of this technology is that can be used to store energy when it’s too much and release it when it’s necessary; so, it can be used to reduce cooling load in a cooling dominate climate, and heating load in heating-dominated climate.

Chapter 4

4. Methodology and Case Study

In order to give an answer to the problem highlighted in the introduction of the thesis, the research methodology includes the following steps (Fig.4.1):

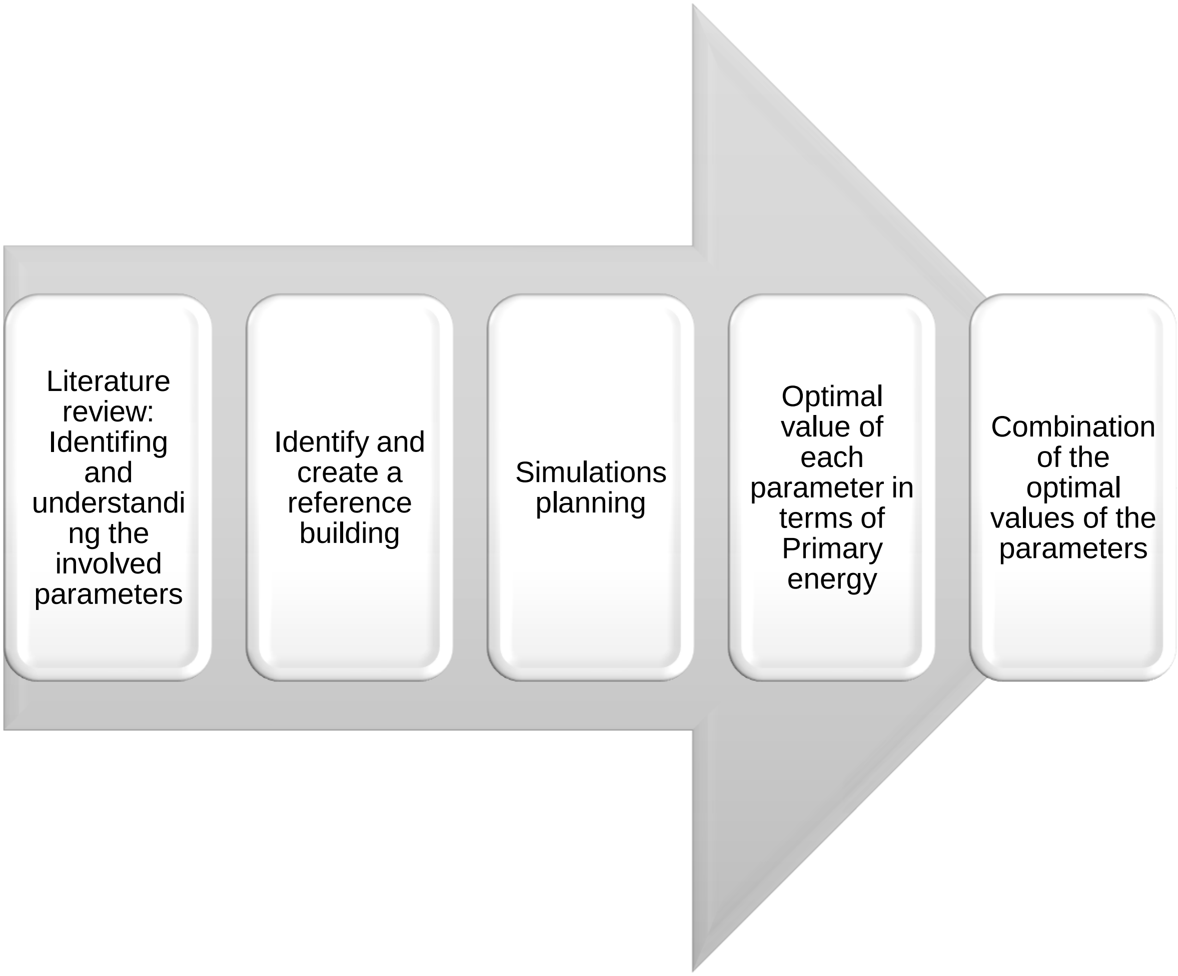


Figure 4.1: Research methodology principal scheme

Annual simulations were run with the software Design Builder v 3.4, paying attention that the comfort parameters were always in the allowed range. A fuel breakdown with the final energy for each area is given as an output. Assessment was performed in terms of primary energy (as required by EPBD), assuming that heat is produced from natural gas and electricity from non-renewable energy sources. Electricity demand includes the loads powered by electrical energy: cooling, room equipment, lighting, fans and pumps (fans and pumps are not often included in literature (Goia, 2016), but as it can be seen their contribute cannot be neglected; while gas demand – just heat for heating purposes. According to IINAS (2015) development of PEF study, the primary energy factors considered are 2.46 for electricity (mixed) and 1.24 for natural gas.

4.1. Case Study

4.1.1. Shape of the building

A medium-high rise building has been chosen as reference building. It has been preferred not to choose extraordinary sizes in order to include in the simulation results all the medium- rise buildings around 15-25 storeys.

A simple building shape has been chosen: prism with square bottom geometry. In this way the results will be less influenced by unusual shapes, protrusions, and complex roof shape, and thus it will be easier to focus on the interested parameters.

In any case, prism with square bottom shape is a good choice even from an energy savings point of view. Each protrusion in fact, adds surface at the envelope and it implies a higher possibility of heat exchange, and so higher consumptions.

Generally, the higher is the building compactness, the higher is the energy performance of the building itself *(Lylykangas, 2009).*

“According to some sources, the recommended shape factor for a passive house is ≤ 0.5 m^2/m^3. Shape factor A/V is dependent on the size of the building. A shape factor of 0.2 m^2/m^3 can be achieved only in large and very compact buildings.”

The bottom sizes for the reference building have been chosen of 30 and 32 metres, and later the height has been chosen depending on the shape factor.

This bottom sizes have been chosen referring to an online research on the typical floor plan for existing office glazed skyscrapers.

The majority of these buildings are with square or at last rectangular bottom shape, with the offices located on the edges of the perimeter, while in the middle, lift and technical compartments are located. (Figg. 4.2 ad 4.3)

The “New York Times Building” 2007 by Renzo Piano in Manhattan is reported as an example.

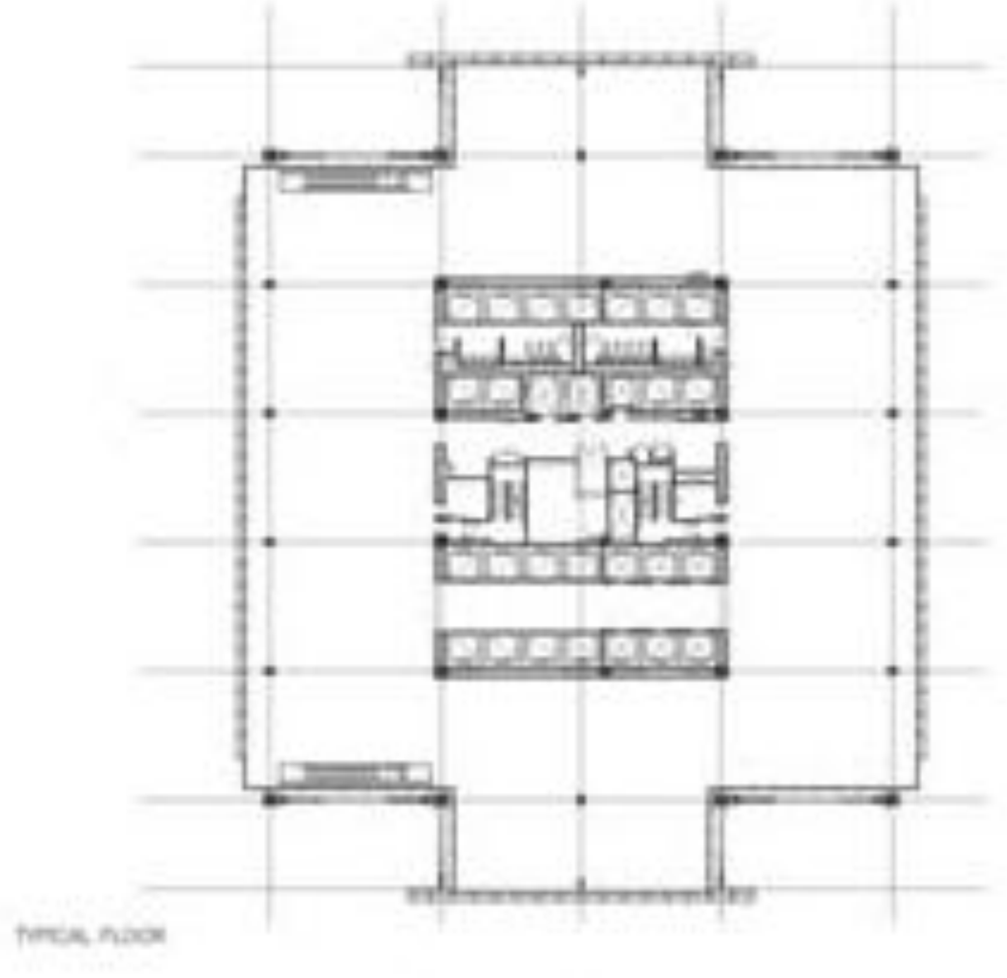


Figure 4.2: Typical floor of NYT Building. Source:”Renzo Piano Building Workshop”

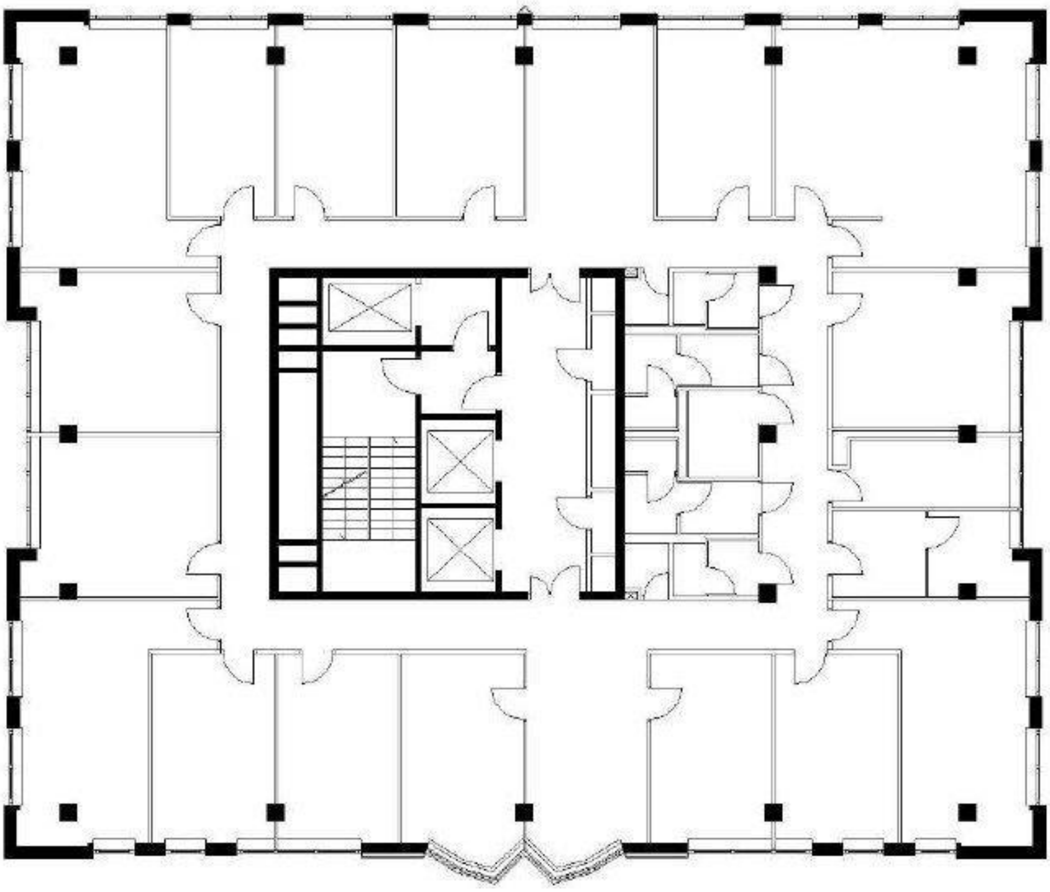


Figure 4.3: One more example of typical floor plan is reported: Eureka tower in Warsaw.

As it was mentioned above, building compactness should be chosen: a circular bottom shape could reduce the lateral area of up to 10%.

Although this implies lower energy consumption, this solution has not been adopted. *(Rehva Journal, 03/2011. Oscar Hernandez-Elithis Tower in Dijon, France).*

The most part of the building have a square or rectangular plan. Thus, this geometry has been adopted in order not to exclude all these buildings, but above all, because energy savings thanks to building shape are not one of the main objective of this study.

Anyway, this office configuration is an advantage considering the purpose of the study. In fact, it is possible to evaluate the consumption and the inside parameters even in each room.

In this way, parameters coming from different facades orientations can be compared. For instance, it can be evaluated if cooling consumption in south oriented office or heating consumption in the north oriented office are more influent on the global energy consumption. Here the typical floor plan drawing of the reference building. (Fig. 4.4)

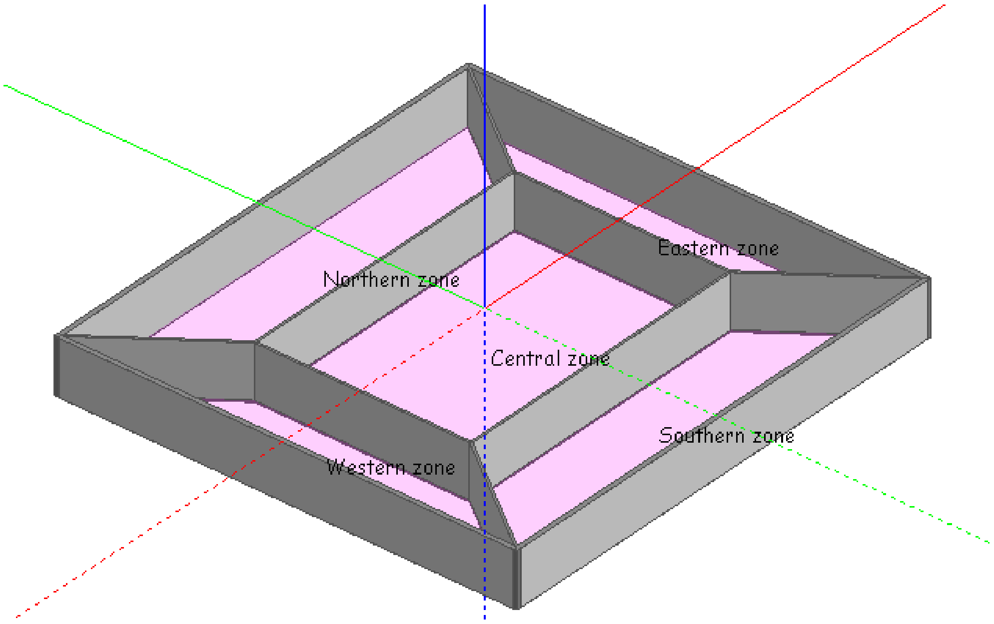


Figure 4.4: Typical floor plan of the reference building used in the simulations

Finally, an optimization study has been conducted in order to choose the building height. (Fig 4.5) (Feng et al., 2016)

Having the bottom building geometry and chosen a typical storey height of medium-rise building of 3,5 metres, it is clear from the graph that above 15 storeys building the shape factor stops to decrease significantly. Thus, the solution which has been chosen is 20 storeys, which correspond at 70 metres high and a 0,143 shape factor value.

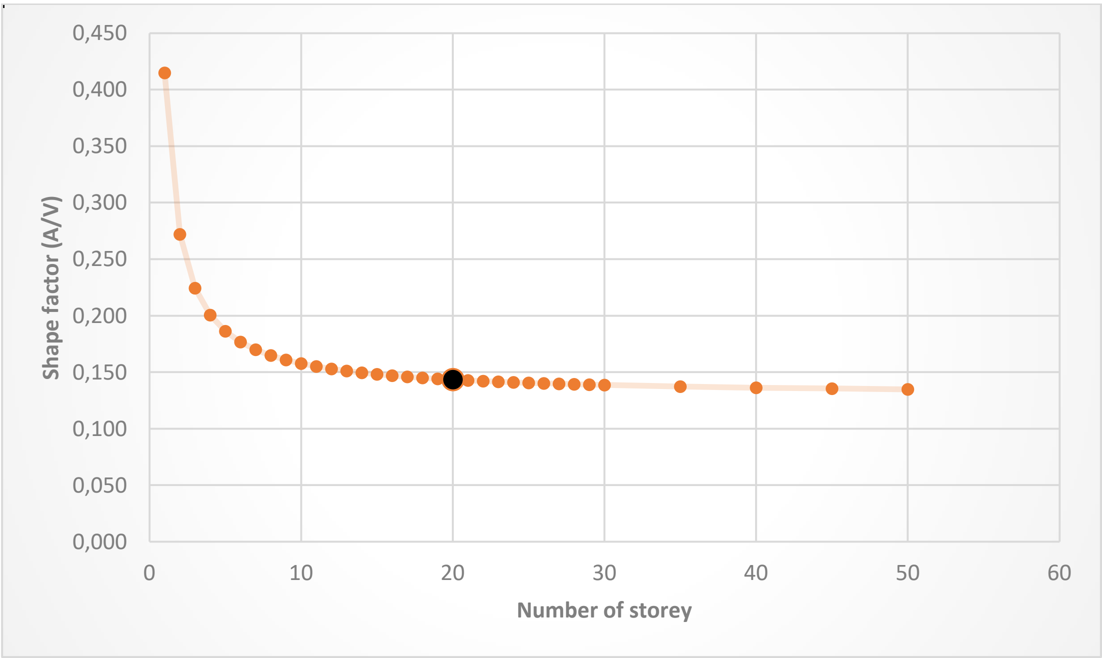


Figure 4.5: Shape factor on number of storeys used as optimization study in the reference building.

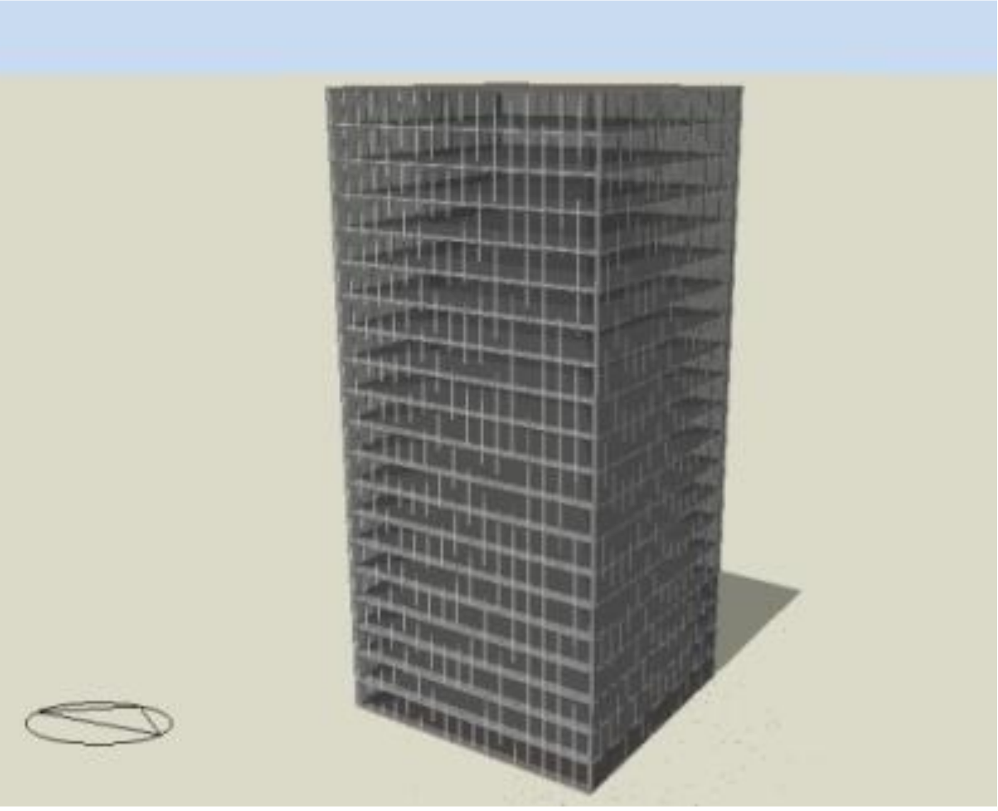


Figure 4.6: Reference building as it appears in the 3D interface of DB5.

4.1.2. HVAC system

Heating Ventilation and Air Conditioning system is one of the most important choices in the reduction of energy requirements in a building.

Nevertheless, this study doesn’t aim at energy savings thanks to HVAC system adjustments: the simulation planning will be discussed later.

Anyway, the presence of a performing HVAC system is out of question. The purpose is to choose a HVAC system that can provide heating, cooling, ventilation and control of comfort parameters.

The HVAC system has to be adaptable to northern and southern European climates by changing a few parameters values.

With the help of “Detailed HVAC” feature of Design Builder software the HVAC system has been modeled. In conclusion, a Fan Coil Unit HVAC system was chosen, equal to each zone. The heating is provided by a Natural Gas Boiler, while the cooling is provided by a Chiller, which is the evaporator of a condenser loop. (Fig 4.7)

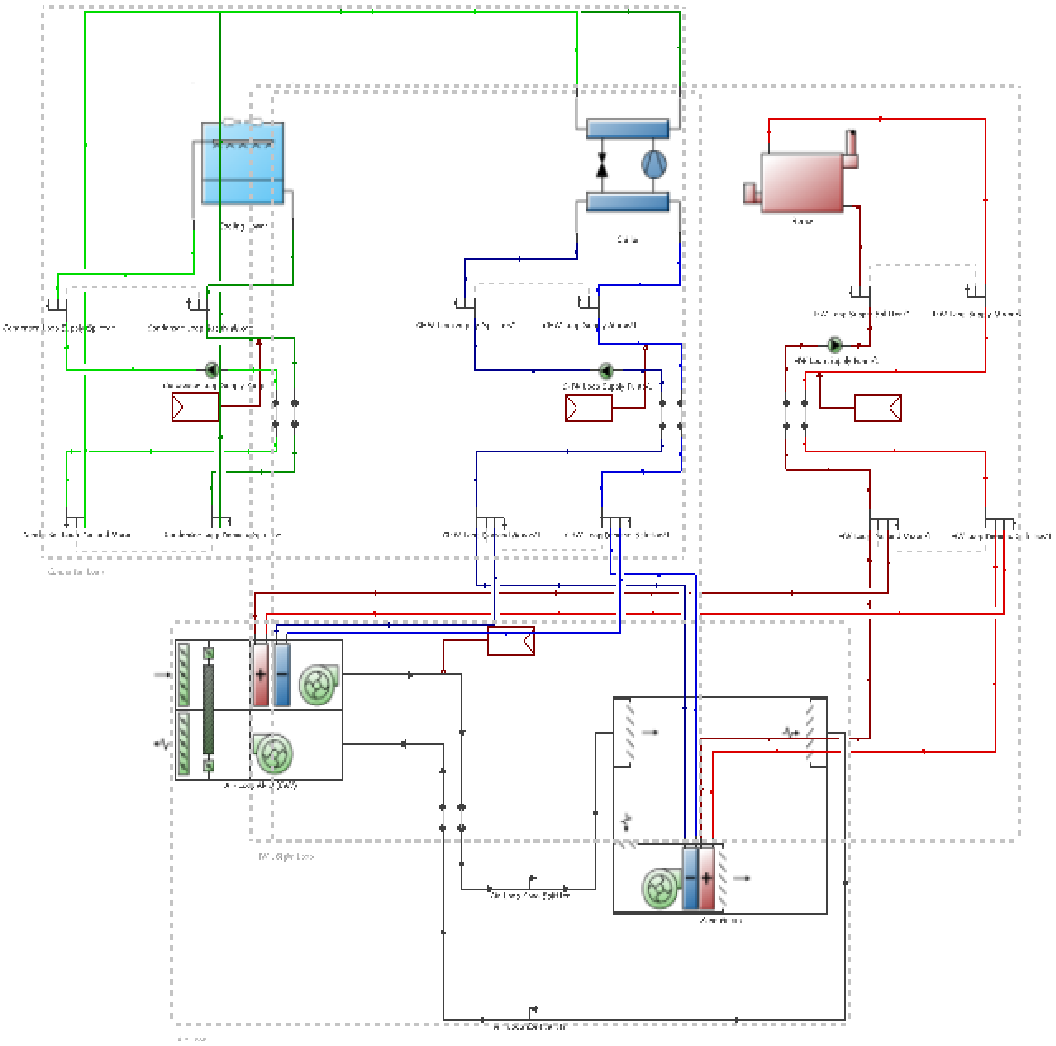


Figure 4.7: Scheme of the HVAC System in general

In the air loop the AHU is a DOAS system. (Direct Outdoor Air Supply system) In fact, AHU only provides fresh air through mechanical ventilation. The AHU is composed by:

- the main fan which pushes the air through all the ducts,
- a heating unit coil, heated by the main boiler, used to warm the fresh air
- a cooling unit coil, cooled by the chiller
- a plate heat recovery system

At AHU level is set the availability schedule for the air loop: since the AHU only provides fresh air, the schedule is set in office occupancy. That means that the AHU supplies fresh air only during the occupancy period, while when there are no people it is turned off. Table 4.1

Office Occupancy Schedule	Timetable	Off	0.25	0.5	0.75	1
	0-7	✓				
	8		✓			
	8-9			✓		
	9-12					✓
	12-14				✓	
	14-17					✓
	17-18			✓		
	18-19		✓			
	19-24	✓				
	Weekend days and holidays	✓				

Table 4.1: Office occupancy schedule for supplied fresh air system. The values from off to 1 represent the fraction of the loop working. Where 1 is the air loop at full load.

In hot water loop, the gas-fired condensing boiler uses natural gas as fuel and here the nominal thermal efficiency is set at 0.890. The strategy used when the boiler is not at the maximum load, is an efficiency curve, automatically uploaded by design builder.

For what concern the availability schedule, the boiler on/off operation is controlled at hot water loop level. This choice enables to set in which month the boiler is working, while the heating thermostat schedule is set at zone level.

The period of boiler activity is differently set depending on the location and is reported in table 4.2.

The chilled water loop is composed by a refrigeration cycle. The condenser is chilled by a condenser loop which chills the water in a cooling tower. This system is more efficient than an air-cooled chiller and thus allows higher COP values.

The reference chiller COP value is 5.5 while the performances curves are uploaded automatically by design builder, as the boiler curves.

Analogously for the boiler, the chiller period activity is set at chilled water level. (Table 4.2)

Equipment	**Values**
Boiler nominal thermal efficiency	0.890
Chiller COP	5.5
Recovery system efficiency	0.75

Table 4.2: Summary of main important HVAC system efficiency values

In each zone of the building a fan coil unit with both heating and cooling coil is located. Moreover, an air distribution and extraction unit connected with the air loop provide new fresh air addition and exhausted air extraction.

At this level (Zone level) the availability schedule for thermostat heating setpoint, thermostat cooling setpoint are set.

Through the edit dialogue a proper daily schedule is written for both cooling and heating system. Table 4.3

Heating Schedule THESIS	Timetable	Setpoint**20**	Setback **12**
	0-5		✓
	5-18	✓	
	18-24		✓
	Weekend days and holidays		✓

	Timetable	Setpoint**26**	**Off**
Cooling schedule THESIS	0-6		✓
	6-18	✓	
	18-24		✓
	Weekend days and holidays		✓

Table 4.3: Thermostat heating and cooling setpoint daily schedule at zone level.

When choosing HVAC system for a model, it was taken into its suitability for northern and southern European climates was taken into account. A fan coil HVAC system was chosen. The operation period for the boiler and the chiller are selected according to the Italian and Lithuanian standards. The efficiency of gas boiler – 0.89, chiller COP – 5.5, heat recovery efficiency – 0.75.Specifications of the building services settings as well as internal loads are given in Appendix A, based on specifications suggested in EN 15251:2008 and EN ISO 13790:2008.

Chapter 5

5. Simulation planning

In literature the main parameters which can influence a single skin curtain wall were found (Lam et al., 2015):

- glazing U-value (Ugl);
- U-value of the spandrel panel (Usp);
- U-value of frame (Ufr);
- solar heat gain coefficient (SHGC);
- visible transmittance (VT);
- infiltration rate;
- window wall ratio (WWR);
- depth and inclination of overhang.

In this paper some modifications are reported in order to make the simulations process as lean as possible without lose any important data. First, glazing U-value and frame U-value are analyzed together because there is no interest to have different simulation for those two parameters. Furthermore, in the national standard the total windows U-value is mentioned and not the glazing and the frame U-values individually. Finally there is no sprandel window, thus the glazing U-value, the frame U-value and the sprandel U-value are all assembled in U-value parameter. Second, Solar Heat Gain Coefficient and Visible Transmittance are analyzed together, because is their relation that enables to select efficient solutions. Third, infiltration rate through the windows is kept constant, as WWR=100%. Finally, the type and geometry of the shading system are analyzed.

5.1. U-Value

In both Italian and Lithuanian standards the windows U-value for a NZEB is given. Thus, in the simulation this parameter will be changed starting from the value given from the national standards to more performing values. (Table 5.1)

Simulations	**1.4**	**1.2**	**1.0**	**0.8**	**0.6**
Location					
Italy-	✓	✓	✓	✓	✓
Lithuania-Vilnius		✓	✓	✓	✓

Table 5.1: The U-values are expressed in W/m^{2}K

5.2. SHGC and VT

Since there are no standards for SHGC and VT, the simulations input data will be the same in Italy and Lithuania. In the SHGC/VT simulations, all the four facades are kept with the same values. The values of SHGC are chosen in order to have some alternatives during the simulations, while, the Design builder library was investigated in order to find reliable SHGC/VT values existing in real windows. The research was focused in finding the higher potential value of VT with the same SHGC (Table 5.2). Furthermore, to avoid too many simulations the glazing U-values was kept constant at 0.8 W/m^2 K.

SHGC	**0.9**	**0.7**	**0.5**	**0.3**	**0.1**
VT	0.95	0.8	0.6	0.4	0.15
VT/SHGC	1.06	1.14	1.20	1.33	1.50

Table 5.2: SHGC value with the corresponding VT value.

5.3. External shading

The process to chose the alternatives of external shading was based in the following criteria: it was investigated which were the shading types that allow to stop the solar gain income during the summer, when the sun azimuth angles are higher (Grynning et al., 2014). On the other hand the system should allow as much as possible incoming solar radiation during the winter.

The first task to avoid summer overheating, the second one to reduce the heating requirements. Again, a too high number of simulation, during this step, the glazing U-value, the SHGC and the VT were kept constant at 0.8 W/m^{2}K, 0.5, 0.5 respectively.

5.3.1. Overhang

In Table 5.3 there are the two steps of simulations for the overhangs shading system. As it is known from the literature it does not make sense to have any shading system in the north façade. As a matter of fact, the direct solar radiation is lightly present in the earliest and latest hours of summer days. The absence of shading system allows the highest amount of natural lighting.

		Projection (m)			
1	East South West Façades	**1.0**	**1.5**	**2.0**	**3.0**
2	South Façade	**1.0**	**1.5**	**2.0**	**3.0**

Table 5.3: Overhang shading system cases

5.3.2. Louvres

The horizontal louvres are located along the whole windows as shown in Figure 5.1. Six different strategies of louvres shading are chosen and reported in the following Table 5.4.

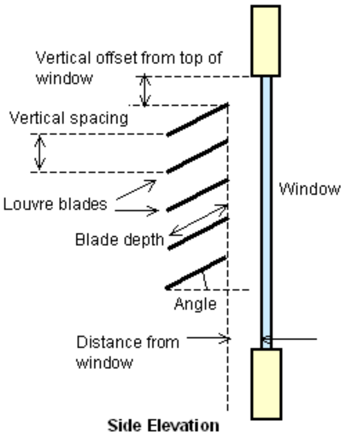


Figura 5.1: Drawing of louvres geometry

Strategy	Projection (m)	Angle (°)	Vertical spacing (m)	Number of blades (m)	Blade depth (m)	Distance from windows (m)
1	**0.5**	**0**	0.35	10	0.2	0.3
2		**15**	0.35	10	0.2	0.3
3		**30**	0.25	14	0.2	0.3
4	**1.0**	**0**	0.7	5	0.7	0.3
5		**15**	0.7	5	0.7	0.3
6		**30**	0.7	5	0.7	0.3

Table 5.4: Louvres shading system strategies

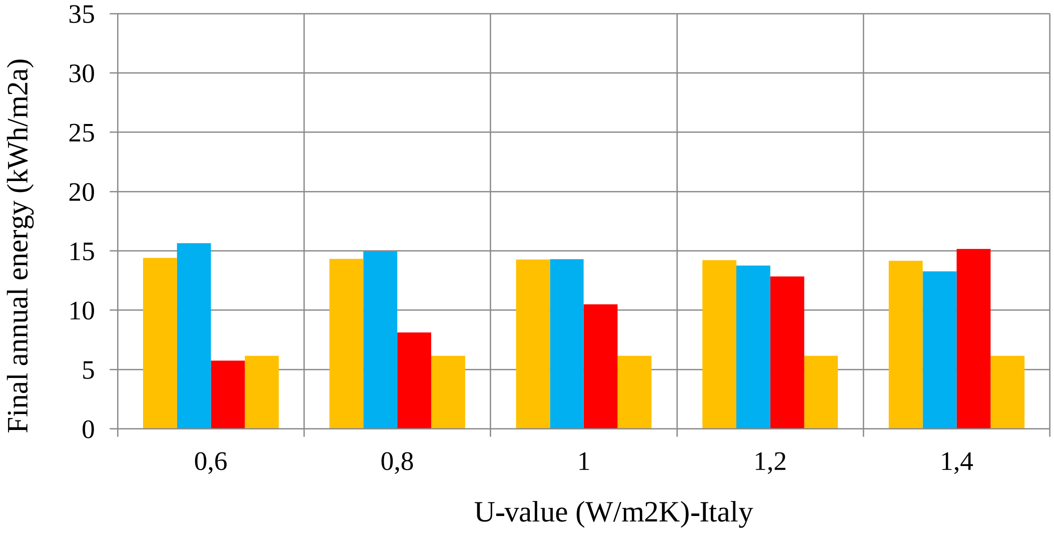
Chapter 6

6. Results

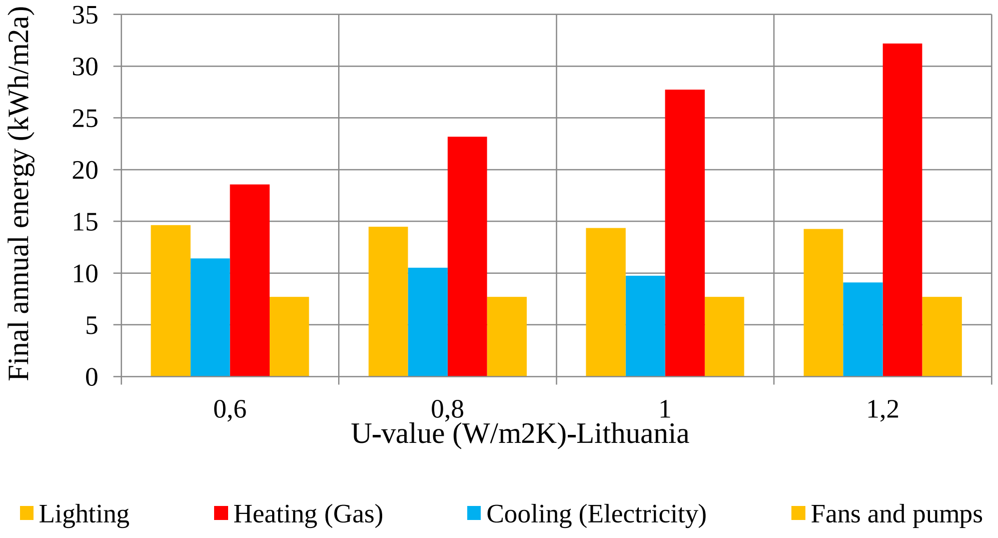
Simulation results are presented separately for each parameter and for different climate. The overall annual primary energy requirement is the value that is mainly analysed, because it is used to judge energy performance of the building, but also analysis of the final energy demand balances is presented to show where problems arise and potential saving exist.

6.1. Glazing U-value

The simulations carried out for the windows U-value show an intense variation in the heating and cooling loads for both Italy and Lithuania, while other parameters were steady as the lighting and the internal equipment energy requirements.



a)



(b)

Figure 6.1: A final energy demand depending on the glazing U-values: **(a)** Italy and **(b)** Lithuania study case

As it is shown in the Fig. 6.1, glazing U-value variation has strong influences on the heating demand reduction. Obviously, more in Lithuania than in Italy, in which the humid continental climate requires much more energy for the heating. Still, in Italy the improvement of glazing U-value from 1.4 to 0.6 W/m2K implicates a reduction of the heating energy requirement from 15 to 5 kWh/m2a.

The improvement of the windows U-value increases the annual cooling energy demand. With very low U-values, the temperature increment could be slightly reduced in the internal offices, but during the night, the low U-value impedes the release of the stored heat.

It can be noticed that the heating energy reduction is much more higher than the cooling energy increment when the glazing U-value is improved. In the case of Lithuania, the use of the best performing windows is definitely compulsory, if the total energy demand needs to be lowered. On the other hand, in Italy, the cooling demand is high, and it is clear that it cannot be controlled nor by reducing glazing U-value, neither by increasing it. It can be useful to keep a low windows U-value in order to reduce the heating demand, while trying to control the cooling demand with other parameters such as SHGC or shading.

In conclusion, in terms of primary energy, the total savings from the standard U-value to the best case are around 4 and 6 % for Italy and Lithuania respectively (Fig. 6.2) – in both cases it can be considered as low and obviously window U- value potential for savings is almost exhausted.

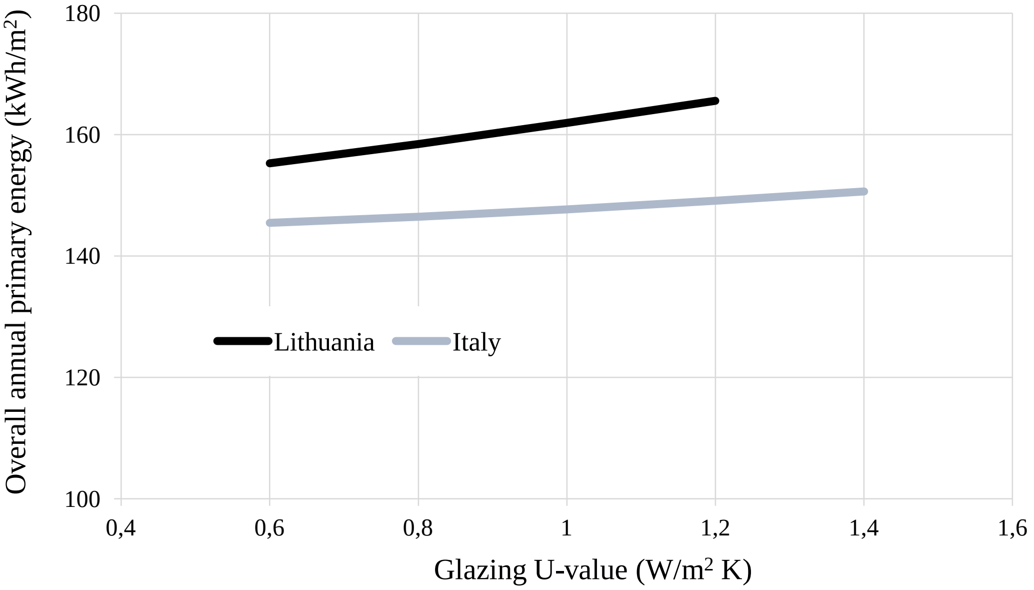
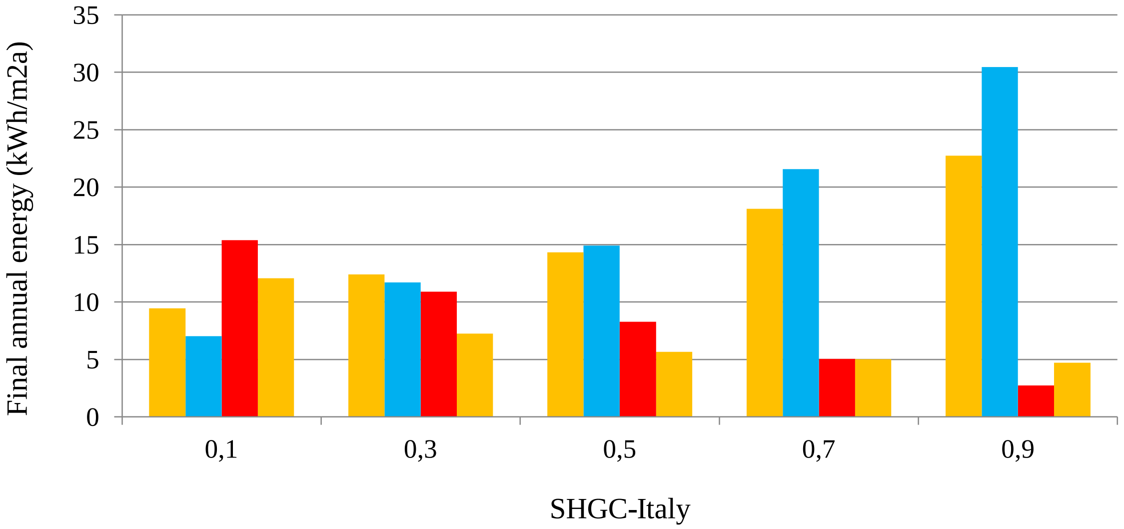


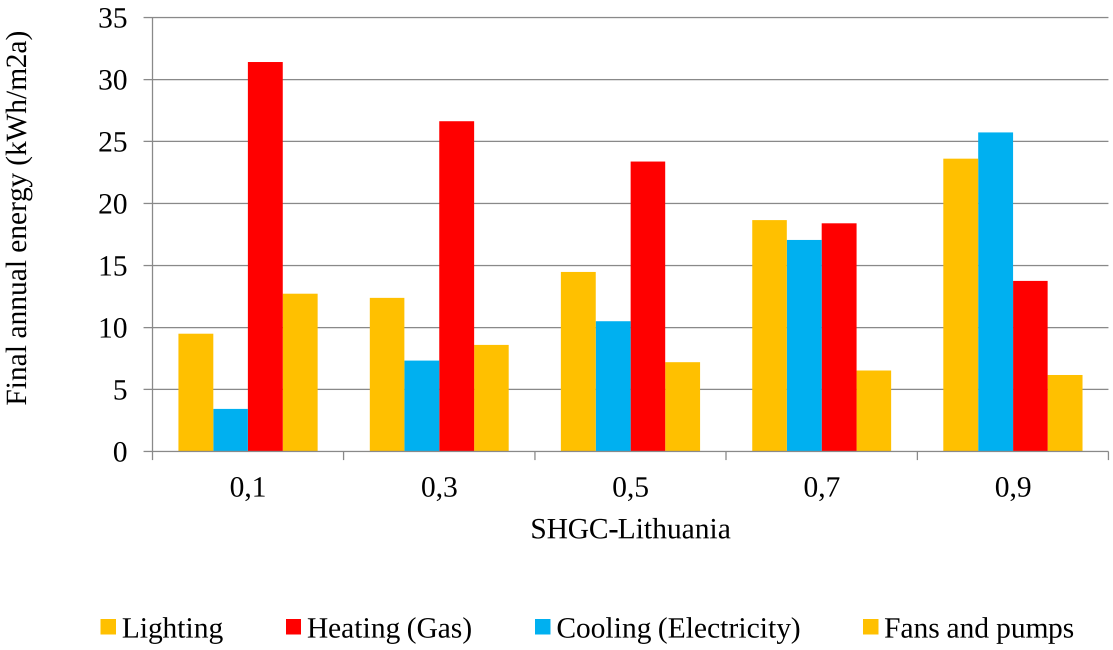
Figure 6.2: Overall annual primary energy requirement depending on glazing U-value for the case studies

6.2. SHGC and LT

The SHGC and LT are strongly influencing three main energy demand components: heating, cooling and lighting energy. For both Italian and Lithuanian case studies, the demand trends are similar (Fig. 6.3): the lower the SHGC, the lower the cooling and the auxiliary (fans and pumps) energy demand, while the lighting and the heating requirement are increasing.



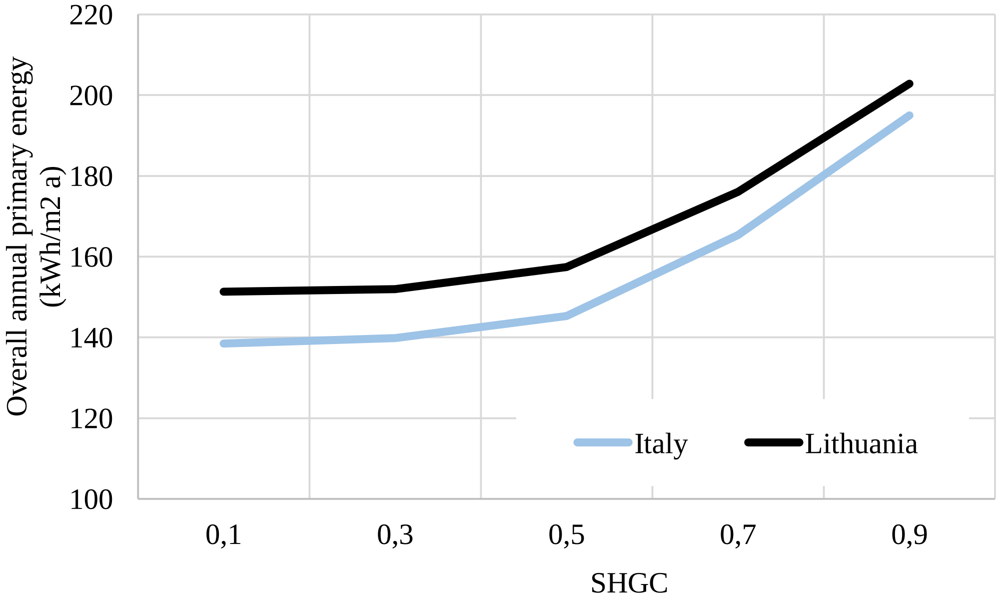
(a)



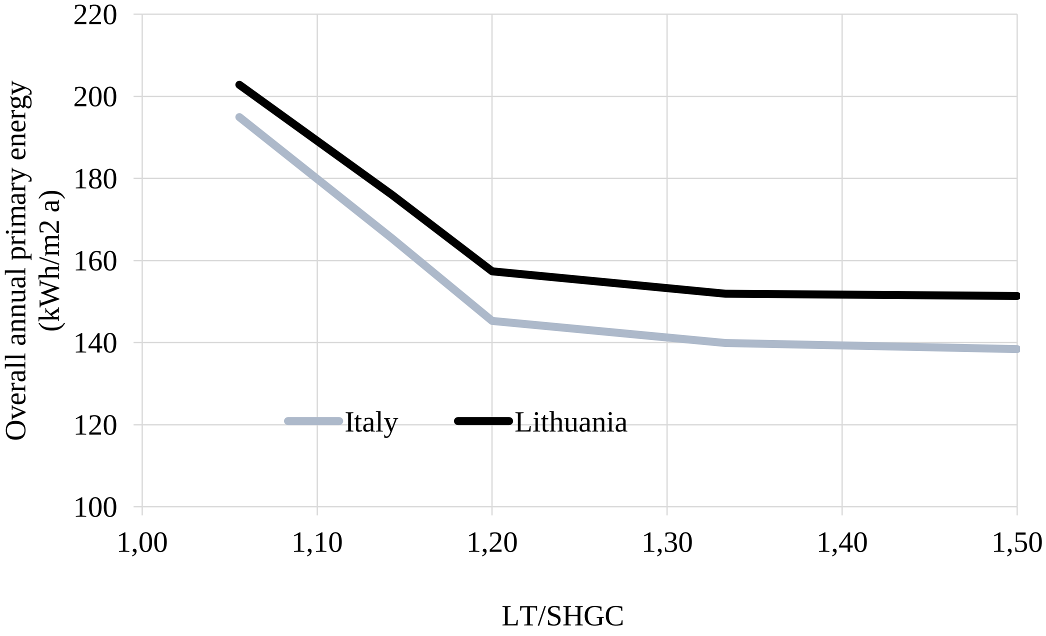
(b)

Figure 6.3: Final energy demand depending on SHGC: **(a)** for Italy and **(b)** for Lithuania

According to the primary energy factor, it is better to save cooling energy than heating one. This brings to the conclusion that in both Italy and Lithuania, the optimal SHGC to reduce the global primary energy is around 0.1-0.3. (Fig.6.4a). In this case, the primary energy savings between the best and the worst case are 29% for Italy and 25 % for Lithuania. Again, this is a strong evidence of the fact that solar gain dramatically influence a totally glazed facade: without prevention against the solar gain, the primary energy demand is around 190-200 kWh/m^{2}a, while with the best solution the primary energy requirement is around 140-150 kWh/m^{2}a. Furthermore, the energy savings in Italy are higher; this shows that in a warmer climate protection against solar gain is extremely necessary.



(a)



(b)

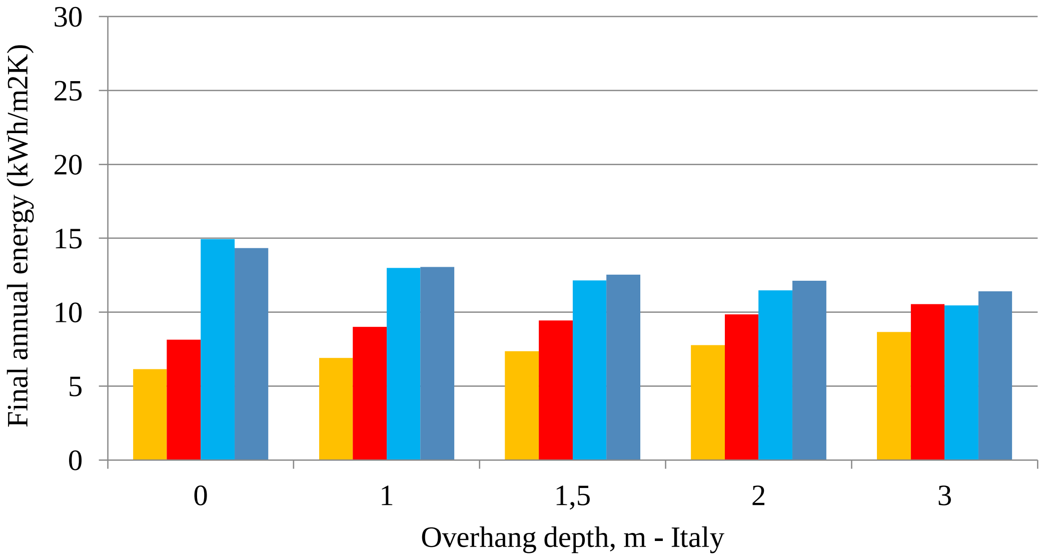
Figure 6.4: Overall annual primary energy demand depending on: **(a)** SHGC and **(b)** LT/SHGC

Finally, it is worth to notice that the higher the LT/SHGC the lower the overall annual primary energy (Fig 6.4(b)). The causes of this result are clear: high values of LT/SHGC imply daylight avoiding the income of solar gain, thus, energy savings on the artificial lighting with slight variation on cooling loads. Again, this result proves what was mentioned in 1.3.4 paragraph: the ideal case is to have as high as possible LT coefficient and as small as possible SHGC value.

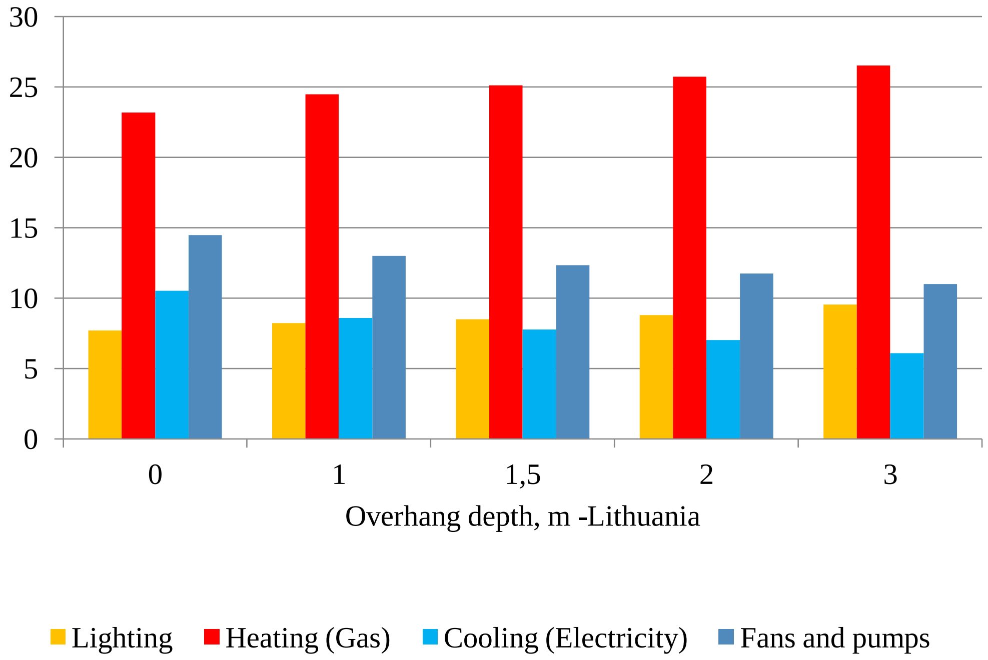
6.3. External shading

6.3.1. Overhang

Simulations were performed in two steps: overhangs only in the South façade, firstly, and overhangs for East, South and West facades later. Here, only the second step is presented (Fig.6.5) because the first one does not bring significant improvements (Fig.6.6).



a)



(b)

Figure 6.5: Final energy demand depending on overhang shading strategy: **(a)** Italy and **(b)** Lithuania

As seen from Fig. 6.5, the deeper is the overhang, the lower is the cooling load, but on the other hand - heating and lighting energy increases. The cooling demand decrease is due to the summer shading, but as can be seen this has a negative effect, since during the winter the solar radiation is stopped, causing the heating and lighting increase. Furthermore, the relative decrease or increase of energy requirement in each area has mostly the same trends for the both cases. This means that this type of shading does not make any difference depending on the climate.

Focusing on the overall primary energy consumption (Fig. 6.6), results show that if shading is applied only on the southern facade, the effect is slight for the Lithuanian case study, while it is almost negligible in the Italian one. On the other hand, in the case of overhangs applied in East, South and West facades the decrease of annual primary energy is evident. As it can be seen from the line slope, the decrease of global energy is equal in both the case studies: around 7 % in both cases. But for the offices overhangs of 3 m depth is rather unusual solution, therefore it can be concluded this type of shading is not recommended for offices both in warm and cold climates.

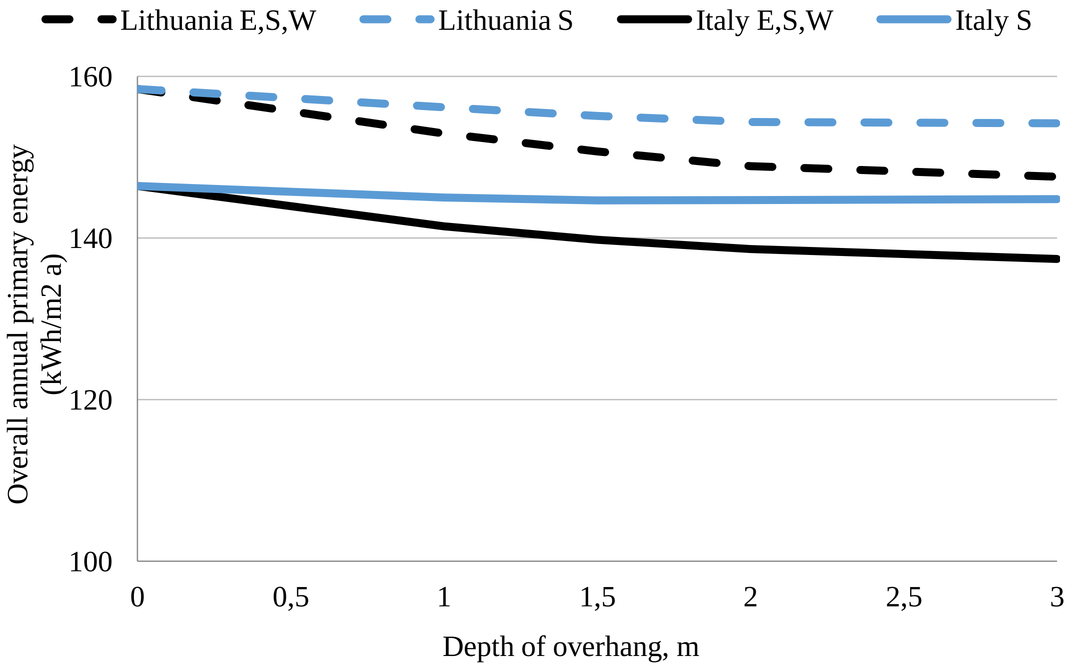


Figure 6.6: Overall annual primary energy demand depending on overhang shading strategy for the study cases

6.3.2. Louvers

Final energy demand for each louvers strategy is presented in Fig. 6.7, Strategy number 3, 5, 6 are the best for cooling reduction in Lithuania, while in Italy the best for cooling reduction is number 3. In both cases, strategy number 6 has too much energy requirement for lighting compared with the other ones. Strategy number 1 would be perfect for lighting energy, but on the other hand, it allows more solar radiation to income, thus the cooling requirement is still high.

In terms of overall primary energy (Fig. 6.8), the most efficient strategy is number 3 for Italy while number 2 and 3 are equally efficient for the case of Lithuania. In the range of louvers alternatives, the heating requirement does not change significantly; while the best solution is that one which can better decrease the cooling value, without darken dramatically the offices' space. In analogy with the overhangs the peaks of energy savings are around 7% for both cases.

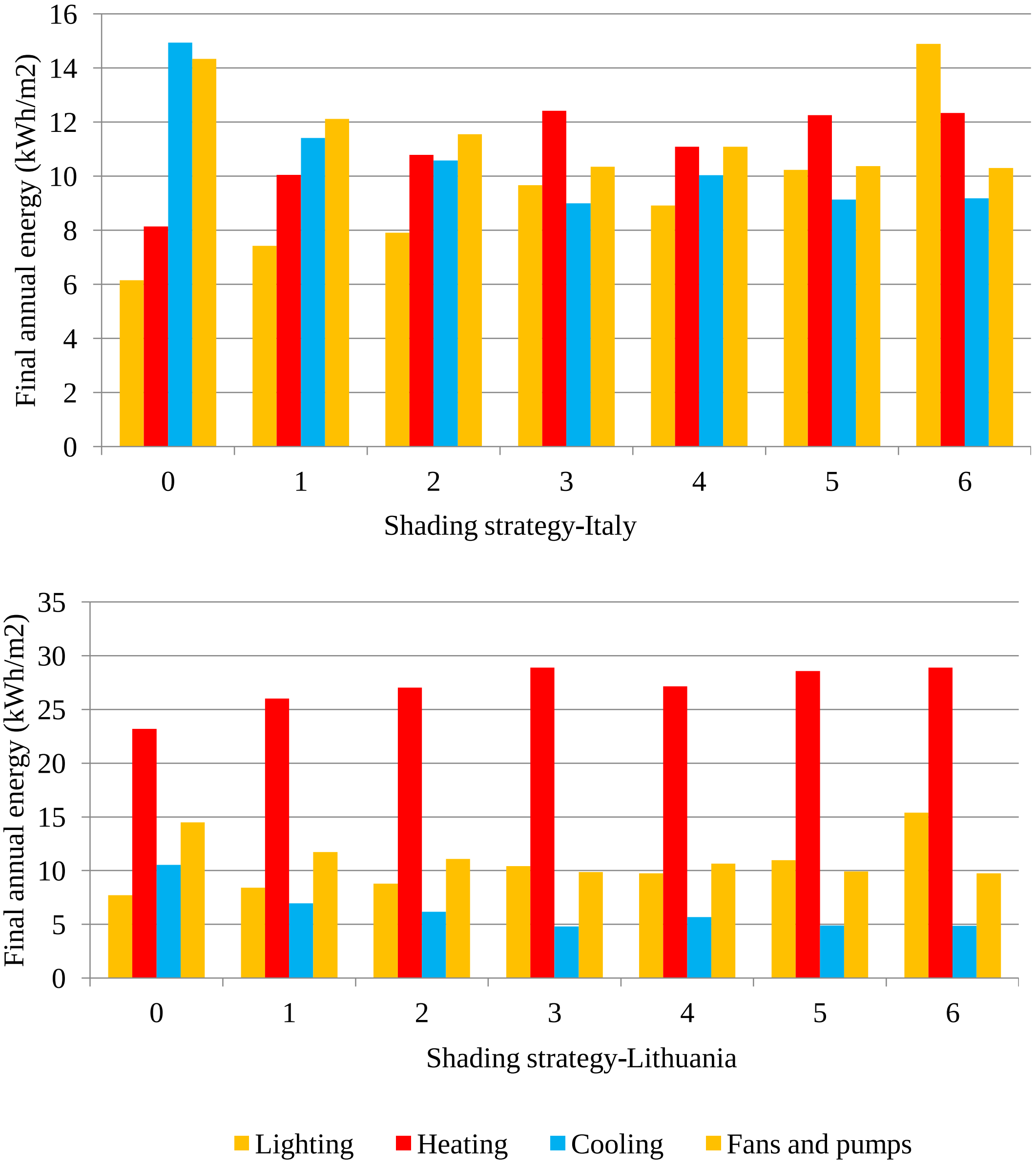


Figure 6.7: Final energy demand depending on louvers shading strategy: **(a)** Italy and **(b)** Lithuania

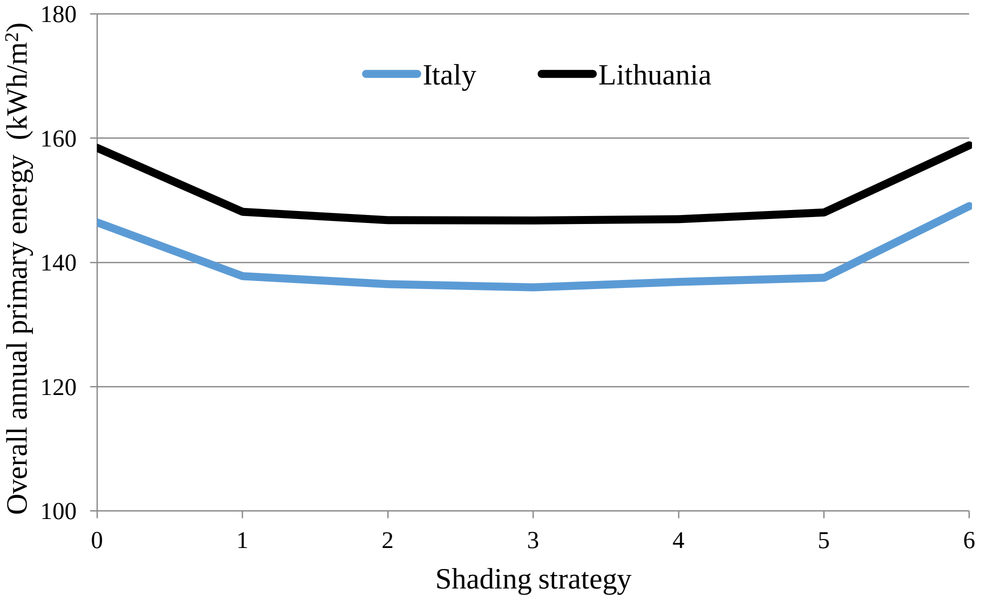


Figure 6.8: Overall annual primary energy demand depending on overhang shading strategy

Table 6.1 summarizes possible savings for all strategies analysed. It is obvious, that significant effect is reached just changing glazing properties. U-value decrease has low energy saving potential and analysed shading strategies as well. Better effect from shading might be expected if shading would have automatically control – this would enable to protect building from solar heat gains in summer, but enable entering them in winter, thus avoiding negative effects and increasing savings.

	Glazing U-value	SHGC and VT	Shading	
Location			Overhang	Louvres
Italy	**4**	**29**	**6**	**7**
Lithuania	**6**	**25**	**6**	**7**

Table 6.1: Savings potential of overall annual primary energy demand, %

6.4. Combination of the optimal parameters values

In both cases the best U-value found is 0.6 W/m^{2}K. For what concern the shading, louvers strategy is preferred and strategy number 3 is chosen as optimal for both cases. The case of choosing SHGC and LT is more complicated. In fact, the most efficient SHGC value would be 0.1 for the Italian case and 0.1-0.3 for the Lithuanian one. However, the SHGC influence analysis was performed in absence of shading system, therefore simulation is repeated to establish the optimal value of SHGC and LT with the presence of the most efficient shading system (strategy 3).

In Fig.14 can be seen that the best SHGC value for both locations is 0.5, when U-value is 0.6 W/m^{2}K and shading strategy with louvers is 3.

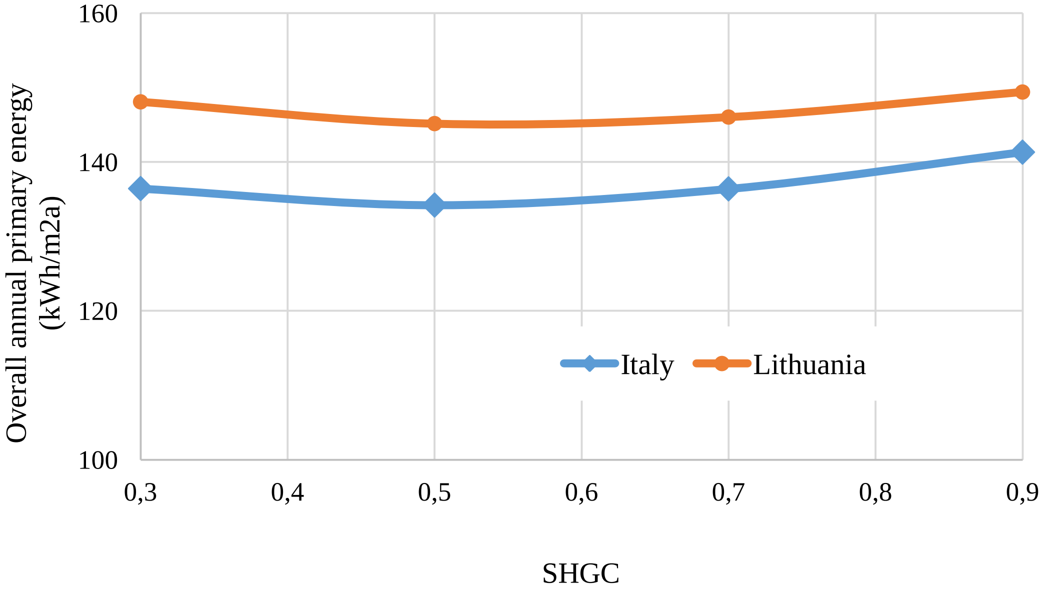


Figure 6.9: Global annual primary energy depending on the SHGC when optimal shading system strategy is on (strategy)

Summarized results are given in Table 6.2 Despite the differences in finally energy balance for different locations, the overall primary energy demand difference is not as high as expected (just around 6 %) and in general analysed energy efficiency measures give nearly the same effect.

	Final energy					Primary energy
	Room Electricity	Lighting	Fans and Pumps	Heating	Cooling	
Italy	20	8.9	10.3	9.9	9.4	**132.0**
Lithuania	20	9.7	9.9	24.3	5.2	**140.3**

Table 6.2: Final energy and overall primary energy in kWh/m^2 for the most efficient solution

7. Conclusion and discussion

Simulation of different alternatives both for Italian and Lithuanian climates has shown that for totally glazed office building glazing U-value has small potential in reduction of primary energy demand, because difference between values required by the standard and best available on the market is decreasing. Estimated overall primary energy savings are 4 and 6 % in warm and cold climates respectively.

The highest impact on buildings energy efficiency is done by glazing properties - SHGC and VT. That is an evidence that the solar gain are the most critical variable in a total glazed building. Anyway, the reduction could achieve peaks of 30 % in the warmer climate only if 0.1-0.2 SHGC values are used. Such values cause high investments and higher artificial lighting costs. Furthermore, many of the glazed facades advantages would be lost, such as the transparency and daylighting. Therefore it is more rational to look at the ratio VT/SHGC, when choosing a glazing. Results have shown that there is a significant drop in energy demand from VT/SGHC value 1.0 to 1.2 and from 1.2 to 1.5 energy saving potential is almost stable. This brings to the conclusions that SHGC of 0.5 and VT of 0.6 could be an efficient choice both in terms of daylighting and energy efficiency, it also does not require high investments into glazing.

Analysis of the shading alternatives has shown that louvers should be preferred in place of overhangs. With the best louvers strategy, the energy savings in the warmer climate are still equal to the colder one (7%). It correspond to results given by Bellia et al. (2013), while for savings values beyond 10 % a dynamical shading system is required (Nielsen et al., 2011).

Summarizing the results it can be stated, that despite differences in energy balance structure, different analysed envelope improvement measures give very similar results both for warm and cold climate. The most important envelope parameter is solar heat gain coefficient, but ration between SHGC and VT must be taken into account. U value as well as static external shading has low energy saving potential for both climates. Combining all the optimal values of the parameters analysed, it is impossible for a totally glazed building with this simple shape to lower the global primary energy under 130 kWh/m^{2}a and 140 kWh/m^{2}a for the Italian location and the Lithuanian one respectively. It is necessary to highlight that the study focuses only in the envelope parameters and not in the power sources. This means that with the use of renewable energy, e.g. a grid PV system on the roof of the building, the primary energy requirements could be dramatically lowered.

APPENDIX A

Settings for HVAC, internal loads, and lighting for the zone office rooms

	Temperature set-point (°C)		HVAC		Internal loads		Lighting	
	Heating	Cooling	Mechanical Ventilation (l/s person)	Heat recovery efficiency	Equipment (W/m^2)	People (W/m^2)	Installed power (W/m^2)	Illuminance set-point (lux)
Occupancy Mon-Fri 7 am-6 pm	22	24	10	0.75	10	11.5	7.5	500
Non occupancy	12	35	0.0	0.75	0.0	0.0	7.5	0

References

Ascione, F., De Masi, R. F., de Rossi, F., Ruggiero, S., & Vanoli, G. P. (2016). Optimization of building envelope design for nZEBs in Mediterranean climate: Performance analysis of residential case study. *Applied Energy*, *183*, 938–957. https://doi.org/10.1016/j.apenergy.2016.09.027

Autodesk Sustainability Workshop – *Glazing properties*. Available from Internet: https://sustainabilityworkshop.autodesk.com/buildings/glazing-properties

A workplace intelligent unit Journal – Daylight in the office – A matter of balance. Available from Internet: *http://s200941466.websitehome.co.uk/uploads/files/Light_and_Colour_-_Daylight_in_the_Office_-_A_Matter_Of_Balance.pdf*

Bae, M. J., Oh, J. H., & Kim, S. S. (2015). The effects of the frame ratio and glass on the thermal performance of a curtain wall system. *Energy Procedia*, *78*, 2488–2493. https://doi.org/10.1016/j.egypro.2015.11.234

BBC News - September, 2, 2013. *Walkie Talkie Skyscraper melts jaguar car parts.* Available from Internet: http://www.bbc.com/news/uk-england-london-23930675

BBC News - May, 27th, 2014. *Could the era of glass skyscrapers be over.* Available from Internet: http://www.bbc.com/news/magazine-27501938

Bellia, L., De Falco, F., & Minichiello, F. (2013). Effects of solar shading devices on energy requirements of standalone office buildings for Italian climates. *Applied Thermal Engineering*, *54*(1), 190–201. https://doi.org/10.1016/j.applthermaleng.2013.01.039

BPIE. 2011. *Principles for Nearly Zero-Energy Buildings*, (2011). Available from Internet:
http://bpie.eu/wp-content/uploads/2015/10/HR_nZEB-study.pdf

BREEAM. 2016 – *Breeam international new construction 2016*. Available from Internet: http://www.breeam.com/new-construction

Bruno, R., Arcuri, N., & Carpino, C. (2015). The passive house in Mediterranean area: Parametric analysis and dynamic simulation of the thermal behaviour of an innovative prototype. *Energy Procedia*, *82*, 533–539. https://doi.org/10.1016/j.egypro.2015.11.866

Bunning, M. E., & Crawford, R. H. (2016). Directionally selective shading control in maritime sub-tropical and temperate climates: Life cycle energy implications for office buildings. *Building and Environment*, *104*, 275–285. https://doi.org/10.1016/j.buildenv.2016.05.009

Buildup European Journal. 2017. The edge: Amsterdam office building with highest BREEAM score to date [online], [cited 11 January 2017]. Available from Internet: http:// www.buildup.eu/en/practices/cases/edge-amsterdam-officebuilding-highest-breeam-score-date

Buonomano, A., De Luca, G., Montanaro, U., & Palombo, A. (2016). Innovative technologies for NZEBs: An energy and economic analysis tool and a case study of a non-residential building for the Mediterranean climate. *Energy and Buildings*, *121*, 318–343. https://doi.org/10.1016/j.enbuild.2015.08.037

Carli, M. De, Giuli, V. De, Tecnica, F., & Padova, U. (n.d.). EDIFICI VETRATI A BASSO CONSUMO ?

Chen, H., & Wei, P. (2012). Utilization of Natural Daylight in Office Buildings, (1).

Dussault, J. M., Gosselin, L., & Galstian, T. (2012). Integration of smart windows into building design for reduction of yearly overall energy consumption and peak loads. *Solar Energy*, *86*(11), 3405–3416. https://doi.org/10.1016/j.solener.2012.07.016

EIB. 2009. *The EIB Statement of Environmental and Social Principles and Standards*. Available from Internet: http://www.eib.org/attachments/strategies/eib_statement_esps_en.pdf

EPBD. September 2014. *Selected examples of NZEBs – detailed report.* Available from Internet: http://www.epbd-ca.eu/wp-content/uploads/2011/05/CT5_Report_Selected_examples_of_NZEBs-final.pdf

EN 15251:2008 – Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics, 2008.

EN ISO 13790:2008 – Energy performance of buildings- Calculations of energy use for space heating and cooling

Eriksson, B. (2009). Energy efficient glazed office buildings with double skin façades in Europe. *Eceee 2009 Summer Study • Act! Innovate! Deliver! Reducing Energy Demand Sustainably*, 1525–1530.

Etzion, Y., & Erell, E. (2000). Controlling the transmission of radiant energy through windows: A novel ventilated reversible glazing system. *Building and Environment*, *35*(5), 433–444. https://doi.org/10.1016/S0360-1323(99)00039-6

European Parliament. Directive 2010/31/EU of the European Parliament and of Council of 19 May 2010 on the energy performance of buildings (recast). Official journal of the European Union; 2010.

Feng, G., Sha, S., & Xu, X. (2016). Analysis of the Building Envelope Influence to Building Energy Consumption in the Cold Regions. *Procedia Engineering*, *146*, 244–250. https://doi.org/10.1016/j.proeng.2016.06.382

Flores Larsen, S., Rengifo, L., & Filippín, C. (2015). Double skin glazed façades in sunny Mediterranean climates. *Energy and Buildings*, *102*, 18–31. https://doi.org/10.1016/j.enbuild.2015.05.019

Ghisi, E., & Tinker, J. A. (2005). An Ideal Window Area concept for energy efficient integration of daylight and artificial light in buildings. *Building and Environment*, *40*(1), 51–61. https://doi.org/10.1016/j.buildenv.2004.04.004

Glasfassaden – die modernen Energieschleudern. (n.d.).

Glass and Glazing Product. 2014. Gherkin man condemns “All Glass” Buildings. *Glass and Glazing journal – June, 3rd, 2014. http://www.ggpmag.com/news/gherkin-man-condemns-all-glass-buildings*

Glass for EU Journal. 2013. The smart use of glass in sustainable buildings, *Glass for Europe Journal,* November, 12th, 2013. Available from Internet: http://www.glassforeurope.com/images/cont/165_90167_file.pdf

Goia, F. (2016). Search for the optimal window-to-wall ratio in office buildings in different European climates and the implications on total energy saving potential. *Solar Energy*, *132*, 467–492. https://doi.org/10.1016/j.solener.2016.03.031

GPH. May, 2005. *Glasfassaden – die modernen Energieschleudern.* Available from Internet: http://www.gph.at/images/gph/service/presse/2005-05_Glasfassaden_-_die_modernen_Energieschleudern.pdf

Gratia, E., & De Herde, A. (2003). Design of low energy office buildings. *Energy and Buildings*, *35*(5), 473–491. https://doi.org/10.1016/S0378-7788(02)00160-3

Gratia, E., & De Herde, A. (2007). The most efficient position of shading devices in a double-skin facade. *Energy and Buildings*, *39*(3), 364–373. https://doi.org/10.1016/j.enbuild.2006.09.001

Grynning, S., Time, B., & Matusiak, B. (2014). Solar shading control strategies in cold climates - Heating, cooling demand and daylight availability in office spaces. *Solar Energy*, *107*(7465), 182–194. https://doi.org/10.1016/j.solener.2014.06.007

Guarino, F., Athienitis, A., Cellura, M., & Bastien, D. (2017). PCM thermal storage design in buildings: Experimental studies and applications to solaria in cold climates. *Applied Energy*, *185*, 95–106. https://doi.org/10.1016/j.apenergy.2016.10.046

Gvozdenovic K., Maassen W., Zeiler W., Besselink H. 2015. Roadmap to nearly Zero Energy Buildings in 2020. *REHVA Journal*, Volume 52, issues 2, March 2015[6-11]. Available from Internet: http://www.rehva.eu/publications-and-resources/hvac-journal-abstracts/022015-abstracts/

Hernandez, O. 2011. Design, planning and actors of Elithis Tower in Dijion, France, *Rehva Journal* May (2011): 53-57

Humanities, A., & Source, P. (1926). Five points towards a new architecture Le Corbusier.

Iasparra, G. 2009. Grattacielo Intesa San Paolo: consumi tripli per il riscaldamento, *Eco dalle città Journal* October (06–2009) . Available from Internet: http://www.ecodallecitta.it/notizie/100412/grattacielo-intesa-sanpaolo-consumi--tripli-per-il-riscaldamento/

IEA - *Energy efficiency requirement in buildings codes, 2008*. Available from Internet: https://www.iea.org/publications/freepublications/publication/Building_Codes.pdf

IEA. (2013). *Transition to Sustainable Buildings - Strategies and opportunities to 2050. 2013*. Available from Internet: https://doi.org/10.1787/9789264202955-en

IINAS, Darmstadt, 2015 – Development of the Primary Energy Factor of Electricity Generation in the EU-28 from 2010-2013. Website pdf: http://iinas.org/tl_files/iinas/downloads/GEMIS/2015_PEF_EU-28_Electricity_2010-2013.pdf

Inanici, M. N., & Demirbilek, F. N. (2000). Thermal performance optimization of building aspect ratio and south window size in five cities having different climatic characteristics of Turkey. *Building and Environment*, *35*(1), 41–52. https://doi.org/10.1016/S0360-1323(99)00002-5

Issuu, June, 2, 2014, Commerzbank tower, DAV analysis. Available from Internet: https://issuu.com/yasha.mir/docs/f13vbd_a2_ymir

Jelle, B. P., Hynd, A., Gustavsen, A., Arasteh, D., Goudey, H., & Hart, R. (2012). Fenestration of today and tomorrow: A state-of-the-art review and future research opportunities. *Solar Energy Materials and Solar Cells*, *96*(1), 1–28. https://doi.org/10.1016/j.solmat.2011.08.010

Kontoleon, K. J., & Bikas, D. K. (2002). Modeling the influence of glazed openings percentage and type of glazing on the thermal zone behavior. *Energy and Buildings*, *34*(4), 389–399. https://doi.org/10.1016/S0378-7788(01)00125-6

Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift, 15*(3), 259–263. https://doi.org/10.1127/0941-2948/2006/0130

Kragh, M. (2000).Building Envelopes and Environmental Systems. Paper presented at Modern Façades of Office Buildings Delft Technical University, the Netherlands. Available from Internet: http://www.permasteelisa.com/upload/docs/pub _TUD02001.pdf

Lam, T. C., Ge, H., & Fazio, P. (2015). Impact of curtain wall configurations on building energy performance in the perimeter zone for a cold climate. *Energy Procedia*, *78*, 352–357. https://doi.org/10.1016/j.egypro.2015.11.665

Leão, M., & Straub, K. W. (2016). Energy efficiency evaluation of single and double skin façade buildings : a survey in Germany, (25), 12–18.

Lee, E. S. (2002). High-performance commercial building facade Author :, (July 2014). https://doi.org/10.2172/834266

LEED. 2016. Guide in leadership in Economy and Environmental certification. Available from Internet: https://www.usgbc.org/cert-guide

Liu C, Wang X. 2000. Curtain wall technology of green building. Journal of Chongqi University of Architecture, 2000; 22(5):27-31.

Liu, M., Wittchen, K. B., & Heiselberg, P. K. (2015). Control strategies for intelligent glazed fa??ade and their influence on energy and comfort performance of office buildings in Denmark. *Applied Energy*, *145*, 43–51.

https://doi.org/10.1016/j.apenergy.2015.02.003

Lloyd Alter. 2010. Can an All-Glass Office Building Really Be Considered Green? *Treehugger journal – July, 6th, 2010*. Available from Internet: *http://www.treehugger.com/sustainable-product-design/can-an-all-glass-office-building-really-be-considered-green.html*

Lylykangas, K. 2009. Shape factor as an indicator of heating energy demand, in Proceedings of the 15th International Wood Construction Conference (IHF), 2009: Sweden . Available from internet: http:// www.forum-holzbau.com/pdf/ihf09_Lylykangas.pdf

Méndez Echenagucia, T., Capozzoli, A., Cascone, Y., & Sassone, M. (2015). The early design stage of a building envelope: Multi-objective search through heating, cooling and lighting energy performance analysis. *Applied Energy*, *154*, 577–591. https://doi.org/10.1016/j.apenergy.2015.04.090

Ministero dello sviluppo economico, Ministero dell’ambiente e della tutela del territorio e del mare, Ministero dei trasporti. 2015. *Decreto Ministeriale dei requisiti minimi*. (26/06/2015)

Motuziene, V., & Juodis, E. S. (2010). Simulation based complex energy assessment of office building fenestration. *Journal of Civil Engineering and Management*, *16*(3), 345–351. https://doi.org/10.3846/jcem.2010.39

Nielsen, M. V., Svendsen, S., & Jensen, L. B. (2011). Quantifying the potential of automated dynamic solar shading in office buildings through integrated simulations of energy and daylight. *Solar Energy*, *85*(5), 757–768. https://doi.org/10.1016/j.solener.2011.01.010

Özkan, D. B., & Onan, C. (2011). Optimization of insulation thickness for different glazing areas in buildings for various climatic regions in Turkey. *Applied Energy*, *88*(4), 1331–1342. https://doi.org/10.1016/j.apenergy.2010.10.025

Oesterle, E., Lieb, R-D., Lutz, M., & Heusler, W. (2001). Double Skin Facades – Integrated Planning. Prestel Verlag: Munich, Germany

Palmero-Marrero, A. I., & Oliveira, A. C. (2006). Evaluation of a solar thermal system using building louvre shading devices. *Solar Energy*, *80*(5), 545–554. https://doi.org/10.1016/j.solener.2005.04.003

Poirazis, H. (2005). *Single Skin Glazed Office Buildings Energy Use and Indoor Climate Simulations*.

Poirazis, H., Blomsterberg, Å., & Wall, M. (2008). Energy simulations for glazed office buildings in Sweden. *Energy and Buildings*, *40*(7), 1161–1170. https://doi.org/10.1016/j.enbuild.2007.10.011

Rotativo, F. (2005). Il Ministro dello Sviluppo Economico Il Ministro dell ’ Ambiente e della Tutela del Territorio e del Mare Il Ministro delle Infrastrutture e dei Trasporti, 1–8.

Roth, K., Lawrence, T., & Brodrick, J. (2007). Double-skin façades. *ASHRAE Journal*, *49*(10), 70–73. https://doi.org/10.1073/pnas.0703993104

Schnieders, J., Feist, W., & Rongen, L. (2015). Passive Houses for different climate zones. *Energy and Buildings*, *105*, 71–87. https://doi.org/10.1016/j.enbuild.2015.07.032

SisTer s.r.l. 2009. Intesa San Paolo, *Verifica di assoggettabilità*, June 2009. Available from Internet: http://www.comune.torino.it/ambiente/bm~doc/relvia1.pdf

Stec, W., & Paassen, D. Van. (2003). DEFINING THE PERFORMANCE OF THE DOUBLE SKIN FAÇADE WITH THE USE OF THE SIMULATION MODEL, 1243–1250.

Straube, J. (2008). Can Highly Glazed Building Façades Be Green. *Building Science: Insights*, (September), 4–7.

Streicher, W. (2005). Best Practice for Double Skin Façades. *Building*.

Susorova, I., Tabibzadeh, M., Rahman, A., Clack, H. L., & Elnimeiri, M. (2013). The effect of geometry factors on fenestration energy performance and energy savings in office buildings. *Energy and Buildings*, *57*, 6–13. https://doi.org/10.1016/j.enbuild.2012.10.035

Tzempelikos, A., & Athienitis, A. K. (2007). The impact of shading design and control on building cooling and lighting demand. *Solar Energy*, *81*(3), 369–382. https://doi.org/10.1016/j.solener.2006.06.015

Wilson, A. 2010. Rethinking All-Glass buildings. *Building Green Journal – June, 29, 2010*. Available from Internet: https://www.buildinggreen.com/feature/rethinking-all-glass-building

Yu, J., Tian, L., Xu, X., & Wang, J. (2015). Evaluation on energy and thermal performance for office building envelope in different climate zones of China. *Energy and Buildings*, *86*, 626–639. https://doi.org/10.1016/j.enbuild.2014.10.057

Zhou, Z., Zhang, Z., Zuo, J., Huang, K., & Zhang, L. (2015). Phase change materials for solar thermal energy storage in residential buildings in cold climate. *Renewable and Sustainable Energy Reviews*, *48*, 692–703. https://doi.org/10.1016/j.rser.2015.04.048

Acknowledgements

To Professor Violeta Motuziene, because she gave me the possibility of carrying this study on, she made me try the world of research and she taught me the importance of being working-indipendent.

To VGTU, because it provided me tools and softwares to develop my research.

To Professor De Carli, because he made an effort giving me the possibility to live this international experience (and not only), and to have confirmed me the importance of humanity in engineering.

To my Parents who always supported me, and did it from far away during this experience.

To my Brothers Pietro and Margherita who visited me in Erasmus and to be my friends.

To Luisa, because she made everything sweeter and more intense, and to Bristol to have been an amazing shelter with you.

To all my friends I have met in Vilnius, to have turned the difficult moments in beautiful ones and the good moments in parties.

To Sebastiano and Pasini to have helped and advised me about living abroad, to Bons, Mary, Simo, Cami and all of my friends to have supported me from far away in this experience and to make me as I am.

“The greater the struggle the more glorious the triumph”
Nick Vujicic

Ringraziamenti

Alla Professoressa Violeta Motuziene, per avermi dato la possibilità di svolgere questo studio, per avermi fatto provare il mondo della ricerca e per avermi insegnato l’importanza di essere autonomo nel lavoro.

Alla VGTU per avermi fornito gli strumenti per svolgere la mia ricerca.

Al Professor De Carli per essersi impegnato ai fini di darmi la possibilità di svolgere questa esperienza internazionale (e non solo), e per avermi confermato l’importanza dell’umanità nell’ingegneria.

Ai miei Genitori che mi hanno sostenuto sempre e durante lo svolgimento di questa tesi anche a distanza; e per il loro esempio.

Ai miei Fratelli Pietro e Margherita per essermi venuti a trovare in Erasmus e per essere due amici.

A Luisa, per aver reso tutto più dolce e intenso, a Bristol per essere stata uno stupendo rifugio con te.

A tutti gli amici conosciuti a Vilnius che hanno reso belli, i momenti difficili e festa, i momenti belli.

A Sebastiano e Pasini per avermi aiutato ad ambientarmi all’estero, a Bons, Mary, Simo, Cami e a tutti i miei amici per avermi sostenuto da lontano in questa esperienza e per rendermi come sono.