# Energy and Technological Retrofit of a Public Residential Building Stock

**The case study of an apartment block in Turin**

Master's Degree Thesis

MERVE TATLI

Politecnico di Torino

Master of Science Program in
ARCHITECTURE FOR THE SUSTAINABILITY DESIGN
2021/2022

**Energy and Technological Retrofit of a Public Residential Building Stock**

Thesis in collaboration with Agenzia Territoriale per la Casa del Piemonte Centrale

**Author**
Merve TATLI

**Supervisor**
Prof. Ricardo POLLO

**Co-Supervisor**
Doct. Matteo TRANE
Doct. Matteo GIOVANARDI

## ABSTRACT (EN)

With the excessive energy consumption in the worldwide, governments and many institutions conduct many research and investigate new building envelope retrofitting strategies to create more sustainable and energy-efficient livable areas. Especially European Commission has established many legislative frameworks related to not just only for energy efficiency and energy saving in the buildings but also reducing Greenhouse Gas Emissions due to increasing CO2 emissions because of fossil energy sources.

This study aims to show the effects of the different retrofitting strategies of the building envelope due to the increase in demand and consumption of energy in residential buildings. The scale of the analysis is that of the neighborhood and the city. For this purpose, rapid evaluation methodologies of the energy retrofit interventions were used, also with the aim of hypothesizing an analysis of the technological intervention strategies of retrofitting on a micro-urban scale. For the purpose of this study, energy estimates of the retrofit interventions were performed using TABULA Webtool and QGIS software. These tools were used in a pilot case of the city of Turin in a district managed by the Territorial Agency for the Casa del Piemonte centrale - ATC. The area of the lot on which the study focused is on Corso Taranto and is located between Vie Corelli, Pergolosi and Mercadante.

To better understand the results of the energy estimation on an urban area, research and case studies were analyzed. The thesis starts from the definition of energy consumption and energy needs on a global scale up to the analysis of the case of Turin, defining the energy profile of Turin and the related problems.

Another purpose of the study of the theoretical part is to explain energy efficiency strategies at the building and neighborhood scale from the perspective of climate mitigation. This part of the study discusses the general problem from both points of view and defines what kind of strategies can be used. During the study it is clearly understood that not only the buildings and the morphology of the neighborhood, but also the environmental factors play a critical role in relation to the sustainability and exploitation of renewable energy sources.

The last part of the theoretical research illustrates the energy saving technologies developed for the new construction or retrofit of energy-efficient residential buildings.

In the analysis part of the pilot case, a type of building repeated in the area was chosen and energy estimates were made. To understand the energy efficiency and energy consumption in a building after the application of different retrofitting technologies, three scenarios were designed that include no retrofit, light retrofit and heavy retrofitting. In the end, all the results were compared to highlight the importance of the different retrofit strategies.


Keywords: sustainable design, energy efficiency, renewable energies, energy demand, energy consumption


## ABSTRACT (IT)

Con l'eccessivo consumo di energia in tutto il mondo, i governi e molte istituzioni stanno conducendo molte ricerche al fine di studiare nuove strategie di adeguamento dell'involucro edilizio per creare aree vivibili più sostenibili ed efficienti dal punto di vista energetico. In particolare la Commissione Europea ha stabilito molti quadri legislativi relativi non solo all'efficienza energetica e al risparmio energetico negli edifici, ma anche alla riduzione delle emissioni di gas serra dovute all'aumento delle emissioni di CO2 causate dalle fonti di energia fossile.

Questo studio mira a mostrare gli effetti delle diverse strategie di riqualificazione dell'involucro edilizio dovute all'aumento della domanda e del consumo di energia negli edifici residenziali. La scala dell'analisi è quella del quartiere e della città. A tale scopo si sono utilizzate metodologie di valutazione speditiva degli interventi di retrofit energetico anche con l'obiettivo di l'ipotizzare un'analisi delle strategie di intervento tecnologico di riqualificazione a scala microurbana. Per lo scopo di questo studio, le stime energetiche degli interventi di retrofit sono state eseguite utilizzando TABULA Webtool e il software QGIS. Questi strumenti sono stati utilizzati in un caso pilota della città di Torino in un quartiere gestito dalla Agenzia Territoriale per la Casa del Piemonte centrale - ATC. L'area del lotto su cui si è concentrato lo studio è su Corso Taranto e si trova tra le Vie Corelli, Pergolosi e Mercadante.

Per comprendere meglio i risultati della stima energetica su di un'area urbana, sono stati analizzate ricerche e casi studio. La tesi parte dalla definizione dei consumi energetici e dei fabbisogni energetici a scala globale sino all'analisi del caso di Torino, definendone il profilo energetico di Torino ed i problemi relativi.

Un altro scopo dello studio della parte teorica è spiegare le strategie di efficienza energetica alla scala dell'edificio e del quartiere nella prospettiva della mitigazione climatica. Questa parte dello studio discute il problema generale sotto entrambi i punti di vista e definisce quale tipo di strategie possono essere utilizzate. Durante lo studio si comprende chiaramente che non solo gli edifici e la morfologia del quartiere, ma anche i fattori ambientali giocano un ruolo critico in relazione alla sostenibilità e allo sfruttamento delle fonti di energia rinnovabile.

Nell'ultima parte della ricerca teorica vengono illustrate le tecnologie di risparmio energetico sviluppate per la nuova costruzione o il retrofit di edifici residenziali ad alta efficienza energetica.

Nel parte di analisi del caso pilota è stato scelto un tipo di edificio ripetuto nell'area e sono state effettuate stime energetiche. Per comprendere l'efficienza energetica e il consumo di energia in un edificio dopo l'applicazione di diverse tecnologie di retrofitting, sono stati progettati tre scenari che comprendono senza retrofit, retrofit leggero e retrofitting pesante. Alla fine, tutti i risultati sono stati confrontati per evidenziare l'importanza delle diverse strategie di retrofit.


Parole chiave: design sostenibile, efficienza energetica, energie rinnovabili, domanda di energia, consumo di energia

# INTRODUCTION

The importance of energy-efficient buildings and energy saving in the buildings has been realized more than before because of higher demand in the cities, higher energy prices, higher pollution due to fossil sources, non-sustainable buildings and low prevalence of renewable energy sources. In this case, it is important to make retrofitting on existing buildings and build new buildings according to proper architectural technologies.

Architectural designs, construction practices, and technologies are available today that minimize energy and resource use in buildings and optimize the benefits to people of high-performance-cleaner air by reducing GHG emissions, more comfortable homes and workspaces, and lower utility bills. In that point, governments can and must play a critical role.

Unfortunately, retrofitting of existing buildings in the third-world countries focuses on structural or aesthetic measures [1]. But most developed countries are setting new legalizations, especially countries in European Union.

Based on data from the European Union, the existing build stock currently accounts for around 40% [2] of the total energy consumption and 36% [2] of the CO2 emissions in the European Union, and the building sector is still expanding.

Increasing the energy efficiency of the building sector is required to lower the total energy consumption and CO2 emissions significantly. This relates to both new and existing buildings as 75% [2] of the building stock is estimated to be inefficient in terms of energy use.

In the light of all these informations and other researches which are done by all engineers and architects, To boost the energy performance of buildings, the European Union Commission has established a legislative framework that includes the Energy Performance of Buildings Directive 2010/31/EU and the Energy Efficiency Directive 2012/27/EU. [3]

In this study, the main point is taken as energy-efficient buildings for the future. The study starts with an explanation of the city of the case and then not just in the residential scale but also explains the smart technologies for the neighborhood scale. According to the study methodology, showing the effects of retrofitting works contribution is aimed in the case residential.

Therefore, the study can be summarized by the following questions:

- Which type of parameters do affect the energy demand and consumption?
- What are the energy efficiency strategies in residential building and neighborhood scales?
- Which type of Technologies we can use for energy saving in buildings?
- Which type of retrofitting strategies can be implemented in residential buildings to increase energy performance?

# INDEX

# 1. ENERGY CONSUMPTION AND PRODUCTION IN THE CITY OF TURIN

# 1. Energy Consumption And Production In The City Of Turin

## 1.1 General Overview

The residential sector is faced with significant economic, environmental, technological, and social issues, primarily as a result of unprecedented global and regional climate change, overpopulation, intensive urbanization, excessive resource usage, and social disparities.

Regardless of the source, energy is a major factor for development. It is needed for transport, industrial and commercial activities, buildings and infrastructure, water distribution, and food production.

Globally, from the architectural point of view, there is a growing concern about the increasing energy consumption and buildings without energy savings, climate change, and associated greenhouse gas emissions. In particular, energy demand in nations with emerging economies is increasing much faster than the developed countries and approximately 30% of the energy consumption [4] in the worldwide is coming from the residential sector. On the other hand, the residential sector takes a very important place in worldwide energy consumption. This is not just because of different people's behaviors and their variable energy consumption in their households but also we can imagine that the residential buildings have a wide variety of structures and materials.

Energy demand is the term used to describe the consumption of energy by human activity. [5] So in this case, it drives the whole energy system, affecting usable energy and energy technologies. All countries must control the energy demand of their public by knowing and improving their energy consumption and production to be one step ahead of the problems. Because the actual challenge is always supplying needed energy without interrupting people's activity. But we know that another problem is energy sources in our world.

Energy sources are changing with many parameters in the countries and cities. This energy consumption brings some consequences. Energy sources can drain away from our world and at the same time, they can give more pollution. To become a winner in this challenge, renewable sources are started to use by the countries and especially in Europe, more legislations are set to create more sustainable and livable areas.

The energy demands depend on many different parameters in the nations. Awareness of architecture and well analyzing of the country area is very particular. In this case, one of the most important point is creating energy production areas for needed energy demands. The energy production capacity of a country is affecting its transportation, building energy performance and heating, climate, public sector and people's lives.



In general, the distribution of the population in the cities and unpredictable immigration, the new buildings which have incorrect architecture and high energy consumption, delayed or incorrect of building retrofitting works, insufficient energy sources in the city territory and inadequate renewable energy source technologies are creating very huge problems to meet with the energy needs.

As described above, there are different parameters to understand energy consumption and demand; like demographics of the cities, climate, etc. These parameters also helps how to develop energy production capacity and create more sustainable areas. In this case, Turin will have its energy characteristics.

The city is located near Alps and the mountains affect very strongly the environment of the city. This position creates different climatic conditions and in conclusion it affect the energy consumption. The mountain position create more weak wind and it helps to keep temperature in more narrow range between day and night [6]. In the end it helps to keep energy consumption lower.

The one of biggest problem in the city is the energy sources. Most common energy sources in the city are Natural gas and then fossil energy sources and electricity are following it [7]. So, the city is still using mostly non-renewable energy sources, especially in private households and in the industry. However, when energy demands of the city increases, the pollution of air and people life comfort are affecting so much.

In general, city will need more renewable energy sources in the future, but it has no enough supply technologies yet. Another point which affects energy consumption in result of energy demand is the architectural condition of the buildings. Generally, there are very few new building projects in the province of Turin. Which means that, most of the buildings are existing buildings and they need retrofitting works to create more energy-efficient city.

## 1.2. Description Of The Province Of Turin

### 1.2.1. Important Factor For Analyzing Energy Consumption And Production: Demographics Of Turin

Among Italy provinces, Turin is one of the wider and the one with the greatest number of municipalities (316 in total). The larger part of Municipalities are very small and 113 of them do not even reach the 1,000 inhabitants and grouping the 2.57% of the overall provincial population.

The resident population (equal to half of the Piedmont's population, 52%, and about 4% of the whole National country) is focused mainly in a few larger towns located on the plain territory. The population density which shows the number of inhabitants living in one square kilometer is very different within provincial borders. In the municipalities with more than 10,000 inhabitants (precisely 28, located mainly in the plain and at the foothills) lives approximately 75% of the overall population.

The table below which shows benchmarking of the most important demographic data about the concept region regarding the most recent year available: 2019 and 2020. [6]

| Demographic data type | 2019 | 2020 |
|---|---|---|
| population at the beginning of the period | 2238663 | 2230946 |
| live births | 14637 | 14303 |
| deaths | 25988 | 32134 |
| natural increase from registry office | -11351 | -17831 |
| registrations from other municipalities | 69360 | 61994 |
| deregistrations to other municipalities | 66481 | 60396 |
| internal net migration from registry office | 2879 | 1598 |
| immigrated from other countries | 12675 | 9733 |
| emigrated to other countries | 5016 | 6377 |
| international net migration from registry office | 7659 | 3356 |
| registrations for other reasons | 3631 | 1962 |
| deregistrations for other reasons | 11617 | 3934 |
| balance for other reasons from registry office | -7986 | -1972 |
| net migration and balance for other reasons from registry office | 2552 | 2982 |
| registrations | 85666 | 73689 |
| deregistrations | 83114 | 70707 |
| increase or decrease due to territorial changes | 0 | 0 |
| total census balance | 1082 | 3109 |
| population on 31st December | 2230946 | 2219206 |
| number of private households on 31st December | 0 | 0 |
| resident population in private household on 31st December | 2211257 | 2200660 |
| average number of members in private household on 31st December | 0 | 0 |
| number of institutional households on 31st December by statistical treatment of the register source | 1613 | 1658 |
| resident population in institutional household on 31st December | 19689 | 18546 |

*Table 1 Demographic balance of province of Turin 2019-2020 [8]*

From the demographic data and demographic trend graph below, the population is not growing. The graph numbers also are telling us that the demographic balance of Turin is intended to remain stable over the next few decades. Immigration numbers can point out for reason of this according to demographic database of Turin.

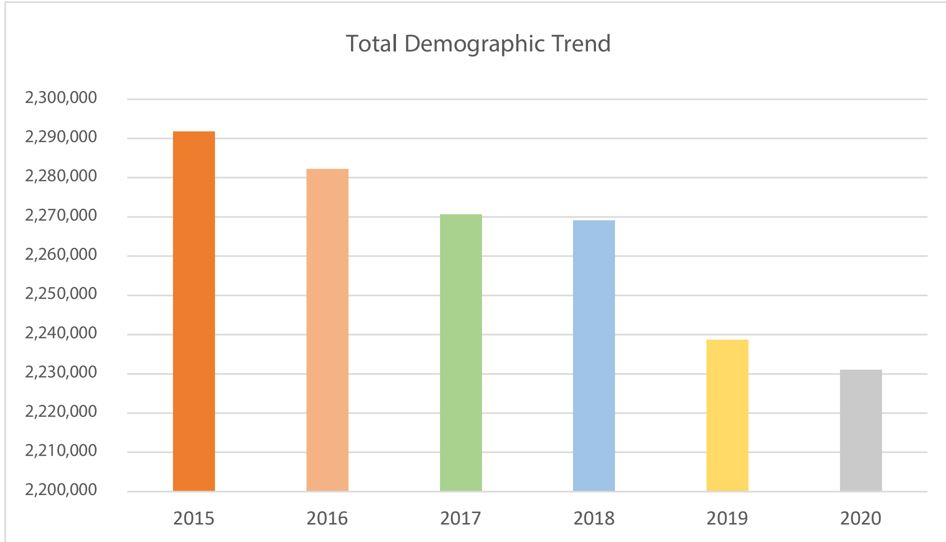



*Figure 1 Demographic Trend About Resident Population of The Region [8] [9]*

Another index to create more ideas is Housing Situation. According to housing situation in Turin, we can understand from Table 2 that dwelling in residential buildings number and number of residents number are very close to each other. Additionally, more than half of the buildings are owned of people and rest of them are available to rent external people.

| Index | Value |
|---|---|
| Residential Buildings | 297.330 |
| Dwellings in Residential Buildings | 1.077.023 |
| Avarage Number of Rooms per Dwelling | 4 |
| Average Size of Dwelling | 83 |
| Dwellings Occupied by Residents | 920.264 |
| Dwellings Occupied by Residents in Property | 614.191 |
| Dwellings Occupied by Resident for Rent | 240.898 |

*Table 2 Detail of The Housing Situation in The Province of Turin [6]*

#### 1.2.2. Environment And Climate

The climate and environment conditions of the territory are one  of most important factors to analyze requirements and they give  a lot of idea about energy needs in the city. In this sense, also different factors affect these conditions. In Turin, the most important factor which effects climatic condition is presence of Alps whose topography is able to deflect and seal the flow of winds on city.

The climatic conditions of the Province of Turin are strongly influenced by the presence of the Alps, whose topography is able to deflect and seal the flow of winds that reach it. The plain surrounded on three sides by mountains and hills in Turin. [6] This condition will help to prevent cold weather and air pollution in Turin.

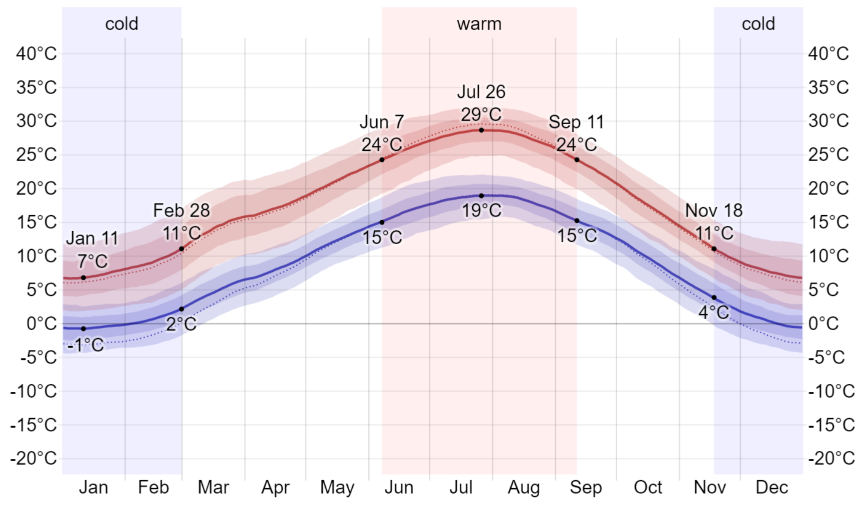



*Figure 2 Trend of Average Daily Temperatures at Different Attitudes in Province [6]*

The figure above shows changes of temperature during the year-random- in Turin and some countryside. According to the figure, the warm season lasts for 3.1 months, from June 7 to September 11, with an average daily high temperature above 24°C. The hottest month of the year in Turin is July, with an average high of 28°C and low of 19°C.

The cold season lasts for 3.4 months, from November 18 to February 28, with an average daily high temperature below 11°C. The coldest month of the year in Turin is January, with an average low of -1°C and high of 7°C.

The annual amount of rainfall will increase approaching the Alps from the plains, due to the effect of forced lifting imposed by the relief on the air coming from the humid Mediterranean air cooling that follows and vapor condensation results in increased cloud cover and precipitation.

Another important factor is the wind factor. Regarding wind situation, the Alps give rise to weak and irregular wind conditions in the city. The frequent Atlantic winds, lively on the plains north of the Alps felt mostly in the high mountains, while the plains and the valleys are dominated by breezes and local winds. [6] In this case, the few days with strong wind can occur especially between autumn and spring – comes dry and mild from the main ridge of the Alps towards the plain, or, in the summer months, rapid and irregular storms, capable of significant damage but on limited areas.



About the solar radiation, according to the research made in 2011, it's possible to say that the annual average of the entire region is about 1350 kWh/sqm; that reaches an optimum value (1500-1600) for all those surfaces exposed to the south and inclined between 20 ° and 40 ° with respect to the horizontal plane. During the year, the summer season obviously is the best one for radiation. In Turin-city it's possible to observe a value of 200 kWh/sqm. [6]

| Radiation | Horizotal | Vertical | Optimal |
|---|---|---|---|
| Minimum | 1234 | 943 | 1418 |
| Average | 1342 | 1093 | 1582 |
| Maximum | 1469 | 1278 | 1784 |

*Table 3 Annual Solar Radiation in Province - kWh/sqm [6]*

#### 1.2.3. Legislative Situation

Another important point related to the city is the legislation which city follow in terms of energy. The building energy performances are shaped according to the legislations and they limit waste for sustainability of buildings.

The legislative situation of the energy sector of the Province is linked with EU directives and their national transposition. Indeed, nowadays they provide an accurate and detailed frame of what is to do to achieve the objectives of energy efficiency and energy saving agreed for Europe. According to the European Union, the five aims  of EU's energy policy are to:

- Diversify Europe's sources of energy, ensuring energy security through solidarity and cooperation between EU countries.
- Ensure the functioning of a fully integrated internal energy market, enabling the free flow of energy through the EU with adequate infrastructure and without technical or regulatory barriers.
- Improve energy efficiency and reduce dependence on energy imports, cut emissions, and drive jobs and growth.
- Decarbonise the economy and move towards a low-carbon economy in line  with Paris Agreement.
- Promote research in low-carbon and clean energy  technologies , and prioritize research and innovation to drive the energy transition and improve competitiveness.  [10]

Below it's reported a summarization of the legislative framework with a short description of it and how the EU directives have been transposed into national, regional and local regulations. The EU directives mentioned are:

- Directive 2001/77/EC – on promotion of electricity produced from RES in the internal electricity market.
- Directive 2002/91/EC – on the energy performance of buildings
- Directive 2010/31/EU – on the energy performance of buildings (recast)
- Directive 2006/32/EC – on energy end-use efficiency and energy services and repealing
- Directive 93/76/EEC
- Directive 2009/28/EC – on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC
- Directive 2009/72/EC – concerning common rules for the internal market in electricity and repealing
- Directive 2003/54/EC
- Directive 2009/125/EC – establishing a framework for the setting of eco-design requirements for energy-related products (recast).
- Directive 2012/27/EC – on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU, subsequently repealing Directives 2004/8/EC and 2006/32/EC. [6]

## 1.3. Energy Demand Of Turin

Explained in the previous chapter shortly, the energy demand is the term to describe  the consumption of energy by human activity. It affects all the life of the habitants. People should create energy efficiency cities to decrease fossil consumption, create sustainable areas and build energy productive cities to provide energy needs.

For Turin, In the last decade, energy consumptions in final uses decreased. According to the some research made during 2009-2011, by more than 15% with a strong reduction recorded. In 2011 the overall energy demand dropped down 50.000 GWh, far away from the top peak data of 2001. [6]

To describe energy demand, different kind of sectors and different kind of energy carriers should be examined. Energy carriers describe the city energy consumption types and which kind of energy type people use. On the other hand, the sectors have very important role to detect correct energy demand for habitants. Because every kind of sector energy demand will be different due to different needs of sectors.

As shown in the following tables and images Economy and Transport both gave the mayor contribution to the decrease. On the contrary Private households' sector is quite constant along the decade with a slight decrease only in the last year and Public sector is also continuing constantly along the decade. As if Industry is losing importance in provincial economics since the Nineties the decrease of energy consumption of Transport is quite surprising and has to be put in connection with the economic crisis which deeply affected the transport of goods from 2008 on.

Public sector remains around 2.5% of total energy demand. Also we can say that Industry is the main responsible of the decrease of energy consumption of productive activities as Trade & Commerce keep on growing giving contribution to  total Added Value of the Province of Turin.

Natural gas looks it is the main energy carrier demanded for Turin, followed by the Fossil liquid and electricity. Oil products were tried to decrease year by year but it is obvious that especially for transportation, fossil resources are needed still especially for Transport and Industry sectors.

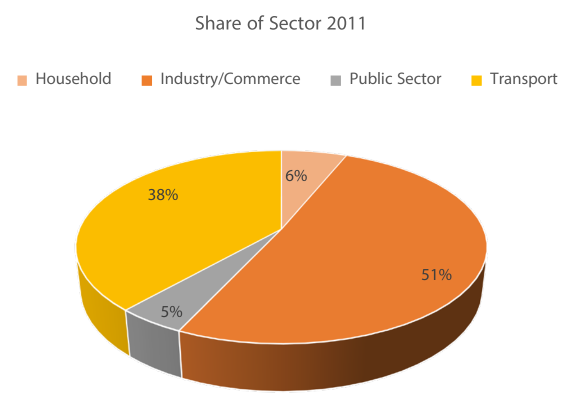



*Figure 3 Share of Sector-2011*

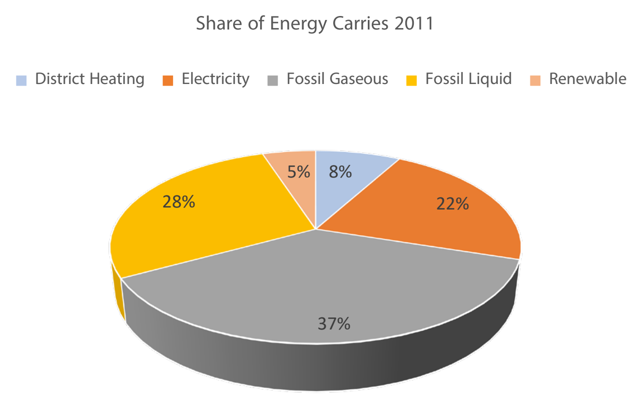



*Figure 4 Share of Energy Carriers - 2011*

According to the research of energy carrier, we can say that the important improvement is not just only decreasing of using fossil liquids but also increasing renewable energy resources. This improvement actually is base stone of sustainable architecture which not just architects jobs but also governments desires during our century.

| Energy Carrier | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|
| District Heating | 3,537,650 | 3,614,330 | 3,636,484 | 3,656,648 | 3,595,148 |
| Electricity | 11,868,967 | 11,352,675 | 11,525,172 | 11,666,967 | 11,505,278 |
| Fossil Gaseous | 20,273,493 | 20,738,176 | 20,787,867 | 20,594,195 | 21,064,118 |
| Fossil Liquid | 20,835,528 | 18,767,370 | 17,605,960 | 17,771,437 | 17,620,032 |
| Renewable | 1,922,574 | 1,960,668 | 2,002,557 | 2,033,948 | 2,068,646 |
| Total | 58,438,212 | 56,433,219 | 55,558,040 | 55,723,196 | 55,853,221 |

| Sector | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|
| Households | 20,245,587 | 19,888,170 | 19,659,988 | 20,198,740 | 20,490,788 |
| Industry/Commerce | 20,535,336 | 20,155,791 | 20,091,073 | 19,437,320 | 19,428,431 |
| Public Sector | 1,100,908 | 1,091,919 | 1,129,862 | 1,109,317 | 1,158,997 |
| Transport | 16,556,381 | 15,297,339 | 14,677,117 | 14,977,820 | 14,775,005 |
| Total | 58,438,212 | 56,433,219 | 55,558,040 | 55,723,196 | 55,853,221 |

*Table 4 Final Energy Demand in Turin between 2001-2005 - mWh [6]*

| Energy Carrier | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|
| District Heating | 3,131,823 | 3,211,326 | 4,172,271 | 4,161,824 | 4,302,994 | 3,727,485 |
| Electricity | 11,956,324 | 11,926,433 | 11,675,161 | 10,686,083 | 10,879,693 | 10,847,739 |
| Fossil Gaseous | 21,237,623 | 19,692,108 | 19,611,272 | 19,421,408 | 21,482,992 | 18,468,185 |
| Fossil liquid | 16,953,639 | 16,893,159 | 14,571,099 | 14,315,980 | 14,867,763 | 13,900,853 |
| Renewable | 2,164,577 | 2,212,594 | 2,261,156 | 2,329,536 | 2,390,282 | 2,453,029 |
| Total | 55,443,985 | 53,935,620 | 52,290,960 | 50,914,831 | 53,923,725 | 49,397,292 |

| Sector | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|
| Households | 19,790,366 | 19,045,849 | 19,478,274 | 19,611,157 | 21,928,829 | 19,679,829 |
| Industry/Commerce | 19,675,783 | 18,986,059 | 18,558,402 | 17,480,524 | 17,708,575 | 16,074,361 |
| Public Sector | 1,223,596 | 1,179,245 | 1,199,561 | 1,138,799 | 1,310,554 | 1,235,890 |
| Transport | 14,754,240 | 14,724,466 | 13,054,723 | 12,684,351 | 12,975,901 | 12,407,213 |
| Total | 55,443,985 | 53,935,620 | 52,290,960 | 50,914,831 | 53,923,725 | 49,397,292 |

*Table 5 Final Energy Demand in Turin between 2006-2011 - mWh [6]*

### 1.3.1. Household Energy Demand

Households use energy for various purposes like space and water heating, space cooling, cooking, lighting and electrical needs. These type of purpose give rise to different energy demands due to house population. In this point, the average number of people in a single dwell and whole city population plays very important role to describe household energy demand.
Private Households represent almost 40% of total energy demand, being the most important sector of final uses of energy. Energy performance of building stock is a key issue in order to set up an Action Plan boosting the reduction of primary energy consumptions, promoting the use of renewable energy sources or cutting Greenhouse's gases emissions. If we consider only thermal consumptions (heating plus hot domestic water production), more than 84% of total consumptions refers to space deals with heating and production of hot domestic water, 13% comes from electric lightning and appliances and 3% from cooking.

Natural gas is the main energy carrier used in Private Households with more than 59% of total demand, followed by electricity (13%) and renewable wood (12%). As for renewable energy sources, apart from biomass which uses is traditionally very important, solar thermal energy shows an important growing trend even though its contribution to the overall demand is still marginal (0,2%). Even more residual is the contribution of the geothermal source. The research which made in 2011related to energy demand of households, is showing below. [6]

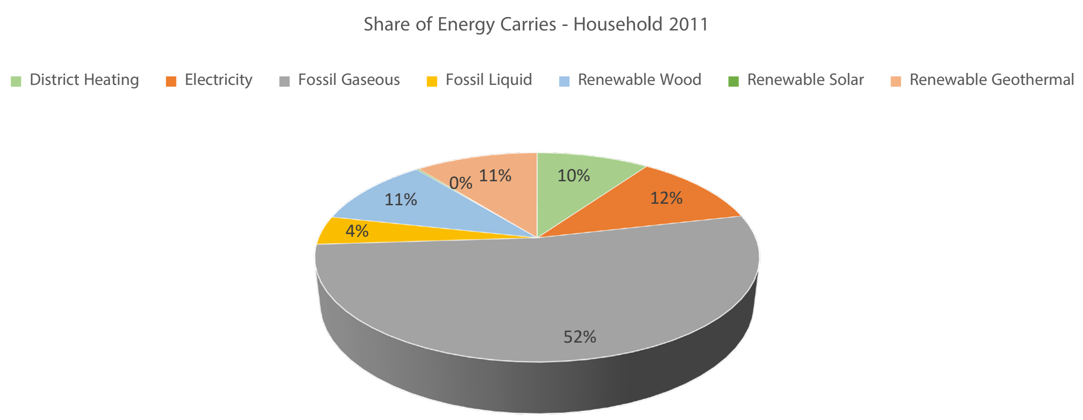



*Figure 5 Final Energy Demand of Households - Share of Energy Carriers in 2011*

### 1.3.2. Transport Energy Demand

Transport is the one of the biggest and most important sectors in people life. In this case, the energy demand is increasing proportionally with population of the city. During the last decades, the renewable energy resources begin to use for energy demands of transportation. But of course, this will not be short period for cities and especially for whole word. Turin city is the one of the sustainable cities in Europe who use electrical public transportation widely along the city and also creates many charge stations for electrical cars for personal transportation for people.
According to research between 2001 and 2011, the energy demand of the transport sector decreased by 25% from 2001 to 2011. [6] The top peak consumptions were recorded in 2001The diesel looks most important energy carrier for transport sector. Its importance grew along the years taking place of gasoline, whose use decreased by nearly half. On the other hand, the alternative fuels like LPG and natural gas are used especially due to low-cost transportation opportunity. LPG and natural gas had a strong increase during this last decade, almost double themselves. Nowadays although the electricity is starting to use for people and government especially public and trains, LPG and natural gas usage are increasing year by year.

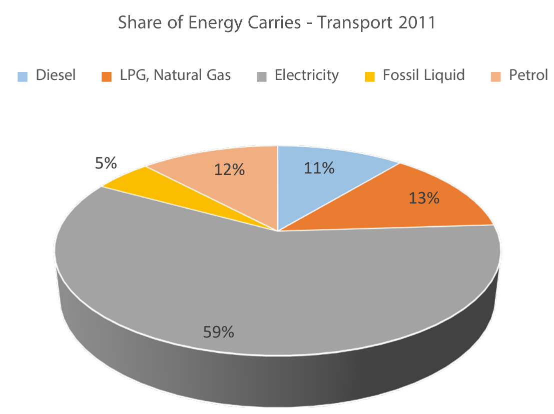



*Figure 6 Final Energy Demand of Transport - Share of Energy Carriers - 2011*

### 1.3.3. Public Sector Energy Demand

The public sector is responsible for 2.5% of total energy demand. Despite what is happening in other sectors its energy demand is increasing during all decades. The increase is very high in electricity, natural gas and in heating from the local district. Fossil liquids are, on the contrary decreasing a lot, mostly regarding diesel consumptions which were replaced by liquid petroleum gas, natural gas and wood. Fuel oil is only used in one big hospital. As for as renewable energy sources are concerned, biomass is used in several wood-chip boilers serving public buildings, such as schools. [6]

### 1.4. Energy Production: Energy Sources In Turin

The ability to separate primary and secondary energy is important in understand energy demand and production in the cities. To control the energy balance, it is important to be able to separate new energy entering the system which is primary and the energy transformed within the system which is secondary energy. The most important distinguishing characteristics of primary and secondary energy are the process and activity involved humans to make use of energy in the source. To take it from the start, all energy on earth originally comes from sun, through natural energy chains, the energy from the sun is transferred to other forms of energy, kinetic or stored. As known, Energy can neither be created nor destroyed. It means , the form of the energy changes one to another. Figure below is describing the general picture of energy sources and transformation. [11]

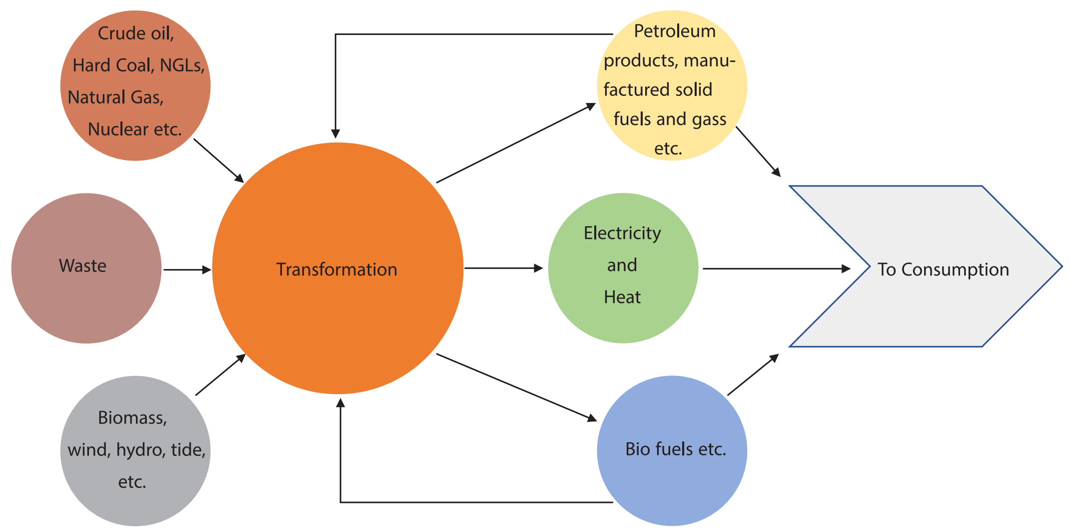



*Figure 7 Primary and Secondary Energy*

### 1.4.1. Primary Sources

### 1.4.1.1. Fossil Sources

Fossil sources, including oil, coal and also natural gas are non-renewable resources on the earth. From past till today, fossil sources were used to provide energy to cities and buildings. But this situation started to change by using renewable energy sources and, for sure in the future, the usage of fossil sources will decrease year by year in the cities.

In the next 20 years, the fossil energy must become a guarantor of the sustainable development of the energy sector for future generations. [12]

In the concept region, there aren't any direct fossil sources or productions on its territory. As a consequence, the Province of Turin is strongly dependent from foreign supplies, in particular natural gas. Because of the lack of fossil energy reserves, the only way to limit the external supply and consumption of fossil sources is to resort to a more consistent use of renewable energy and increase efficiency in the final use of energy. [7]

### 1.4.1.2. Natural Gas

Natural gas plays important role in the global energy mix, Today, to help meet the strategies development needs of urban energy and reduce carbon emissions, natural gas can play a pivotal transition role, especially in a country which has relied heavily on coal for decades.

Though making significant progress toward the maximum possible use of clean, renewable forms of energy, such as hydro, thermal, solar, and wind power, it will take a long time before countries can completely abandon the use of fossil fuels. [13]

Global natural gas demand is critical factor for cities. Due to high consumption, mostly, the cities are providing necessary natural gas from external suppliers.

The energy system supply of the province depends mainly on natural gas, which was 54% in 2000 and 68% in 2011 of total energy supply. This dependency is thus increasing since this source is being used more and more for electricity production. All-natural gas used in the concept region is imported from foreign regions by the national transport grid. Main suppliers are foreign countries, such as Russia and North African countries. [7]

### 1.4.1.3. Renewable Sources

As discussed before, high living standards of people leads to develop more energy sources. But due to high consumption risks and also harms of non-renewable sources, renewable energy sources are started to use by people in the cities. Especially from last decades till today, also with government precautions, people start to use renewable energy sources in their livable areas.

Renewable energy sources increased their share also to reduce the consumption and emissions. Wind, biomass and hydropower are the most relevant renewable source though it is very probable that solar energy will start giving an important contribution in next years.

Renewable sources consumed in the Province of Turin are hydropower, geothermal energy of low enthalpy, solar energy (thermal and photovoltaic), wind power energy and biomass in its various possible forms: wood, biogas and biofuels. [7]



### 1.4.1.4. Wind Power

Wind power is one of the powerful renewable energy sources. Overall, using wind power to produce energy has fewer effects on the environment than many other energy sources. Because as known, the wind power don't release emissions that can pollute the air or water. In general, renewable energies are a critical element for reducing greenhouse gases emissions and achieving a sustainable development.

Until recently, building integration of renewable sources was focused on solar technologies. Nevertheless, building integrated wind turbines can and must be part of the solution to the global energy challenge. [14]

About this type of source, it's important to note that since 2010 there was a production of wind energy in the Province of Turin. Below two maps are reported: they come from a study conducted by ARPA Piemonte and the Province of Turin and indicate the average annual wind speed at 10 and 50 meters. [7]

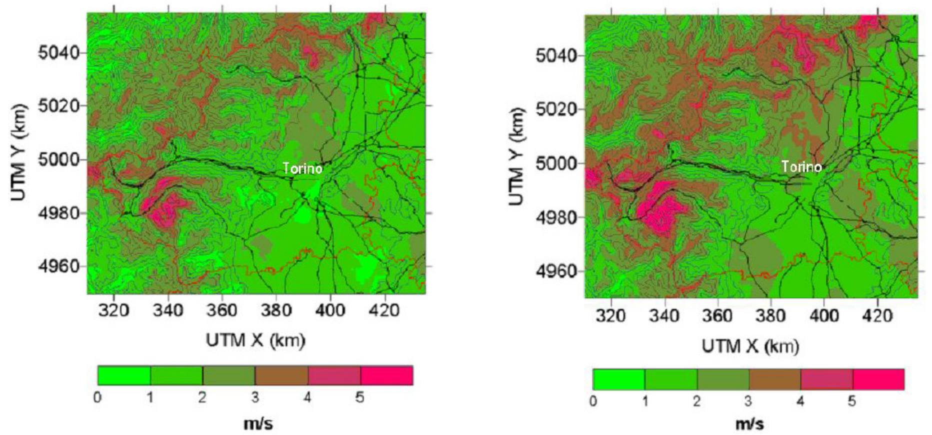



*Figure 8 Average Annual Wind Speed at 10 Meters and 50 Meters Above The Ground [7]*

### 1.4.1.5. Solar Power

Energy is considered as a main influence on urban configurations. Solar energy is light that is emitted by sun. While every location on Earth receives sunlight over a year, the amount of solar radiation that reaches any one spot on the Earth's surface varies. By considering this variations, solar technologies capture this radiation and turn into useful energy forms for people.

However, there is a difficulty on translating the city models based on theoretical renewable energy concepts into practical applications. With this objective, a methodology to intervene in existing cities based on the study of solar access is developed. As a result, solar power can consider another important energy source for all cities, like Turin. [15]

From a research conducted on about 50 municipalities of the metropolitan area of the city of Turin, the theoretical capacity of solar thermal energy (reaching the maximum objective allowed from the law: that is the 60% of the needs of hot water for half of the inhabitants) is about 470 MW; if we could install solar PV panels on the rest of the free buildings' roof of these municipalities, it's possible to reach a capacity of 512 MW for electricity. [7]

It's worth noting that these data derive from a study conducted on the most populated part of the province, so that the results should be increased by making more investment in whole city. About the industrial level, the existing capacity of plants is about 267,6 MW (2012) with a number of plants of 1.490. Few of such plants were installed on the ground, but for the future installations are no more eligible for public founding due to land use protection. [7]

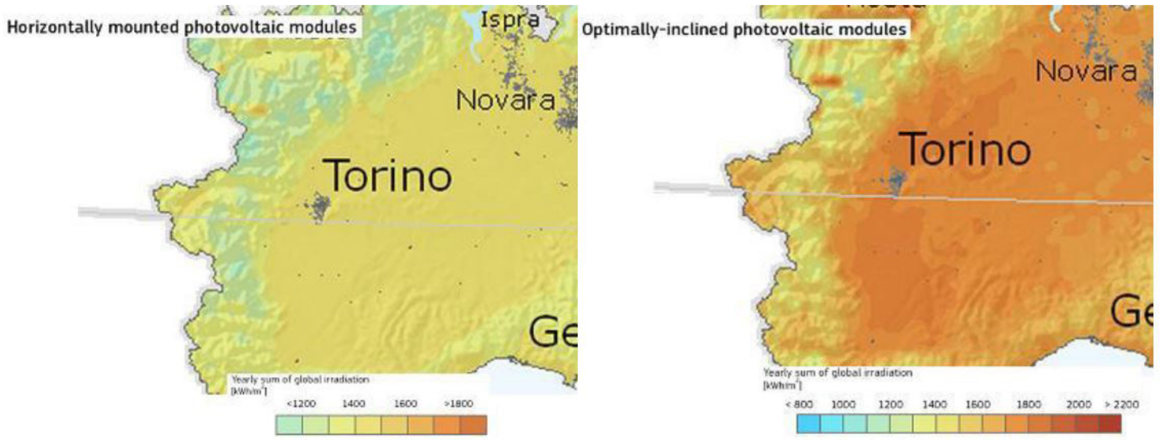



*Figure 9 Solar Irradiation per Year in Turin Province [7]*

### 1.4.1.6. Geothermal Power

Geothermal energy is a collective term referring to Earth heat extraction and use of the ground capacity to absorb and store thermal energy to supply heat or cold. Thermal ground exchange or shallow geothermal energy has been increasingly used in the housing sector to sustain comfortable room temperature. Increasing utilization of geothermal energy, particularly in urban areas, requires integration into urban planning processes. [16]

In the province of Turin, the contribution of this source is lower than 1% of the total renewable in 2011. As you can see from the picture below, the provincial territory is not one of the best places of the nation regarding this type of source. The existing capacity of its plants was about 29 MW as total power of more than 280 installations, in fact the current capacity is 32 times higher than ten years before capacity. [7]

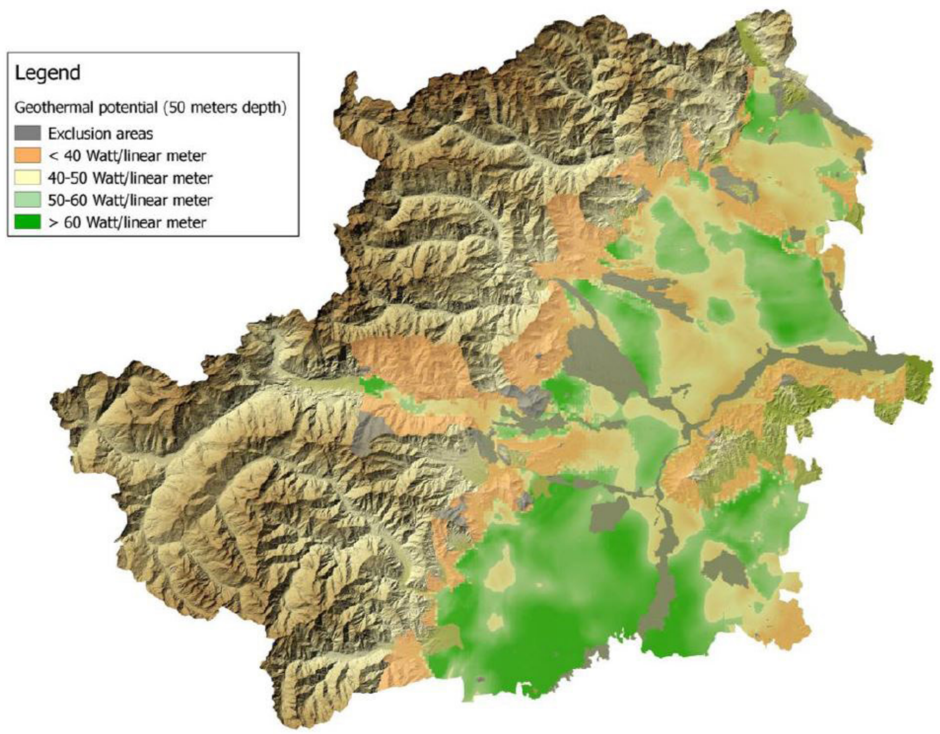



*Figure 10 Map of Geothermal Sources - low enthalpy - at a Depth of 50 Meter [7]*

### 1.4.1.7. Hydroelectric Power

Hydroelectric power has been leading source of renewable energy across the world. A lot of dams are built in the countries to increase their sustainable energy sources. Over the years, dams have been used for land management and also food control to store water for irrigation and agriculture to provide reaction and navigation and to address management of aquatic resources. It is easy to understand why hydroelectrical power represents the largest renewable energy source of electricity because 71% of global production of renewable energy. [17]

From the Energy Report of the Province of Turin, in 2011, the hydroelectric power production was about 2.285 GWh. The contribution on the total RES supply is about 38%. From 2000 the production didn't change so much: in fact it was very similar, 2.153 GWh.

This source is historically established in the Province of Turin, mainly for the positive orographic situation and the very high drainage density. This potential derive primarily from a more efficient exploitation of the existing plants and a rationalization of the system.

The principal barrier hindering the use of hydropower energy is the environmental impact of new plants and the difficulty to obtain new licenses.

About the storage system, it's important to underline that some storage hydropower systems are running for long time in our province pumping the water in the system during low peak hours and generating electricity during top peak hour. Below it is reported the map indicating the spatial distribution of main hydropower plants and all the small hydro plants on the province territory. [7]

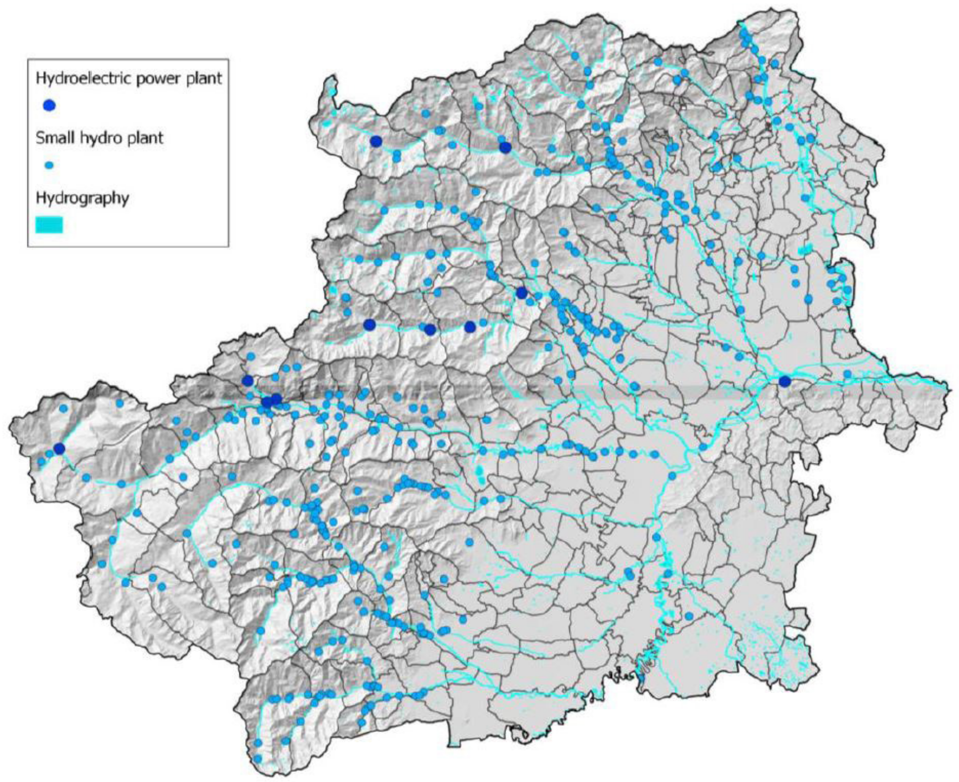



*Figure 11 Location of hydroelectric Plants in the Province* [7]

#### 1.4.1.8. Biomass Energy Utilization

With growing awareness of the impact of fossil fuels on the natural environment and their common usage in buildings, architects are increasingly required to specify and accommodate alternative energy sources in their design approaches. Biomass is the production of fuel from organic raw materials, most commonly woodchips and pellets. Biomass such as raw woodchips and pellets are converted to energy by a variety of means. One of the most common is thermal conversion, where biomass is compressed into briquettes, and burned to produce steam, which in then powers turbines to produce electricity. Another method, pyrolysis, involves heating biomass to 200-300 degrees Celsius (390-570 Fahrenheit) to produce a dark liquid known as pyrolysis oil that can be combusted to generate energy, and in the future, may also replace petroleum. [18]
www
Biomass is the largest renewable source in the province with an energy contribution of almost 58% on the total of RES. This use of such supply consists of 2/3 of energy used directly by end-users (log wood, pellets and wood chips used in boilers) and 1/3 from the processes of production of electricity and heat (from wood chips, biogas and oils power plants). [7]

#### 1.4.1.9. Waste And Other Renewable Energy Sources

Another renewable source that deserves to be mentioned for the energy production is the "waste". Based on the data collected by the Waste Observatory of the Province of Turin and the ATO-Rifiuti Torinese, the total production of municipal waste in 2011 decreased by 2,3% compared to 2010 (about 26,000 tons less). The residual urban waste after recycling is reduced as much 3.1%, and therefore the need for disposal. A part of the total amount of these waste are used to produce electrical and thermal Energy in a plant near Turin City: the so called "Gerbido incinerator". [7]

### 1.4.2. Secondary Energy

#### 1.4.2.1. Electricity

The electricity is the flow of the electrical power of charge. Electricity is not just only a part of the nature but also the most widely using forms of energy. Electricity is considering as secondary energy source because it is produced by converting primary energy such as natural gas, coal, nuclear energy, solar energy, wind power and etc.

On the other hand, electricity also is type of energy carrier. Because it can carry the energy to convert other forms such as mechanical energy or heat.

In the province of Turin, the electricity were produced with different methods for last decades. More than 80,2% of electricity comes from thermal power plants, 18.5% from hydro plants and 1,3% from photovoltaic, the contribution of wind energy is negligible. [7] The thermoelectric sector is largely also cogeneration, so they should be useful heat energy produced. The heat generated can distributed or sold to end-users through district heating networks and the remainder self-consumed by users industrial.

Renewable energy is also used to produce electricity in the province. Even more important is the share of domestic electricity needs met with local renewable energy production. The 2010 datum is particularly important because in Europe there was a 21% target of electricity production from renewable total electrical consumption. Just as it was for Europe as a whole in the province of Turin this objective therefore has been reached and exceeded. It's always hydropower to hold the largest share of renewable energy electricity with 85% of the total production. [7]



#### 1.4.2.2. Heat

Heat is classified as secondary energy source. In human's life, heat plays very important role to keep people's life in comfort such us wood burning stoves, electrical blanket, heaters etc.

Heating is becoming more and more important in the overall energy balance of the province of Turin. The heating energy is distributed to private households' customers. [7] As we can see from pie chart which represent share of households heated by district heating in Turin, Heating represents nearly 12,5% of total thermal consumptions of buildings.

The total energy consumed is made up mostly for natural gas generally in the world and after natural gas biomass (including biogas) comes with lower rate. The remainder is attributable to petroleum products (fuel oil and diesel fuel).

The heat generated is more than two-thirds distributed or sold to end-users through district heating networks and the remainder self-consumed by industrial users. Finally, a residual amount of heat comes from thermal power stations, mainly up and integration of the existing district heating networks. [7]

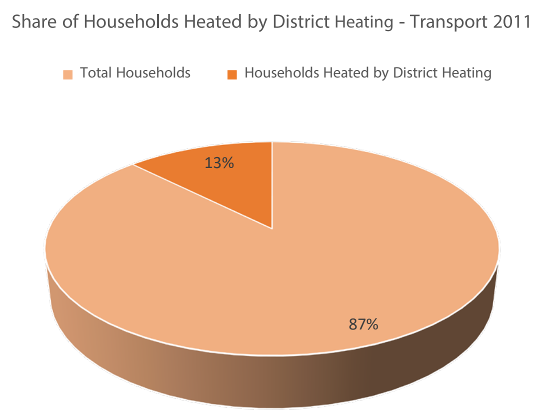



*Figure 12 Share of Households Heated on Total Households*

#### 1.4.2.3. Refined And Synthetic Fuels

Synthetic fuels are liquid fuels that basically have the same properties as fossil fuels but are produced artificially. They can be used in the same way as fossil fuels are used all around the world.

The fuels used in the province of Turin are: gasoline, diesel, liquid petroleum gas and fuel oil. No refinery process take place within the provincial borders and all fuels are imported from other regions and foreign countries. [7]

The transport sector is the main one to use this type of sources especially more than half of consumptions are related to diesel. Its importance grew along the years taking place of gasoline, whose use decreased by nearly half. The preference of people moved from gasoline to diesel as prices of fuel raised up during nineties and the last decade, so that a lot of diesel cars were sold taking place of traditional petrol ones.
This can be explained only by taking into consideration the transport of goods. Freight transport was affected by economic crisis as well as industry and this situation is clearly reflected in the energy demand/supply.

# 2. BUILDING ENERGY MODELLING AT NEIGHBORHOOD AND BUILDING SCALE IN CLIMATE MITIGATION PERSPECTIVE

## 2. Building Energy Modelling At Neighborhood And Building Scale In Climate Mitigation Perspective

### 2.1. General Overview

New urban development helps to control and fight with climate change and to create new livable and energy efficient urban areas to obtain better environmental sustainability.

All the cities in the world start to change building methods by considering the energy demands and productions according to new setting targets to reduction of greenhouse gas (GHG) emissions in order to achieve low environmental impacts and to address climate change. The energy consumption of buildings has a significant impact on urban sustainability and climate change, and these phenomena are more pronounced in high-density urban contexts.

In Italy and in most European countries, energy policies are focused on two prior actions to reduce energy consumption and GHG emissions: an improvement in energy efficiency and an exploitation of the available renewable energy sources. To achieve energy sustainability, number of solutions were adopted by using of building envelopes and urban spaces to produce energy from renewable energy sources (RES). The balance of energy demand and supply should be at the smallest scale possible: at building scale, block of buildings, neighborhood scale or urban scale. Using these methods always shaped according to the environment of the territory. The environment has important factor when architects and engineer define the priority areas or type of energy which they can supply from territory. On the other hand, the energy saving performance of buildings are influenced by several factors such as the building shape, the heating and cooling system efficiencies, the type of users, and the behavior of the people there in. [19]

### 2.2. Energy Efficiency Strategies In Neighbourhood Scale

The energy consumption patterns of buildings located in dense city centers are highly independent on the surrounding urban neighborhood, compared to the low density, suburban/rural regions, where the building energy consumption patterns are similar to an isolated building energy consumption patterns. [20] In this case, due to more complex results of the buildings when analyzing all of them together, the strategies are improved in neighborhood scale.

As decentralization is a prerequisite for sustainable urban development, the incorporation of sustainability principles in neighborhood design becomes crucial, for several reasons.

- First, the neighborhood is the basic unit of the urban organism.
- Second, the problems presently encountered at city level are the cumulative consequences of poor planning at the neighborhood level.
- Third, neighborhood scale development is also a relatively typical form of development, both for private real estate developers and for public interventions.
- Fourth, efficient and sustainable urban infrastructure, including buildings, transportation, urban vegetation, and water (i.e., water supply, wastewater, and stormwater) systems require detailed design at neighborhood scale, not at the city scale.
- Fifth, decisions made at the neighborhood scale are highly pertinent to quality of life. [21]

#### 2.2.1. Defining A Sustainable Neighbourhood

A sustainable community is defined not only by its walkability. Which reduces reliance on motorized transportation. A sustainable community is one of that relies mostly on-site renewable energy sources and closes water, wastewater, and solid waste cycles within itself, reducing environmental impact and increasing resilience. A pleasant place to live, a sustainable neighborhood emphasizes social fairness, employment, and a sense of community.


*Figure 13 Definitons of Sustainable Neigborhood [21]*

### 2.2.2. Features Of A Sustainable Neighborhood

People want to live in a sustainable neighborhood which provides benefits in terms of socially, environmentally, economically, healthy and safely. In this case, sustainable neighborhood can characterized by:

a. Adequate space for streets and an efficient street network and give priority to walking, cycling and transit
b. Encourage energy efficiency and provide required energy demands
c. Promote efficient use of resources
d. Social mix
e. Neighborhood should be socially cohesive and diverse, with a mix of housing types and employment opportunities

When all futures are combined, the neighborhood scale structure is shaped with main characteristics. To complete the picture, features related to energy and materials, to water and waste must also be added (see Figure below), to encompass the metabolism of the whole neighborhood, as also will discuss in the next sections.

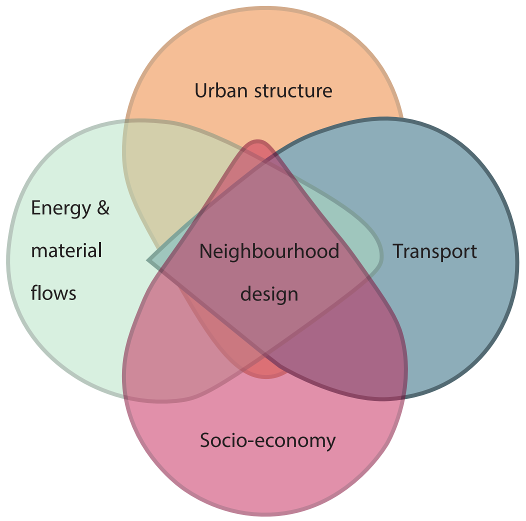



*Figure 14 Integrated Design Components of A Sustainable Neighborhood [21]*

### 2.2.3. Integrated Neighborhood Design

The realization of a sustainable neighborhood relies on a multifaceted and integrated design approach. Infrastructures are usually designed independently by specialists in the individual areas (e.g., transportation, water distribution, wastewater treatment, or building design), without any mutual interaction.

A successful neighborhood systems integration requires strengthening the synergies and interconnections between existing subsystems of a city in an effort to add value to the whole urban system. [21] [22]

Sustainable neighborhood design, on the other hand, necessitates the understanding of such mutual interactions, i.e. a different, integrated, design process in which  the infrastructure systems are designed as a whole, as well as the connections between the neighborhood and the larger urban region, as several design constraints have roots beyond the neighborhood scale.



Neighborhoods do not exist in isolation, they are part of metropolitan system which they are connected. Sustainable neighborhood design is a holistic concept requiring the integrated design of energy, transportation, water, and building infrastructures, as well as urban greening; but however it is not all.

An ideal solution must also set target for social equity and economic viability, and both must be considered as part of the sustainable neighborhood design process,  which should promote social inclusion and economic activities, while keeping in mind that urban infrastructures last for decades, and so their economic viability cannot be evaluated in short time period.

A multidisciplinary design team is required to create such a neighborhood. In addition to architects and urban designers, it requires also the participation of landscape architects, engineers, urban planners, ecologists, bacteriologists, transportation planners, physicists, psychologists, sociologists, economics, and other specialists.

### 2.2.4. New Model Of Urban Metabolism

It is required to develop a new model of urban metabolism that minimizes energy resource consumption while also reducing waste creation. [21]

A sustainable neighborhood, as we see in the figure below, must minimize dependence of input flows by maximizing reliance on local, small-scale, reliable energy and food production, as well as maximizing reuse/recycling of water and commodities.

This entails: decentralized energy production, primarily from renewable energy sources , combined with energy efficient buildings and appliances; increased efficiency of the transportation system for goods and people, replacing  private car mobility with public transportation, car sharing, bicycles and walking; increasing energy production from wastewater and reduction of emissions due to non-renewable energy sources.


*Figure 15 Sustainable Physical Urban Metabolism Circular [21]*

### 2.2.5. From "What " To "How"

When the information needed related to "what sustainability", there are a lot of literature and guidelines. But when it comes to "how", it is really important process to create most suitable solutions. The main reason for this is that the combination of all requirements of sustainability in design because of integration all like energy production and energy demand balance, neighborhood and city design, green areas, water and waste systems. What appears to be the best choice if the subsystem is considered in isolation may not be (and usually is not) the best when the subsystem is treated as a part of the whole system, as it affects other subsystems and is affected by them.

Most of the time, the energy aspects are left to someone during the creation of building design which affects neighborhood design scale. In this case, to cover these needs cost to people much more than first time. The realization of the new building design must involve energy aspects to know how energy sustainability buildings design.

It is time to realize that the aim of the neighborhood design is sustainability, which implies the maximization of energy self-sufficiency with renewable resources, efficient use of energy and water, decentralized energy, water and waste systems, minimization of motorized mobility, and so on. Decentralized energy, water and waste infrastructures have a significant impact on urban form and structure, as it has mobility, and vice versa.

### 2.2.6. Sustainable Neighbourhood Aims

A sustainable neighborhood is a neighborhood whose design integrates into a holistic vision the following aims:

• Climate responsiveness and context; finding out what the unique site constraints, climatic conditions and opportunities are

• Renewable energy for zero green house gas emissions; creating self-sufficient on site energy producer buildings, finding out how energy can be generated and supplier emission-free and how to minimize energy demand in the buildings and transport.

• Zero-waste; to create closed loop eco system in neighborhood scale, finding out how to turn waste into a resource.

• Water cycle; creating urban water management and high-water quality, finding out how to promote rainwater collection, wastewater recycling and storm water harvesting techniques and trying to obtain energy from wastewater.

• Landscape, gardens and urban biodiversity; integrating landscapes, urban parks and gardens and urban agriculture to maximize biodiversity and to minimize the urban heat island effect.

• Sustainable transport and good public space; finding out how can we get people out of their cars, to walk, to cycle and use public transportation.

• Local and sustainable materials with less embodied energy; finding out what kind of materials are locally available.

• Livability, healthy communities and mixed-use programs; finding out how urban design recognizes the need for affordable housing to ensure a vibrant mix of society and multi-functional mixed use programs. Land use development patterns are the key to sustainability. A compact, mixed use city delivers more social sustainability and social inclusion.

• Local food and short supply chains; finding out which strategies can be applied to grow food locally in gardens and in small spaces in the nieghborhood.

A neighborhood designed according to these ten aims is not only a sustainable neighborhood, but it is also resilient, as it incorporates the three main elements of resilience: efficiency, diversity and redundancy It is also a neighborhood capable of creating employment, because of the economic activities generated.

These all aims creates mutual dependencies among many disciplines to create building environment in neighborhood scale. In figure below, there is the flow for neighborhood scale which shows dependencies between all dimensions of sustainability design.



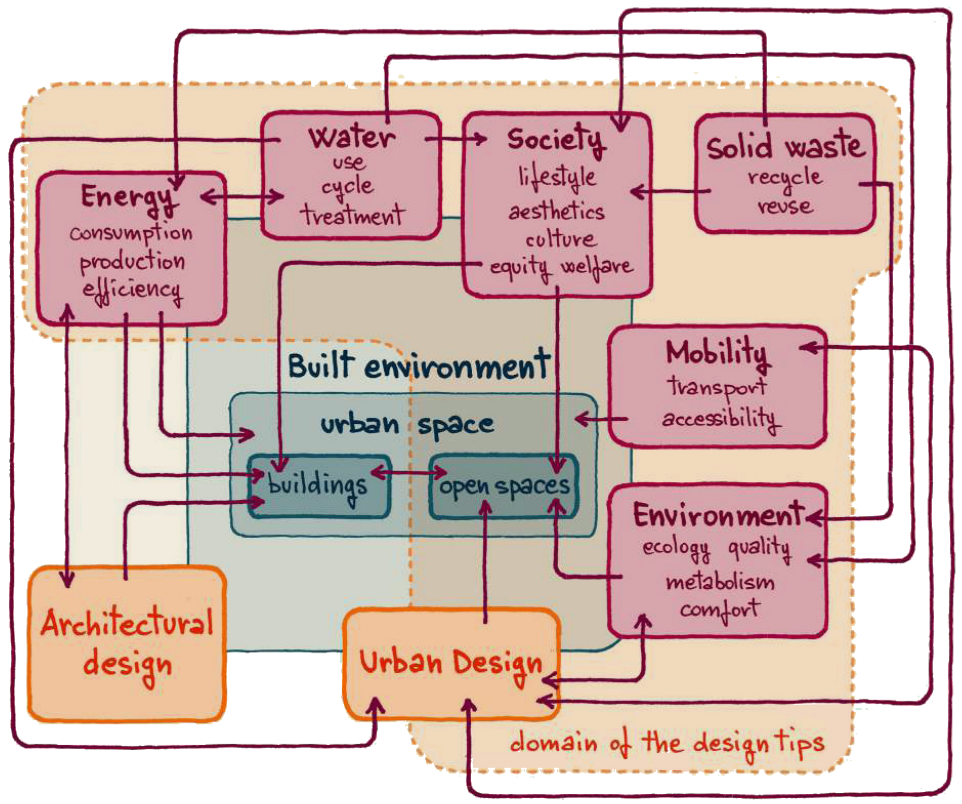



*Figure 16 The Spatial Dimension of The Built Environment-and The Urban Space in Particular-Collects Inputs from Different Domains. The Mutual Dependencies Among Disciplines, Buildings and Open Spaces Define The Complexity of The Work [21]*

### 2.2.7. Design For A Sustainable Neighborhood

To reach the target of sustainability design and energy aims, which means also creating self sufficient energy building environment, firstly, minimizing the amount of entropy generated by urban metabolic process and enabling the reduction of the negentropy flow entering the system without impairing its function by maximizing its thermodynamics efficiency.

The fulfilment of this aim involves several combined actions, namely:

• Minimize energy demand of buildings
• Minimize energy demand for transport
• Maximize efficiency of energy conversion technologies
• Fulfil the remaining energy consumption with renewable energy sources
• Optimise the water cycle
• Enhance solid waste reuse and recycle
• Close energy, water and waste cycles on site
• Minimize indirect GHG emissions [21]

As discussed also during the literature part of the thesis, sustainable energy and building design requires some performance to obtain the design response. In the figure below, performance requirements and design responses flows are demonstrated.

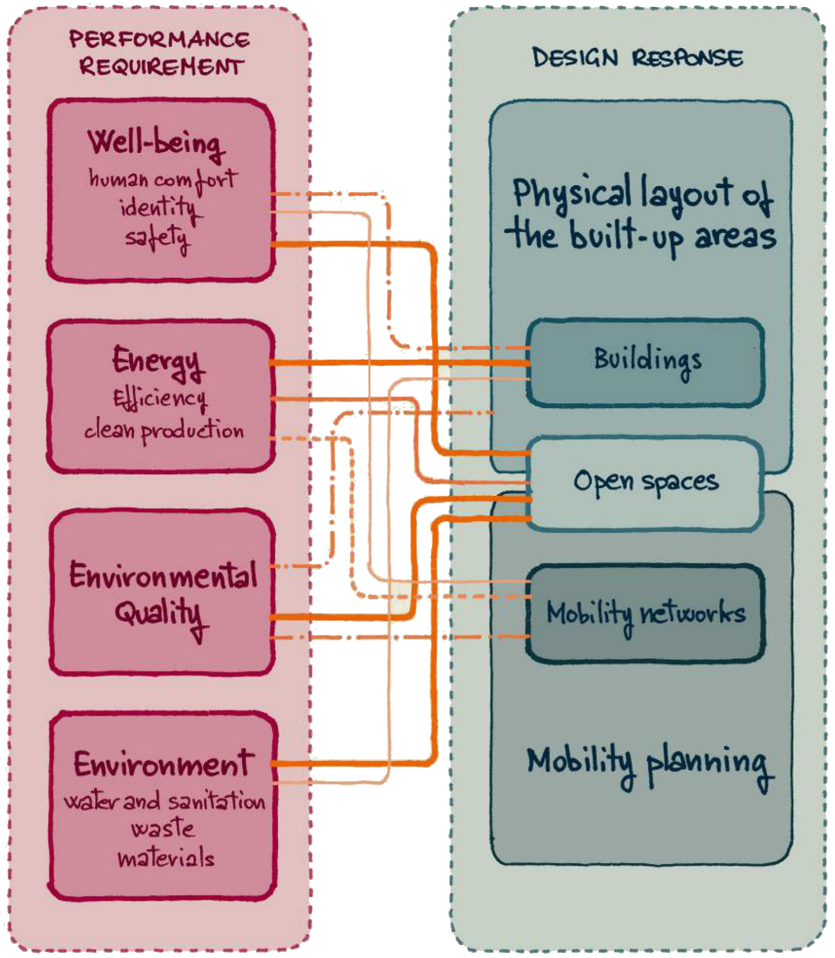



*Figure 17 The Interplay Between Performance Requirements And Design Response Of Different Domains Of The Built Environment [21]*

#### 2.2.7.1. Minimize Energy Demand In Buildings By Means Of Climate Responsive Urban Neigborhood Design

As buildings are main contributor to greenhouse gas emissions, it is important to assess the performance of existing buildings and assist the design of new suitable buildings through building energy simulation. During simulations, the climate measurements are used. However, different building forms and architecture have big impact to neighborhood scale microclimate parameters. [23]

Buildings require energy for heating and cooling, the generation of hot water, lighting, and home appliances. The usage of energy for hot water production and residential appliances is determined by behavior of the user and it is beyond the control of the urban neighborhood designer. Energy for heating, cooling and lighting, on the other hand, depends significantly on the urban designer, as the amount of energy required, i.e. the energy demand for obtaining thermal and visual comfort, depends not only on building design, but also on the capability to control local climate and microclimates with appropriate neighborhood design, as the more uncomfortable it is outdoors, the more uncomfortable it is indoors, and the more energy is required for heating or cooling.

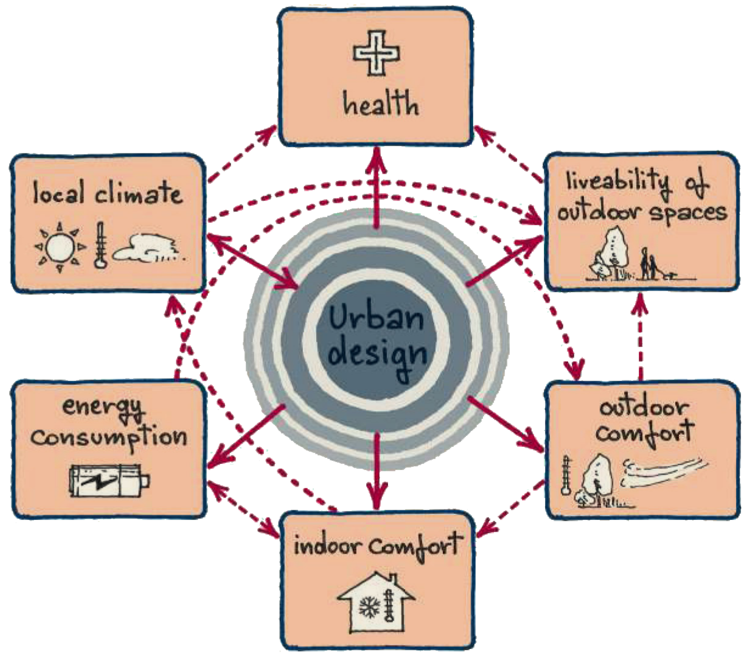



*Figure 18 Complex Interactions Between Factors In Urban Design [21]*

Controlling local climate and microclimates, in turn, has an impact on the health of residents and the livability of neighborhood. Given the complexity of the interactions between urban design, local climate, outdoor and indoor thermal comfort, energy consumption, environmental impact, health and livability of outdoor spaces (see figure above) and the importance of local climate control, a basic knowledge of urban climatology and thermal comfort principles is necessary for the urban designer, whose task is to design the urban layout in such a way as to create comfortable outdoor conditions through an appropriate control of energy balances on three levels: building, street delimited by buildings (canyon), neighborhood (see figure below).

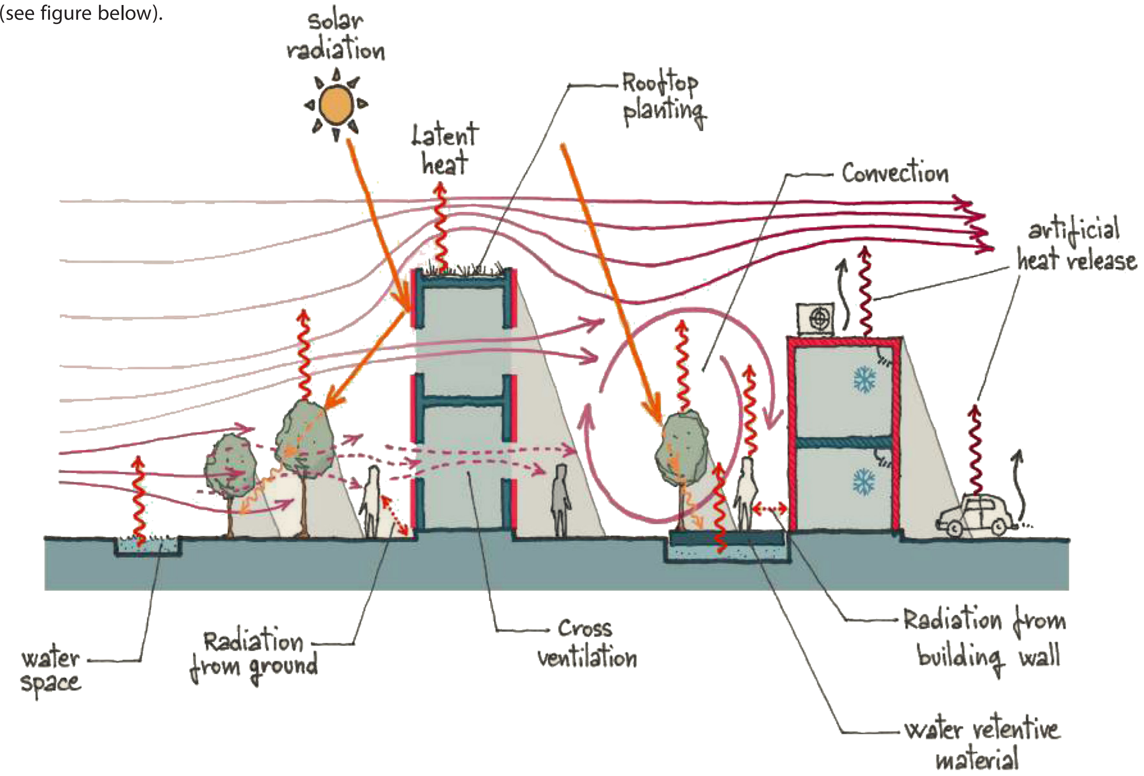



*Figure 19 The Urban Thermal Environment Needs A Balanced Understanding Of Air Temperature, Solar And Surface Radiation And Wind [21]*

Climate responsive urban design is the prerequisite for sustainable urban development: its aim is to enhance outdoor comfort, thus reducing the need for heating and cooling in buildings.

At the neighborhood scale, climate responsive urban neighborhood design is most effective method where the geometry of building areas can be manipulated to enhance shadows, where the materials used for buildings and streets, as well as their color, must be carefully chosen to maximize albedo and optimize thermal mass and where the appropriate control of street orientation and green areas can lead to more comfortable outdoor conditions.

The primary aim of energy-efficient urban design is to minimize heat gains and to maximize heat losses. This implies controlling the short and longwave radiation in urban canyons, as the goal should be to find an urban geometry that is self-shading, using an intelligent combination of building heights and geometry, if necessary complemented with horizontal shading elements such as canopies, awnings and urban vegetation, and favoring air movements, by manipulating the geometry and relative positions of the buildings according to the prevailing winds. In light of the above, the main factors to control in climate responsive building design are (see figure below):

- The three-dimensional volume formed by buildings that abut streets (so called 'canyon geometry 'effect), to control solar radiation;
- The thermal properties of urban surfaces, i.e. heat storage and reflection of solar radiation;
- The anthropogenic heat;
- The evapotranspiration, by means of green areas;
- The wind patterns. [21]

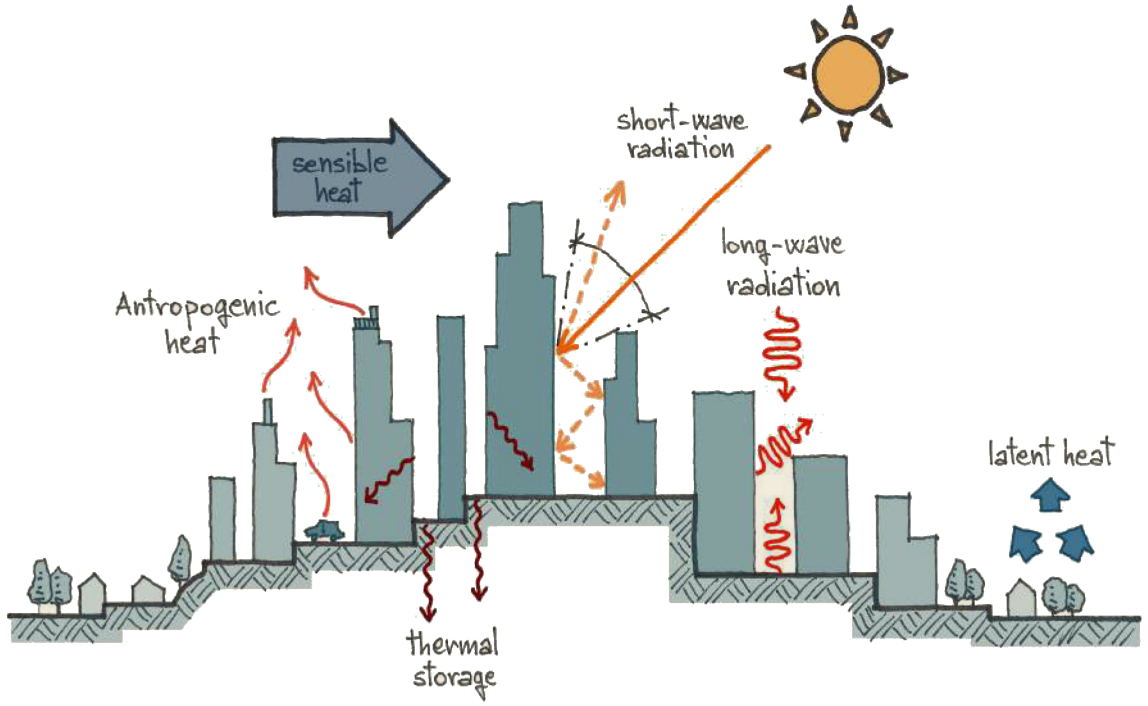



*Figure 20 Urban Surface Energy Budget [21]*



#### 2.2.7.1.1. Climate, Comfort And Energy

Climates on the Earth can be classified at different scales. A first classification is based on "macroclimates", as in figure below. Macroclimate is the climate which contains relatively large geographic area. [24] When we look more closely at a macroclimate, a more detailed classification appears, and we can see that the area is subdivided into meso-climates.

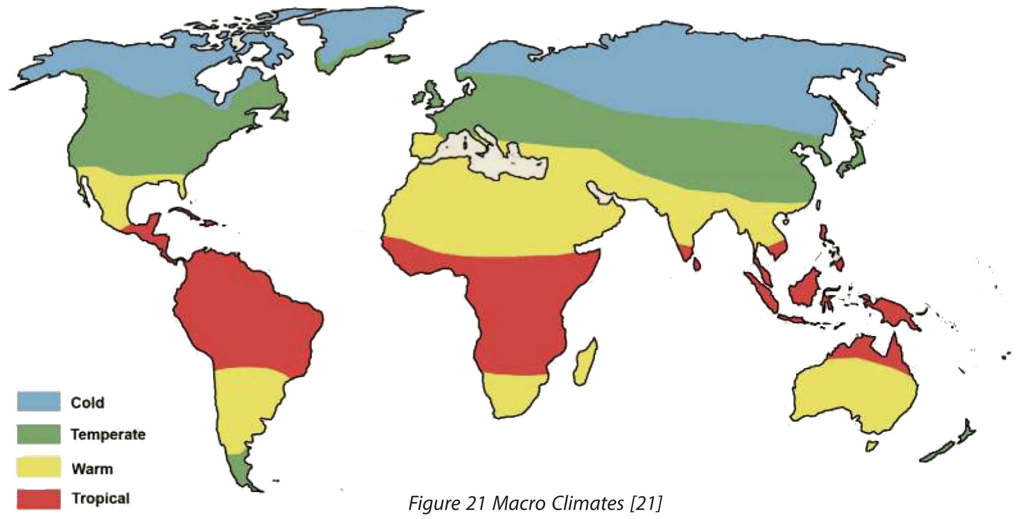



*Figure 21 Macro Climates [21]*

The meso-climate is the average of a small set of climatic variables. As a result, a closer examination of one of the meso-climates reveals a variety of local climates, each resulting from various ground surface properties such as location, exposure, color, heat capacity, moisture contect, soil permeability, and roughness of the ground surface. (see Figure below as an example).

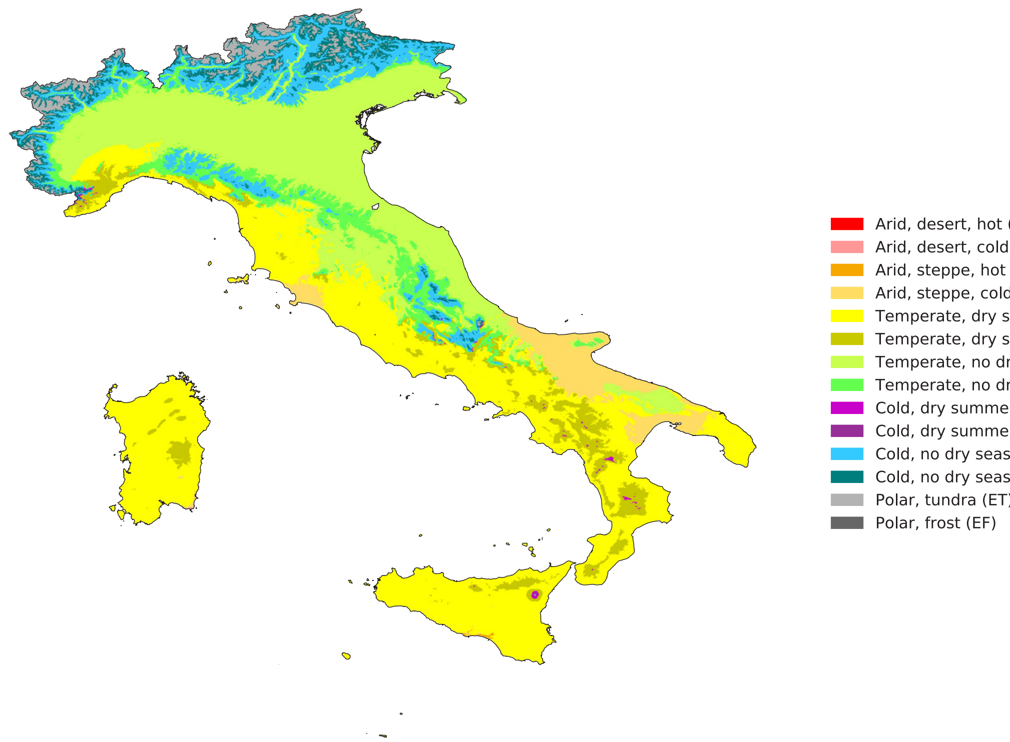



*Figure 22 Meso Climates, Köppen-Geiger climate classification map for Italy (1980-2016)* [25]

Local climate is the climate of area characterized by observation at one or several stations in the given area and generally related to an area ranging from a few square meters to a few hectares, such as the side of a hill, a valley, or a portion of the built area. [21] [26]

It is characterized by more or less marked changes in environmental parameters with respect to the surrounding context (temperature differences, relative humidity, wind, sunshine, etc.), due to the specificity of the places defined by topography, urban morphology, orientation, nature of materials, proximity to water, presence or absence of vegetation, etc. The anthropogenic heat loads (traffic, heating, and cooling of buildings, etc.) may also have a significant impact.

Finally, within the same local climate, a number of microclimates can be found: surface and air temperatures may vary by several degrees in very short distances. Microclimate is the climate environment inside the given area , determined by special microclimatic observations. [26]

Outdoor comfort, which is determined by the local climate in a given location, determines indoor comfort, which is the driver of energy consumption due to the need for heating or cooling. Consequently, there is a link between local climate and CO2 emissions.

On the other hand, local climate, and its microclimates, is strongly influenced by urban design, as evidenced by the so-called urban heat island, and by the common experience that there may be hotter or cooler spots or areas in the same neighborhood, or around the same building. Thus, there is a nexus between urban design and CO2 emissions. [21]

Climatic analysis must be a component of urban design process, and it should be done as early as possible. In this case, it is important to include the urban climatologists to the design team.

#### 2.2.7.1.1.1. Urban Heat Island (UHI)

An Urban heat islands is an urban area or metropolitan area that is significantly warmer than its surrounding rural areas due to human activities and refer to the higher temperatures in developed areas compared to more rural surroundings. [21] [27]

Air temperature depends significantly on that of the surface below it, and urbanized land has a greater capacity to absorb solar radiation because of the morphological configuration and characteristics of the materials it is made of; thus, these surfaces are hotter than nonurbanized ones, and the temperature is higher.

The majority of buildings in cities are made of concrete and other man-made elements. They store more heating during the day because they have a higher thermal capacity than the natural environment. The heat stored will raise overnight urban temperatures, particularly if tall buildings hide the city's sky view, limiting the heat's release back to atmosphere.

Furthermore, vegetation has little or no cooling effect, and there is heat from mechanical cooling of buildings and because of car traffics. As a result, temperatures in metropolitan areas are several degrees higher than in rural areas, especially during the night. (Figure below)



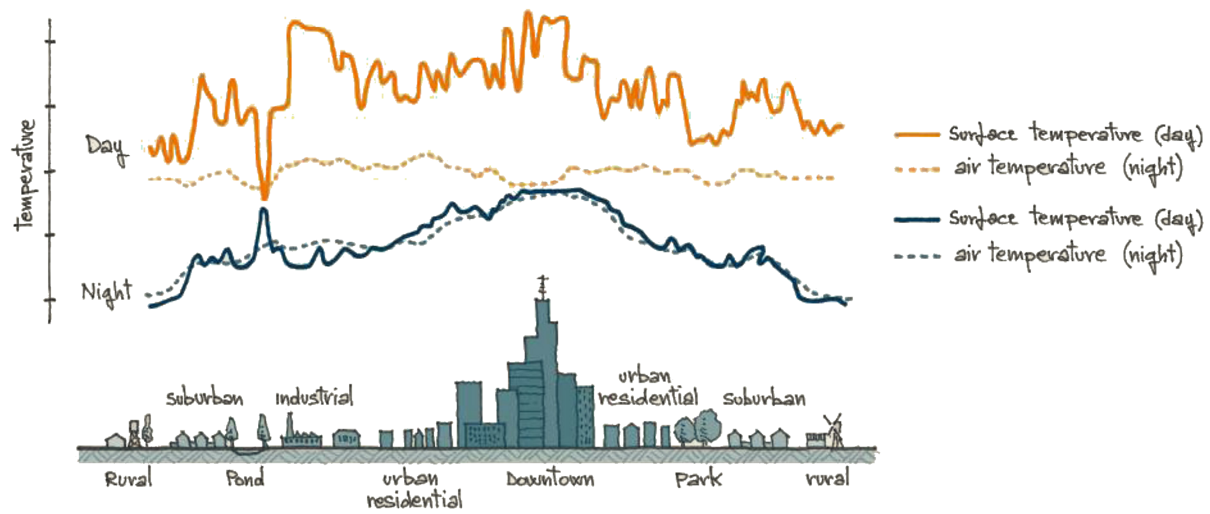



*Figure 23 Surface And Atmospheric Temperatures Vary Over Different Land Use Areas. Surface Temperatures Vary More Than Air Temperatures During The Day, Far Less During The Night. The Surface Temperatures Over The Pond, Almost The Same Day And Night, Show The Effect [21]*

#### 2.2.7.1.1.2. Impact of outdoor thermal comfort on urban energy consumption

One of a building's functions should be to adjust unfavorable external environmental conditions in order to provide a livable indoor environment. The level of the required alteration is mostly determined by the distance between the outdoor environmental conditions and the requirements required to achieve a comfortable state.

As a result, the outside climatic factors that determine thermal experience should be regulated first by urban design, because they are the primary drivers of indoor thermal sensation. The more uncomfortable the outdoor environment is, the more uncomfortable the indoor environment will be, or the higher the energy usage will be if cooling or heating is offered.

The impact of outdoor thermal comfort on energy consumption at the urban or neighborhood scale is not limited to its relationship with indoor comfort, as pleasant urban environments can encourage the use of more environmentally friendly modes of transportation, such as walking, cycling, and public transportation.

Furthermore, outdoor thermal comfort has a direct impact on people's health, behavior, and use of outdoor spaces, and can help to promote social, economic, and cultural life. As a result, the urban microclimate and its consequences for thermal comfort should be given top consideration in a sustainable urban design approach.

### 2.2.7.1.2. Solar Exposure: Street Width And Orientation; Building Height And Shape; Materials

To develop energy efficient measures in new buildings, it is necessary to know the levels of solar radiation reaching every piece of the building which could be used to install solar panels or thermal connectors. Additionally, solar radiation can be used for the estimation of natural lighting on its window and consequently, to guarantee solar rights, especially in cities with a great presence of skyscrapers. Daylight also has a positive influence on the human health and their behaviors, and it contributes to improving the indoor climate, increasing thermal comfort, consequently, reducing the energy demand of a dwelling. [28]

Easy way to take advantage of solar radiation is designing the buildings by using passive solar radiation methods. The passive design is based upon climate considerations, attempts to control comfort (heating and cooling) without consuming fuels. Easiest way to control heat gain and heat loss and air flow is to use proper orientation and shape of the building. This actions helps also to maximize the use of free solar energy for heating and lighting and apply a free natural ventilation for building cooling. [29] So this can be achieved by finding such a building solid geometry to reduce its overheating.

Solar radiation in neighborhood scale is also depends on street design and choosing right material by additionally to building shape and geometry. The design of neighborhood area ant its building shape affect all urban concept. Also parameter which obtaining in one neighborhood design but in different countries which have different type of climate surely will give different results to the designers. To explain better, the urban canyon become good example.

Part of the incident solar radiation reaches the bottom due to multiple reflections on canyon walls (see Figure below). It contributes to the heating of the canyon's floor, and additionally, the walls heat up due to the radiant energy absorbed. Ultimately, the solar radiation heats the air and increases the mean radiant temperature.

The design of urban canyons plays an important role in creating the urban climate. Urban canyons are characterized by their height/ width (H/W) and length/width (L/W) ratios and by their orientation; the aspect ratio H/W, in turn, affects the Sky View Factor11 (SVF) – as shown in Figure and the airflow. Therefore, street design influences both thermal comfort at pedestrian level and the global energy consumption of buildings. [21]

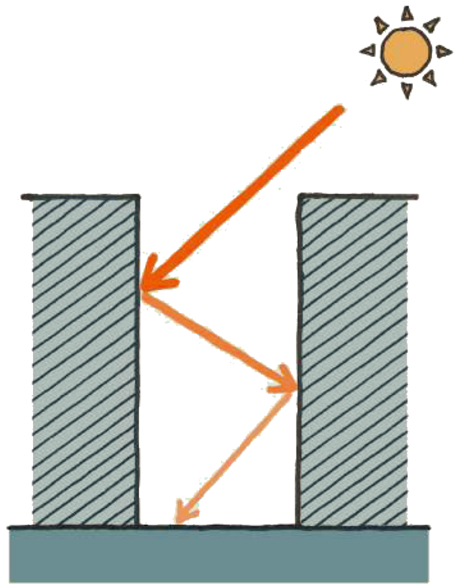


*Figure 24 Multiple Reflections On The Canyon Walls [21]*

The narrower and deeper the canyon, i.e. the higher the value of the aspect ratio (building height/street width, H/W), it can take more reflections and the more radiant energy. Depends on the albedo of the wall's surface also the amount of energy reflection can change.

The higher the absorption coefficient (= the lower the albedo), the more the radiant energy is absorbed by the upper part of wall and the lower the amount reaching the bottom of the canyon. [21]

In this case we can comment that low albedo walls should improve the streets thermal comfort. But there will be drawback also. The absorbed energy is partly conveyed to the inside of the structure and it will cause to indoor discomfort.



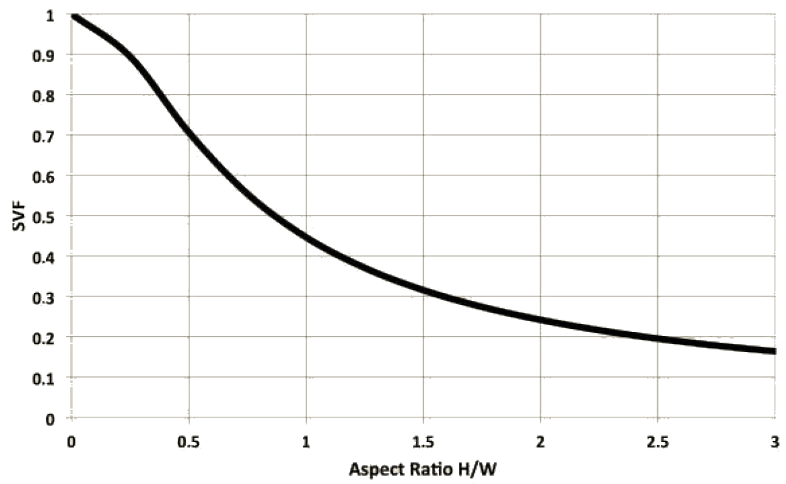



*Figure 25 SVF As A Function Of H/W In The Center Of The Floor Of A Symmetrical Semi-Infinite [21]*

H/W ratio also affects the Sky View Factor, thus the amount of long-wave radiation emitted towards the sky, which in turn affects the overall energy balance of the canyon. [21]

In a street in which H/W is high, the ground surface and the lower portions of walls may remain in shade for part of the day (how long it depends on the latitude and on the orientation) [21], as a result, they are mostly exposed to diffuse radiation from a small portion of the sky vault which visible from ground level. If ground and walls are not heated up, the longwave emission towards the sky can be negligible and the air at ground level remains cooler than it would be in spaces with higher solar exposure.

The physical properties of urban canyon surfaces have a significant effect on the magnitude and the time distribution of the energy fluxes absorbed and emitted, as they depend on the absorption coefficient of the surface of the materials, i.e. their albedo. [21]

The effect of high walls and ground albedo on thermal comfort and energy consumption is comparable to that of shading, so surface temperature do not rise significantly and neither do the near-surface air temperatures or mean radiant temperatures. The mean radiant temperature is an important metric parameter because the effect of hot pavement on pedestrian comfort is not only affected because of heated up air above it but also long-wave radiation emitted by both the pavement and the canyon walls.

Thus, to prevent or reduce the temperature increase of the surfaces, there are two strategies:

- increase their shading
- increase their albedo. [21]

High albedo gives indoor comfort but when we think H/W ratio, ti is not good so much high albedo in terms of outdoor comfort.

The materials' conductivity and thermal capacity are also important. The thermal mass of the urban canyon behaves similarly to the thermal mass of buildings. The temperature variations amplitude is a function of the quantity of mass capable of storing heat, and peak temperatures are decreased and delayed.

### 2.2.7.1.3. Creating shade in open spaces

Outdoor places with shade are more livable. Sidewalks are the most common and thus important open spaces in the streets. They are not only transit zones, but also they are important for their various potential uses, such as small aggregations or shopping (see figure below). In general, shade is a critical requirement for neighborhood design.

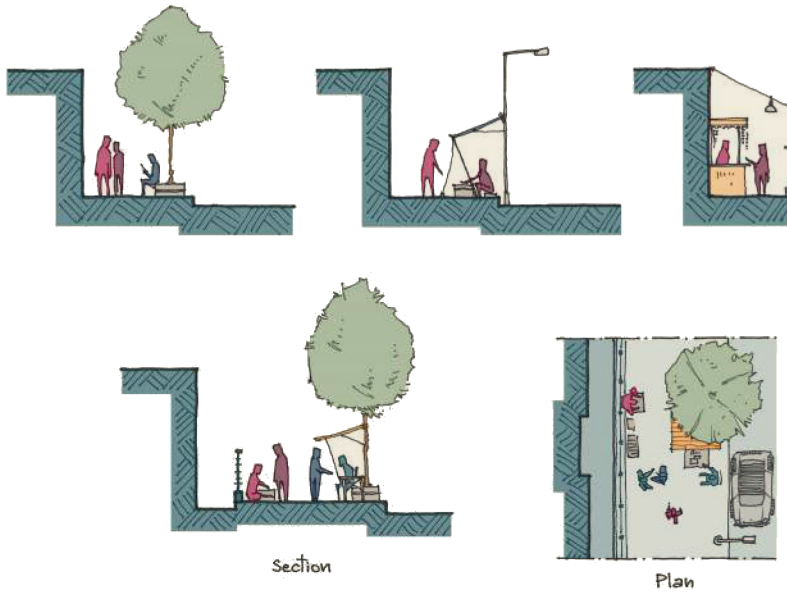



*Figure 26 Multiple Used Of Sidewalks [21]*

Additionally, Arcades, which are sometimes the only way to shade sidewalks in the streets, are another option for having shading partly or totally during the day time (see figure below).

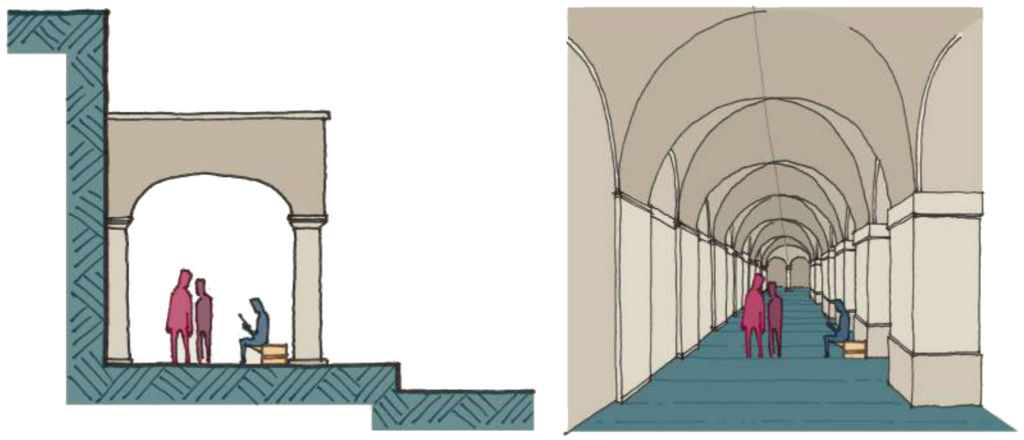


*Figure 27 Arcades [21]*



### 2.2.7.2. Air Movement

Air movement provide a major opportunity for buildings in that they enhance both energy efficiency and occupant comfort. Additionally, it greatly affects outdoor and indoor thermal comfort, as well as the energy exchanges of the buildings. [21] [30] To examine the air movement in the neighborhood and urban areas, CFD analysis can be used. (see figure below)

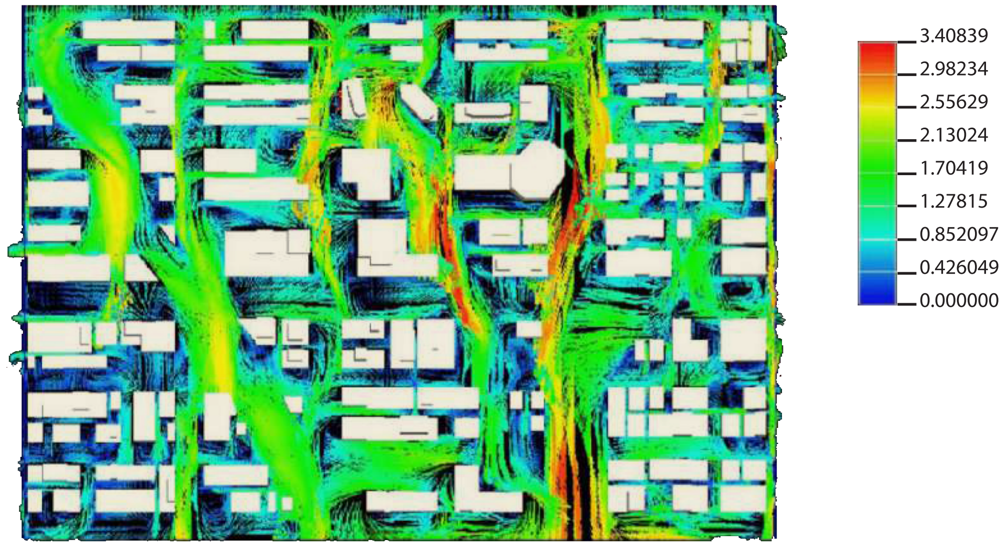



*Figure 28 Example Of CFD Analysis Of Wind Pattern In Urban Context [21]*

Studies on wind behavior in an urban context show that effective ventilation of urban streets may be promoted by applying the following general guidelines:

- Avoid uniformity in building height, canyon width and canyon length; uniformity reduces eddies, thus ventilation;
- Keep the length of street canyons as short as is practical, to promote flushing at street intersections by corner eddies. [21]

We can imagine that, in hot climates the wind flows needed much more than cold climates. Breezeways can be in the form of roads, open spaces and low-rise building corridors through which air reaches the inner parts of urbanized areas (Figure below). [21]

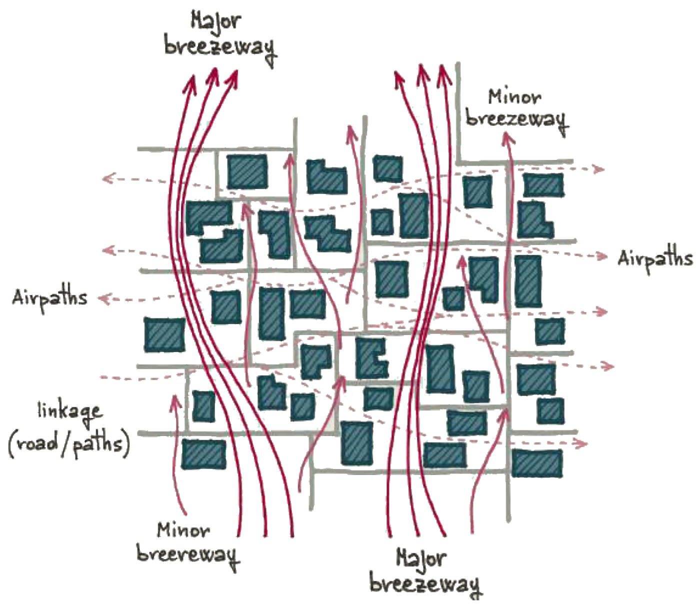



*Figure 29 Favoring Breezeways [21]*

To keep people in comfort and keep energy saving in the buildings, the distance between each building in the neighborhood area is important to use actively the air movement.

The staggered design of the blocks allows the wind to pass through the gaps between the blocks in the front row to the blocks behind them. (see figure below)

Studies carried out for Hong Kong (hot humid climate) lead to the following guidelines: [21]

- Permeability equivalent to 20% to 33.3% is a good starting point for neighborhood design (Figure below);

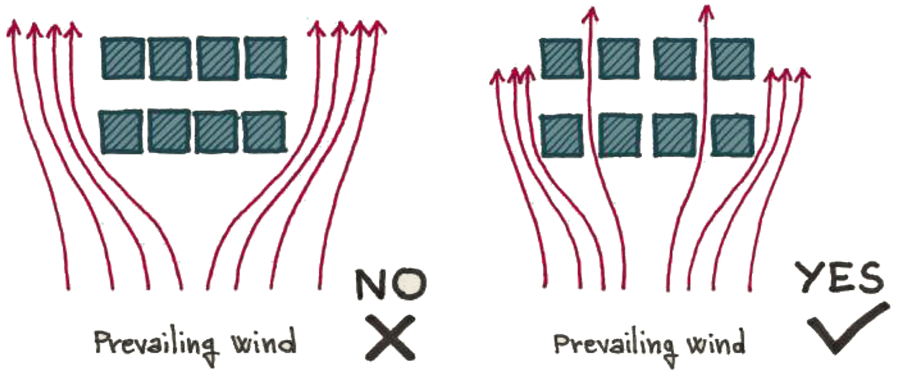



*Figure 30 Closely Packed Buildings Impede Air Flow [21]*

- Building height variation across the neighborhood and decreasing height towards the prevailing wind direction should be adopted to promote air movements (Figure below);

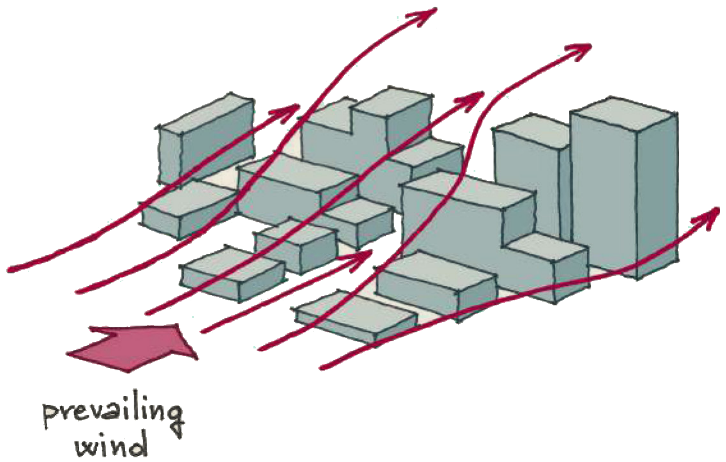



*Figure 31 Gradation Of Building Heights Helps Wind Deflection And Avoid Air Stagnation [21]*

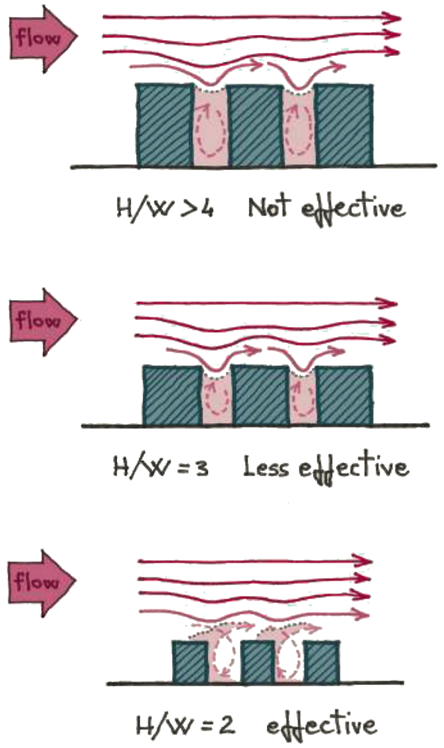



*Figure 32 Canyons That Are Too Narrow And Deep Reduce The Effectiveness Of Air Movement [21]*

- In canyons, aspect ratio H/W should not exceed the value of 3 (Figure 32), as excessive building heights reduce air movement;

- With high ground coverage it is important to consider measures such as building set back, so that the neighborhood average ground coverage can be lowered (Figure 33). Greening at ground level in these areas further improves the urban climate for pedestrian activities. A ground coverage < 70% is recommended;

- When a neighborhood is by a waterfront, properly orientated air paths connecting to the waterfront or open spaces are effective in bringing air ventilation into it (Figure 34);

- Open spaces in urban areas allow wind to flow into them and benefit pedestrians with air movement. In general, the dimensions of the open space should be no less than twice the average height of the surrounding buildings. This would create a height to width ratio < 0.5;

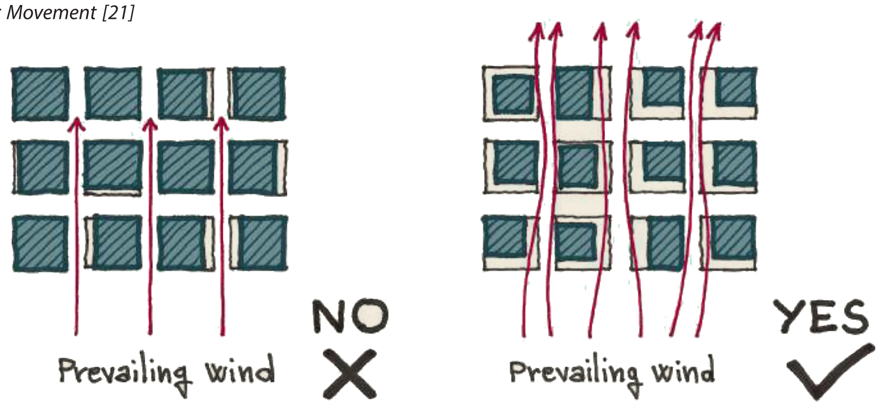



*Figure 33 Reduction Of Ground Coverage By Building Setback [21]*

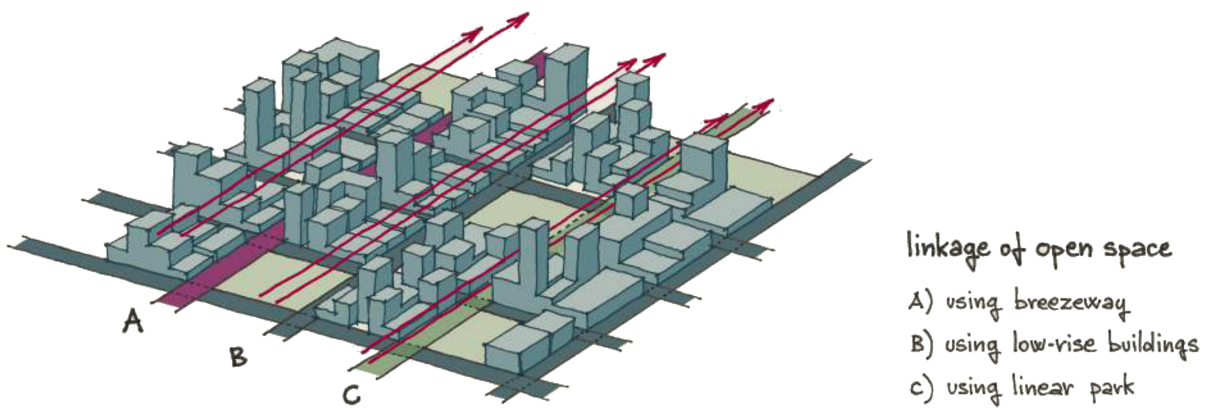



*Figure 34 Ways Of Creating Breezeways And Air Paths In The Neighborhood [21]*

• Where possible, open spaces may be linked and aligned in such a way as to form breezeways or ventilation corridors. Structures along breezeways/ventilation corridors should be low-rise (Figure below);

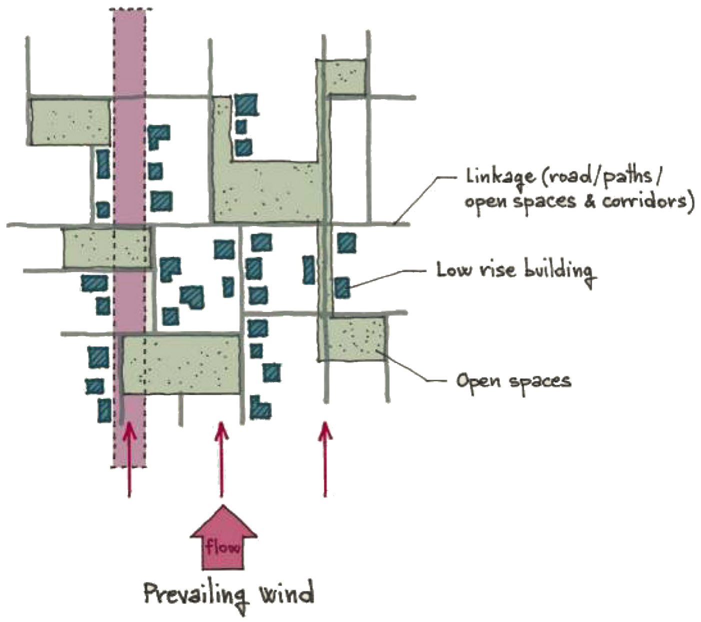



*Figure 35 Link Open Spaces To Form Ventilation Corridors [21]*

• A series of main streets/wide avenues should be aligned in parallel, or up to 30 degrees to the prevailing wind direction, in order to maximize the penetration of the prevailing wind through the neighborhood (Figure 36). However, the optimum canyon orientation for wind exploitation (parallel to wind direction) should also be carefully considered in relation to these additional conditions:

• Best canyon orientation from the point of view of solar exposure;

• Optimum wind direction for effective indoor ventilation.

In upland climates, air movement is beneficial during the hot season, but should be minimized during the cool one. This could be obtained by grading the height of the buildings, with the higher ones acting as a protective barrier against the cool winds, taking into account the direction from which they blow. [21]

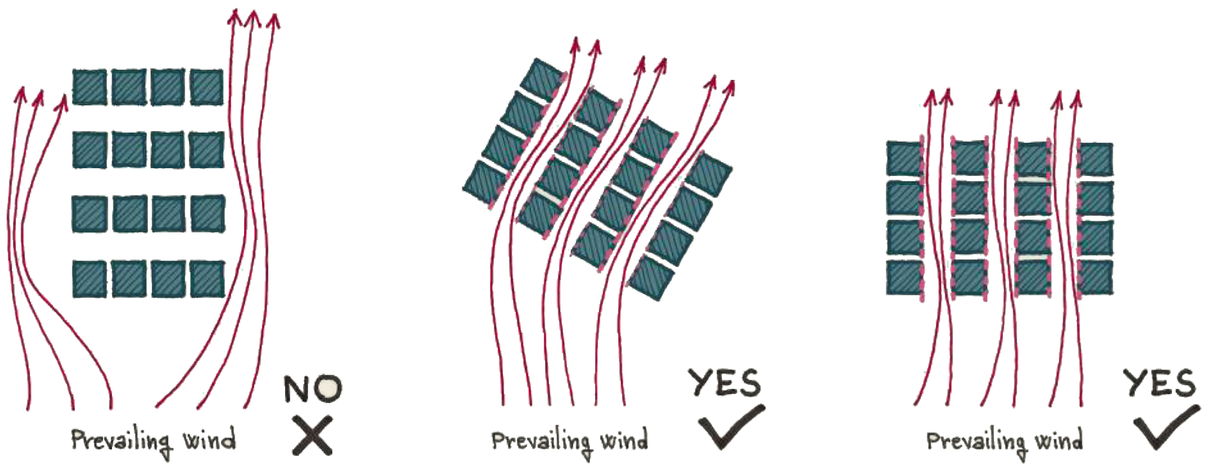



*Figure 36 Orientation Of Street Grids [21]*



#### 2.2.7.3. Green Spaces

Green spaces is always what people look for all the time. Sometimes, people wants to see green spaces for their meditation, relaxation and health, and sometimes, they want them for a walk, play with their children. But there are also architectural aims of green spaces which also can called vegetation.

Vegetation affects the energy exchanges between buildings and the environment in some ways. In case of presence of green spaces in neighborhood or urban areas, plants will release less sensible heat to the adjacent air because of evapotranspiration. In this case ambient temperatures will be more cooler than less green spaces areas. Then, the cooler surface will not emit much infrared radiation, thus reducing the radiant load on buildings surfaces. On the other hand, vegetation provides shading to the area which affects the solar heat load on building surface. In this case, the solar heat load on buildings surface will significantly reduced.

Not all the effects induced by vegetation are positive, in relation to the comfort and energy consumption of buildings. For example, vegetation can reduce solar gains but also net long wave losses at night. Also their presence will reduce the wind speed between the buildings which is restricting potential for natural ventilation indoors and weaking convective exchanges. The overall effect of vegetation, however, is always largely positive.

Studies carried out in Singapore (School of Architecture (b), NG 2012) (hot humid climate) showed that a 0.8 °C reduction in ambient air temperature is to be expected for a 30% ratio of green to built area (Figure below). [21]

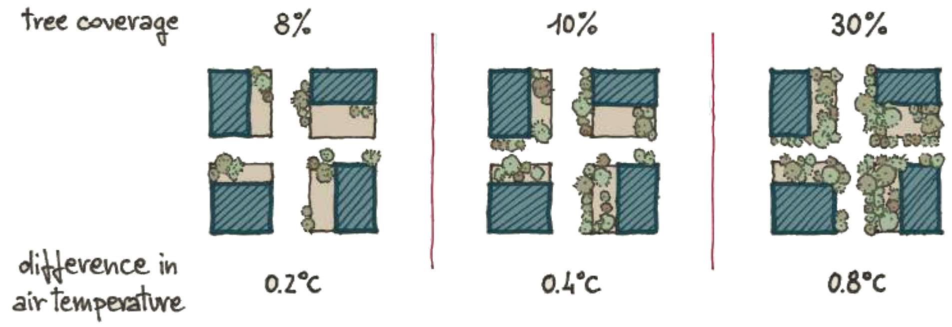



*Figure 37 Simulations Carried Out For Hong Kong [21]*

##### 2.2.7.3.1. Urban Parks And Green Spots

Air and surface temperature in parks may be significantly lower than in the surrounding built-up area, creating what is called a "park cool island". [21] The presence or absence of shade, its albedo, water availability, and the thermal properties of the underlying soil all influence the surface temperature during the day, resulting in a classification of urban parks based on the type of vegetation and how it is arranged: grass, grass with tree borders, savannah (grass with isolated trees), garden, forest, and multi-use.

The park cool island may become a "park warm island" at night, as trees block nocturnal long-wave radiative heat losses from the underlying and surrounding surfaces by blocking part of the sky, and moisture increases the thermal capacity of the soil, resulting in a slower rate of surface temperature drop. In relation to the volume and size of trees and the extent of irrigation, urban parks may be warmer at night than built-up regions.

In consideration of the cooling effect of green areas and of the social value of urban parks and green spots, 15- 20% of the neighborhood land should be allocated to open green spaces. [21]

### 2.2.7.3.2. Green Roofs And Green Walls

A vegetative layer developed on a rooftop is known as a green roof. Vegetation on a green roof, as elsewhere, shades surfaces and takes heat from the air by evapotranspiration. The temperature of the roof surface and the surrounding air is reduced by these two actions. (Figure below).


*Figure 38 Temperature Differences Between A Green And Conventional Roof* [21]

Green roofs are becoming more and more popular among architects. There are pros and cons in this practice:

• in an experimental study in Japan it was found that a bare concrete roof gave rise to a room temperature of nearly 40 °C, with ivy cover the room temperature dropped to 24-25 °C. However, the night-time cooling experienced by the bare concrete roof was slightly better than the ivy-covered roof;

• in Athens, Greece, indoor temperatures measured with and without a green roof in summer led to an estimate of a cooling load reduction of up to 48% in non-insulated buildings with night ventilation; but in a well-insulated building this reduction became negligible (less than 2% reduction). [21]

These findings imply that when calculating total benefits, the life-cycle cost of a green roof system should be considered, especially when compared to the life-cycle costs of well-insulated structures.

Green roofs also improve the surrounding air temperature on account of the cooling effect of evapotranspiration, provided that building-height-to-street-width (H/W) ratio is low (<< 1). When the ratio H/W is high (> 1, high density urban development) roof greening is ineffective for human thermal comfort near the ground. [21]

In addition to green roofs, another option is the green wall, sometimes referred to as living wall or vertical garden. These walls can involve placing trellises or cables in front of exterior walls and allowing vines to grow up them, or can be more elaborate, with plants actually incorporated into the wall. Green walls can be very effective for improving outdoor and indoor comfort in canyons with low H/W, as they combine the following benefits:

• they have low albedo (thus low reflected solar radiation towards the bottom of the canyon);

• they do not heat up because of evapotranspiration (thus the long-wave radiation emission is low);

• they shade the walls permanently (thus the heat flow through walls is small). The main drawback with green roofs and walls is the need for effective maintenance and for water, besides the high initial cost.

• Constructing nature-inclusive buildings with green roofs or living walls instead of non-natural materials is an effective and affordable way of climate change adaptation (see Figure below).



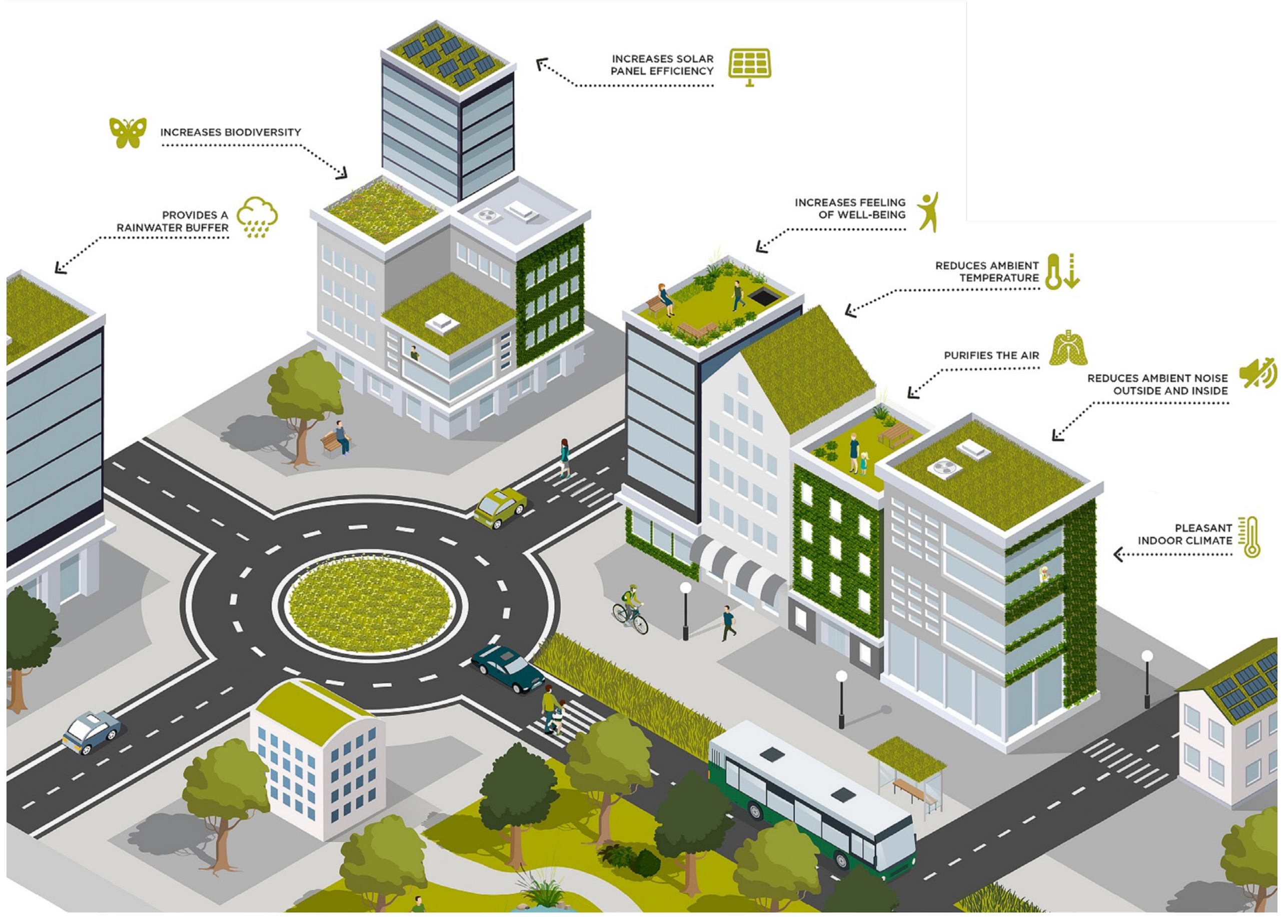



*Figure 39 Green Roofs And Living Walls Provide Many Advantages Within Urban Areas* [31]

### 2.2.7.3.3. Trees

Trees are one of the most critical factors which affects the microclimate of neighborhood and also energy characteristics of the buildings. There are some beneficial effect of trees on the microclimate. Due to trees, solar heat gains on a building's envelope and on urban surfaces, including human bodies, are lowered because of the shading they provide.

A building's long-wave exchanges are reduced because of the lower temperature of shaded surfaces. Also because of the evapotranspiration process, the dry-bulb temperatures are lowered.

Heat dissipation via transpiration depends on the water balance of the tree. A single large tree can transpire 450 liters of water per day, consuming 1000 MJ of heat energy to drive the evaporation process [21].

In the presence of unrestricted water, transpiration will cause substantial cooling. However, if water supply to the root system is restricted, it causes the closure of stomata, reducing the transpiration rate, thus the cooling capacity.

This explains why the effectiveness of trees as cooling agents in hot arid climates is usually lower than in hot humid ones, unless the appropriate quantity of water is provided. The use of trees as microclimate modulators in hot arid climates entails a very careful design of the water cycle.

Trees can improve the microclimate of streets, leading to improved outdoor and interior comfort as well as lower cooling energy use; nevertheless, there are some guidelines to follow in order to maximize their effectiveness:

- To avoid suppressing the ventilation canyon vortex system and corner eddies, tree crowns should not occupy considerable canyon volumes. It's especially important to leave enough distance between crowns and nearby walls.
- Trees should not be taller than the roof line, as this will reduce the amount of entrained above-roof air needed to ventilate the street canyon.
- The street is less obstructed by wide tree spacing, which allows rooftop flow to build vortices.
- Trees have a smaller effect in shallow canyons (H/ W<0.5) [21] than in deeper ones.

Tree shading is significantly more effective than shade provided by a solid shading component. The reason for this is that a canopy made of any material absorbs solar radiation on its upper surface, heats up, and both upper and lower surfaces emit long-wave radiation, the amount of which is determined by the component's superficial properties (spectral absorption and emissivity) as well as its insulation characteristics.

In any case, the lower surface will be hotter than air, releasing more long - wave radiation than the leaf crown, which is normally near to ambient air temperature. As a result, when a person or a building is shadowed by a dense tree crown, the energy received is lower than when shadowed by a surface of any substance.

Another quality of trees is their ability to sequester and store carbon in their trunks, leaves, and roots, acting as carbon sinks, so contributing to a reduction in GHG emissions.

Trees, however, have drawbacks. The most important, as shown below, are:

- they may act as obstacles to air movement, so decreasing the convective heat transfer for cooling urban structures;
- they restrict long-wave radiative heat losses of the ground, i.e. nocturnal cooling.


*Figure 40 Benefits of Urban Trees* [32]

#### 2.2.7.4. Urban Agriculture

Growing plants and raising animals in and around cities is referred to as urban and peri-urban agriculture. It is a "local food" system that offers urban people with a diverse range of horticultural crops grown within the city or in the surrounding.

Agriculture plots on city property are a unique type of urban greening. Even if they are less effective for cooling than trees with wide canopies or lawns, they can nevertheless contribute significantly to UHI mitigation and can be incorporated in greening initiatives with a triple dividend. The first is environmental:

- reduction GHG emissions as a result of lower air conditioning energy use due to their cooling effect;
- reduction of GHG emissions as they reduce the need to transport products into cities from distant rural areas, generating fuel savings, fewer carbon dioxide emissions and less air pollution;
- recycling of organic waste;
- recycling of appropriately treated wastewater, to be used for irrigation;
- replenishment of water tables, as rainwater can percolate through them;
- flooding mitigation.

The second dividend is socio-economic, deriving from the employment created, directly (farming; estimated at one job for every 110 m2 of cultivated land) and indirectly (sales, organic waste collection and treatment for compost production)18, plus the increase in food security. [21] The third dividend of urban agriculture relates to health: it provides foods that are rich sources of vitamins, minerals and Phyto-chemicals – essential for good health.

Organic waste recycling and compost production need a major commitment from the community, and can be more easily adopted at the neighborhood level if the benefits are directly linked.

#### 2.2.7.5. Pavements

Pavements, which are usually built of asphalt or concrete, cover a considerable percentage of a city's ground surface due to their low albedo.

On clear days, during the hours in which the sun is high in the sky, their surface can reach peak temperatures of up to 60-70 °C, as they absorb 95 to 65% of the solar radiation reaching them. [21]

The technique to reducing the heat island effect caused by paved surfaces originates from the use of permeable, or porous, paving in urban areas. (Figure below).

Permeable pavements, which were originally developed to control storm water, are also an efficient alternative for controlling urban energy balance. Porous asphalt applications, pervious concrete applications, permeable pavers, and grid pavements are examples of permeable pavement technologies that are meant to allow air, water, and water vapor into the spaces of their surface.

Water passes through the voids and into the soil or supporting materials below when wet. As the surface heats up, moisture evaporates slowly, taking heat away from the pavement and keeping it cool by evaporative cooling. Grass or low-lying vegetation can be found in some permeable pavement systems.

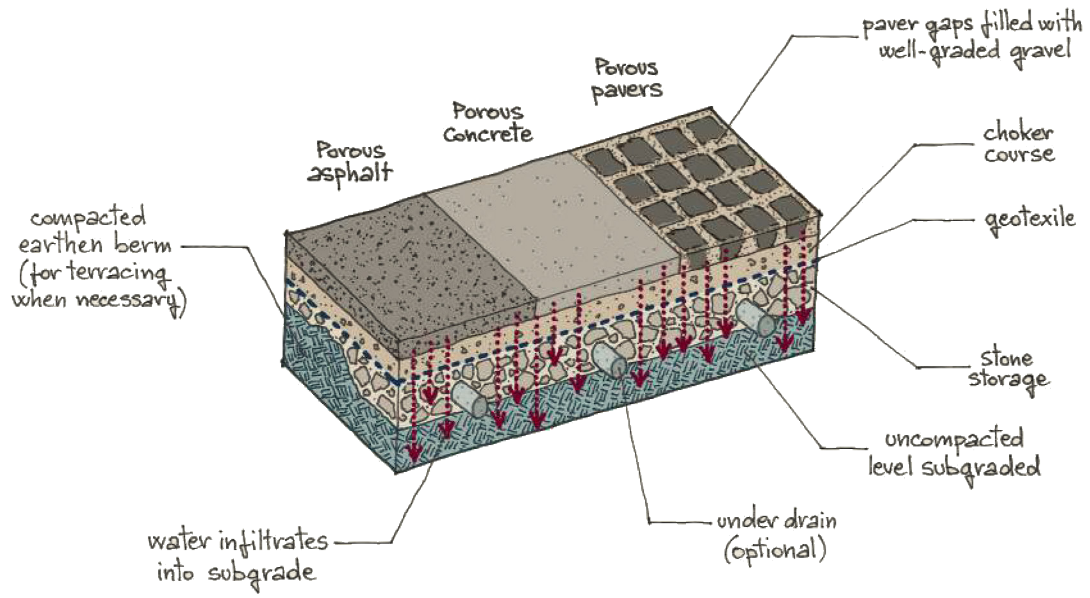



*Figure 41 Types Of Porous Pavements [21]*

#### 2.2.7.6. Cool Roofs

Traditional roofing materials have low solar reflectance (or albedo) of 5 to 15%, i.e. they absorb 85 to 95% of the energy reaching them and become hot. Even white colored roofs cannot have a solar reflectance exceeding 50%, as they reflect only the visible part of the solar spectrum, which accounts for less than 50% of the energy incident on it and the rest (UV and IR) is almost entirely absorbed. [21]

Traditional roofing heats up not only because of its poor albedo; another characteristic of the material's surface impacts the temperature reached: its thermal emittance, or the ability to radiate more or less energy at a given temperature, or how readily a surface gives off heat.

As a result, when exposed to sunlight, a high-emittance surface will reach thermal equilibrium at a lower temperature than a low-emittance surface, because the high-emittance surface emits heat more quickly.

The combination of solar reflectance and thermal emittance have significant effects on surface temperature, as shown in the example of Figure below for three different roof types.

"Cool roofing" refers to the use of highly reflective and emissive materials. They are capable of reflecting not only in the visible spectrum, but also in the near infrared, and their emissivity is high at all the wavelengths of the solar spectrum.

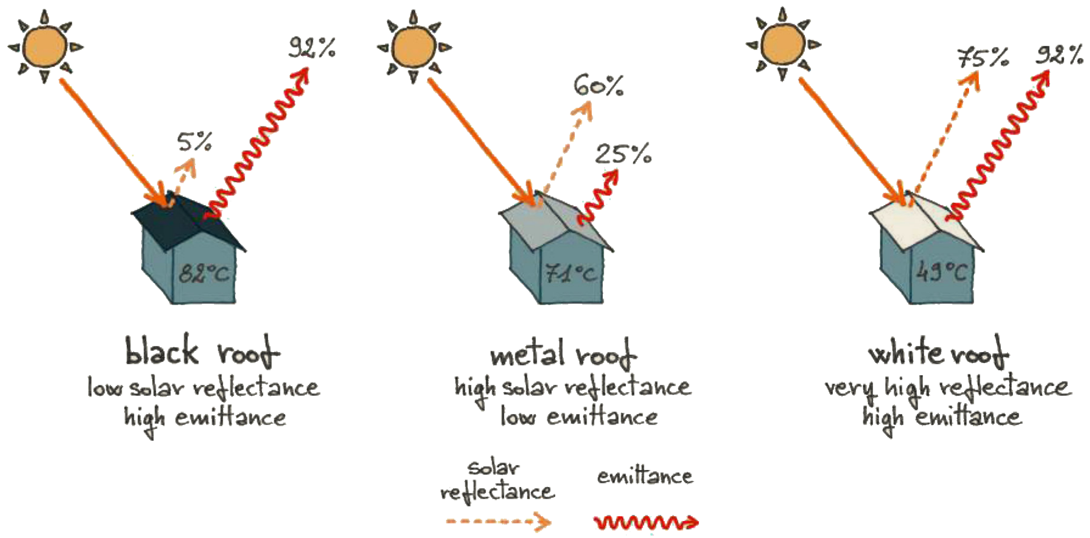



*Figure 42 On A Hot, Sunny, Summer Day, A Black Roof That Reflects 5% Of The Sun's Energy And Emits As Long-Wave Radiation More Than 90% Of The Heat It Absorbs, Can Reach 82°C. A Metal Roof Will Reflect The Majority Of The Sun's Energy While Releasing As Long-Wave [21]*

### 2.2.8. Minimize Energy Demand For Transport Through Neigborhood And Urban Design

The urban transport sector accounts for a large proportion of urban CO2 emissions. The world transport sector in 2010 was responsible for approximately 23% of total energy-related CO2 emissions,40% of which were due to urban mobility. Urban transport energy consumption is expected to double by 2050, despite on-going improvements in vehicle technology and fuel-economy; 90% of this growth in urban transport emissions is expected to come from private motorized travel and will largely take place in developing countries. [21]

The arrangement of the neighborhood and urban form have a significant impact on how we move in the area, hence urban design has a significant impact on mobility. Because of their different intrinsic efficiency, the design of spaces and functions can influence the choice of different transportation modes, and this choice influences energy usage.

Furthermore, transportation energy demand is influenced significantly by urban, district, and neighborhood design, and it is possible to reduce it through appropriate density and mixed land use (close proximity of work, home, and services) or even by extending the connection of functions at the individual building scale. Providing infrastructure at the neighborhood level to facilitate cycling and collective and individual high-efficiency transportation, for example, is critical to lowering energy demand and consumption.

A holistic approach to urban development is essential, with actual integration of transportation planning with space and functional arrangements at the neighborhood scale. In fact, transportation planning decisions are not simply technical engineering decisions; they have a significant impact on the use of the public domain, and urban planning decisions have obvious and direct implications for accessibility and mobility. These considerations are finally reflected in neighborhood design, because walking, cycling, public transportation, and sustainable communities must be considered "as a single network, one that replaces the transportation concept of mobility with a community aim of accessibility."

In the following, the connection between the design of the physical space and mobility is highlighted (Figure below), with the focus on new neighborhoods. "When there is significant new development, then it will be important for transport and land use to be developed together".



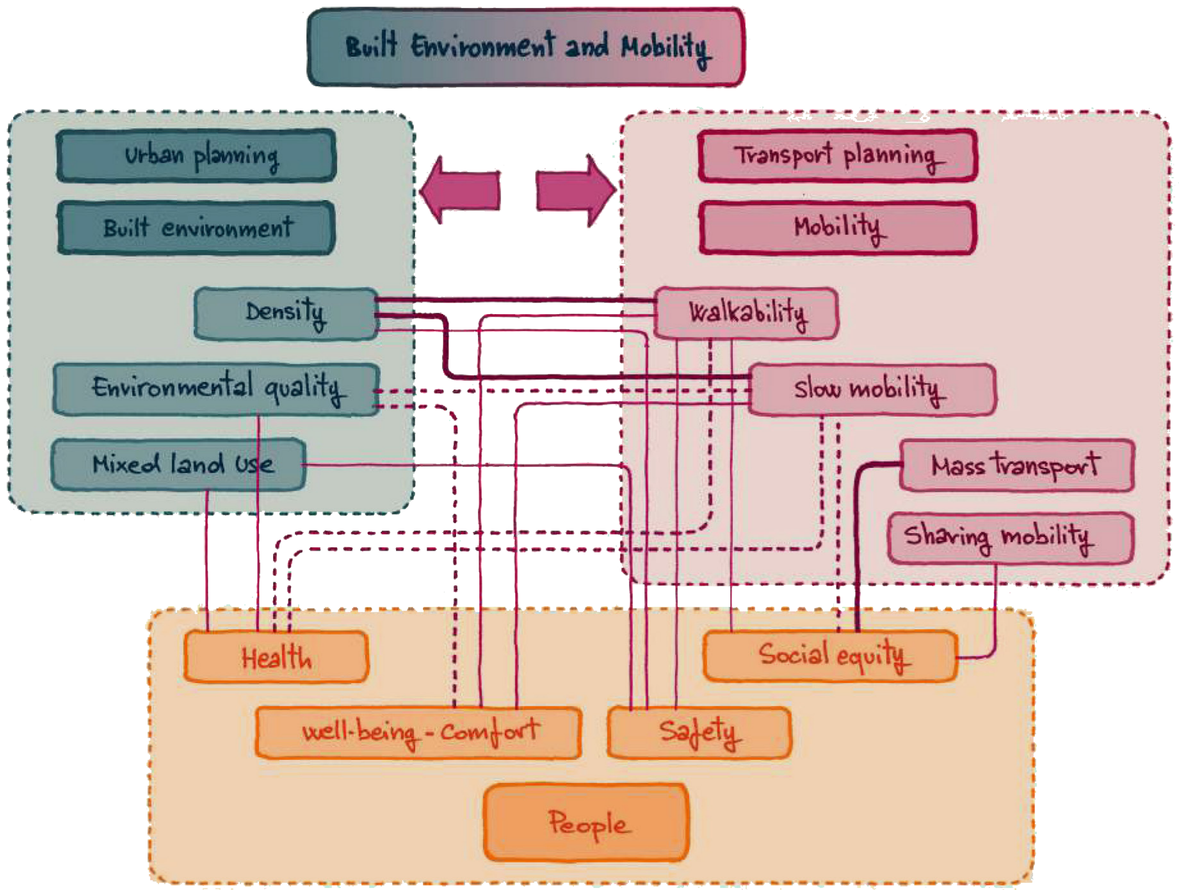



*Figure 41 Interplay Between Built Environment, Mobility And People: Significant Themes And Relationships [21]*

As noted also before, transport is the second most important origin of CO2 emissions. The term "maximizing energy efficiency of transportation" relates to the efficiency of various modes of transportation. This means they must be efficient not only in terms of their engines or motors, but also in terms of their function: moving people and things from one location to another.

In other words, energy efficiency is measured not only in terms of an efficient, low-emission engine, but also in terms of the number of people transported and the distance traveled (Figure below). As a result, there are two modes of transportation for which the urban designer should supply infrastructure: bicycles and public transportation.

Electric automobiles are becoming more common, which introduces a new challenger in transportation efficiency if the car batteries are charged with electricity generated by a renewable energy source and a car sharing system is established. To encourage this trend, city planners should create distributed parking places where automobiles may be picked up and delivered, as well as recharged using renewable energy.

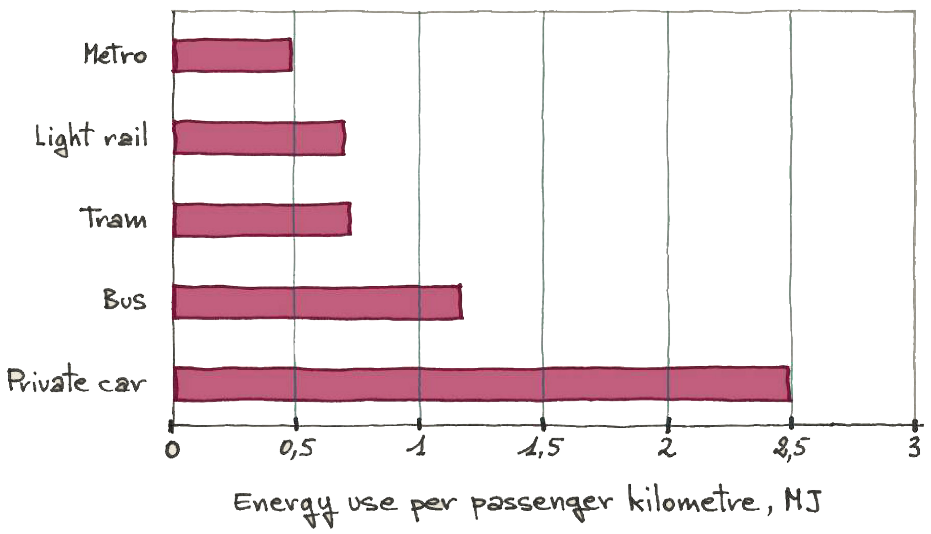



*Figure 43 Transport Energy Efficiency [21]*

### 2.2.9. Maximize Efficiency Of Energy Conversion Technologies

Choosing the most efficient energy conversion technologies for the urban system's operation requires optimizing energy streams from an energetic perspective. Buildings (residential and commercial), transportation, and industry are the three traditional categories for dividing urban energy use. The construction sector typically ranks top in industrialized cities, whereas the transportation sector typically rates first in emerging cities. (Figure below).

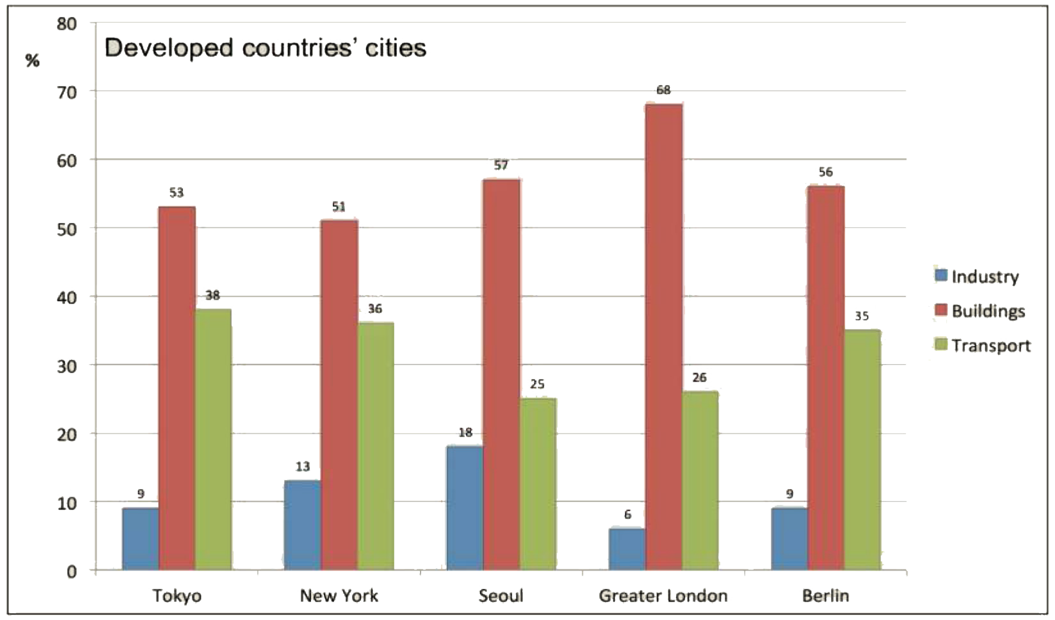



*Figure 44 Developed Countries' Cities*

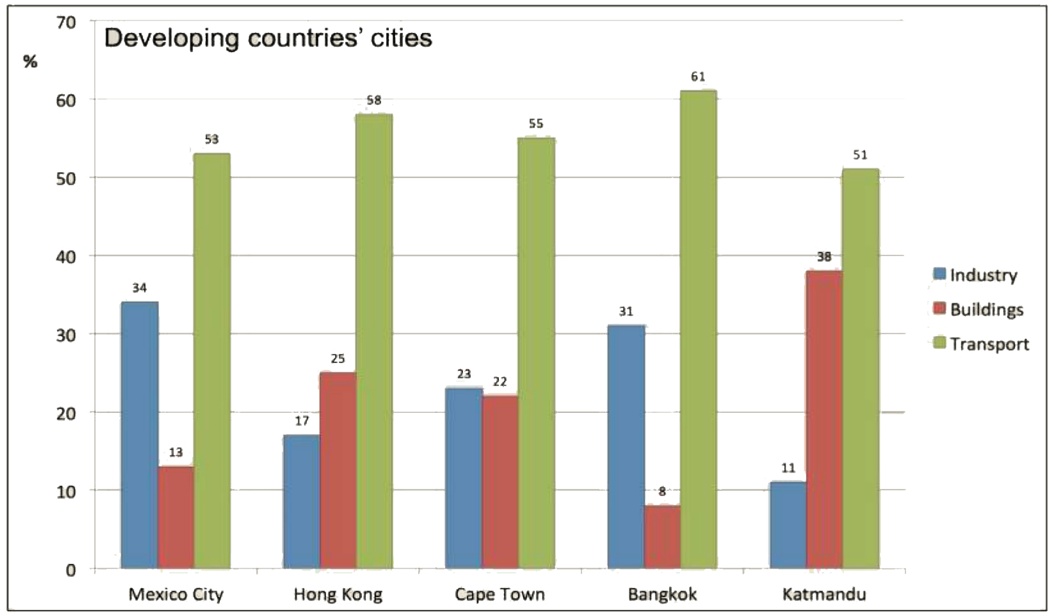



*Figure 45 Energy Consumption By Sector In Selected Cities – Data 1999-2005 [21]*

Heat is traditionally produced by burning biomass or fossil fuels, however this method is not necessarily the most efficient in terms of exergy, as in the case of delivering hot water or space heating, for example.

According to the Second Law of Thermodynamics, burning fuel in a boiler to obtain an ambient air temperature of 20 °C or water at 40°C for showering is the most inefficient way of attaining the desired result (because we use high grade, i.e. high exergy, heat when we need it at low grade, i.e. low exergy).

On the other hand, the production of electricity with a thermal power plant necessarily implies the production of some low temperature heat. In this way the overall efficiency of the system is significantly improved. This technological approach is named cogeneration, or CHP (Combined Heat & Power). [21]

Cogeneration is defined as the sequential generation of two forms of useful energy from a single primary energy source. Typically, the two forms of energy are mechanical (transformed generally into electricity) and thermal energy.

CHP is widely used in many cities in industrialized countries where heating and hot water are required during the year. This is not just cost-effective but also thermodynamically.

For this purpose, CHP is not economically viable. However, CHP can also help with cooling (Figure Below), thanks to absorption chillers that use waste heat to produce chilled water, which can then be delivered to the area's residential and commercial buildings (district cooling, Figure below). A CHP system for a neighborhood or district can offer energy, cooling, and domestic hot water (DHW). This allows the generated electricity to be used for reasons other than running air conditioners.

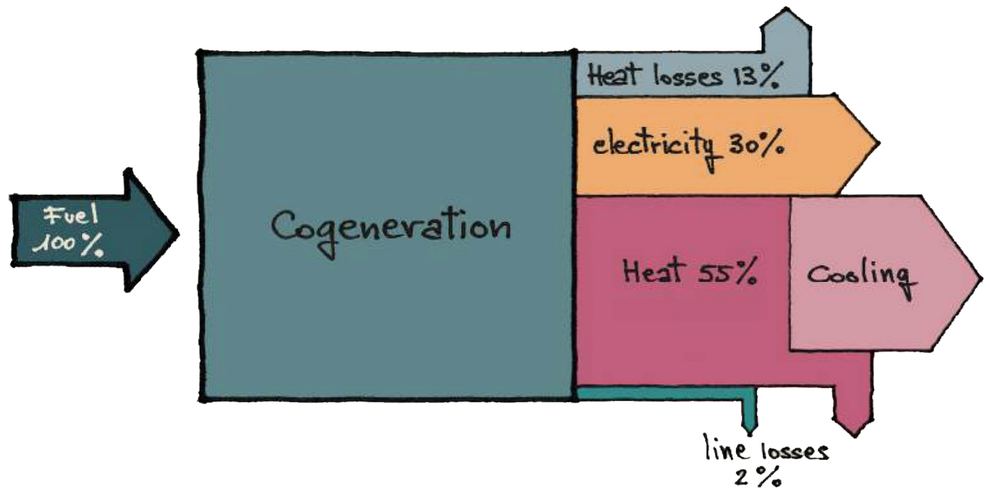



*Figure 46 Cogeneration Heat Used For Chilled Water Production [21]*

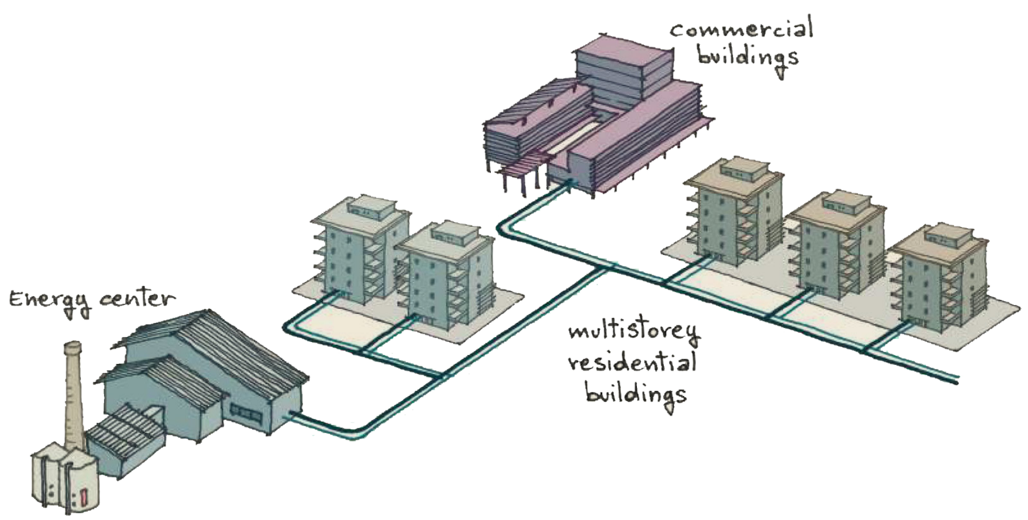



*Figure 47 Illustration Of A District Cooling System [21]*

When it is used for heating, it pumps heat from the outdoor to the indoor environment, heating it; when used for cooling (refrigerators, air conditioners), it pumps heat from the indoor to the outdoor environment; as heat is subtracted from the indoor environment, its temperature decreases or remains constant in spite of the heat flow coming from the outdoor environment. This is the way an air conditioning system works: it cools down indoor air and blows hot air into the outdoor environment, increasing the anthropogenic heat produced by motorized traffic and cooking.

There is a method to make this process more efficient: instead of blowing the heat produced outdoors and wasting it, it can be used to produce hot water with some smart equipment. This reduces the amount of energy used to produce DHW. This method can be applied at the building, block, and neighborhood levels, with the latter being the case if district cooling is in place.

### 2.2.10. Fulfil The Remaining Energy Consumption With Renewable Energy Sources

At the neighborhood scale, the potential for renewable energy sources is determined by the climate and the neighborhood architecture. The potential for solar and wind energy is determined by the climate, i.e. the availability of solar radiation and wind, as well as the quantity of suitable surfaces that can be covered with solar panels and the settlement texture, which impacts wind velocity. Biomass potential is determined by neighborhood design, as it comprises wood and leaves from tree and bushes pruning in parks, green spaces, and tree-lined roadways, among other things. It also depends on the type of wastewater treatment system in place, as well as the number and size of urban agriculture plots.
The utilization of renewable energy technology poses a considerable challenge for urban designers since it imposes significant limits. PV systems, for example, have an impact on roof albedo and size, the latter of which is important if zero-energy buildings are desired. PV (Photovoltaic) systems could be used to power fleets of electric cars, and the ideal situation would be for these cars to be parked in dedicated outdoor parking lots with PV canopies; in this case, the challenge is to optimize the size and location of the parking lots in relation to the number of cars and the PV area required to charge them.

#### 2.2.10.1. Mini Grids Concept

Solar and wind energy output is not programmed since PV systems cannot produce at night and both PV and wind systems create more or less electricity depending on weather conditions; consequently, demand and supply are unlikely to meet. Connecting to the main grid is the simplest method, as it delivers power when renewable production is insufficient and absorbs power when production exceeds need.

There are two possibilities if a connection to the main grid is unavailable or the power source is inconsistent. They are frequently used in combination. The first alternative is to use batteries or other storage devices to store electricity. The second option is to have a generator with programmed energy sources like fossil fuels and biomass as backup.

Both the storage option and the generator require a control system to regulate their output so that instantaneous power demand is met by corresponding instantaneous power production.
Mini-grids, also known as micro-grids, are local energy systems made up of distributed energy resources, distributed consumers, and, optionally, storage. [21]

Programmable and non-programmable renewable generation, energy storage facilities, and/or optional fossil-fueled generation and load control are all part of a microgrid design for a sustainable neighborhood (Figure below). This new system will be scalable, which means that expanding loads may need the construction of additional generators without compromising the present microgrid's stability and reliability. Wind and solar-powered generators, as well as biomass-powered systems, are common distributed energy options for microgrids.

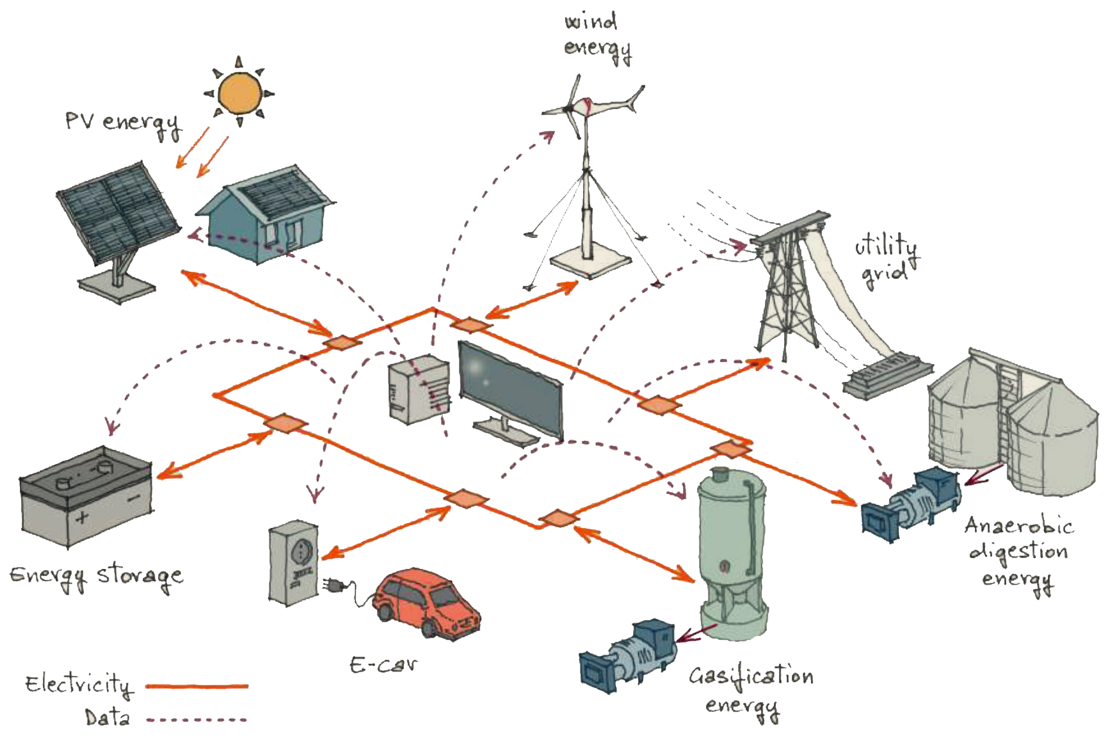



Figure 48 Concept Of A Mini-Grid [21]

Mini-grids (or smart grids, as they're sometimes called because of the "smart" control system that manages them) are an almost mandatory technical option in new urban developments, especially in developing countries, where the majority of the infrastructure for electricity production, transmission, and distribution has yet to be built.

### 2.2.11. Optimize The Water Cycle

Water and energy are strongly linked. Water is used in the production of energy, and energy is utilized in the pumping, treating, and distribution of water (Figure below). Water demand has been rising in tandem with population growth, requiring more and more energy. In tropical regions, water and energy are particularly linked because vegetation increases outdoor and indoor comfort while lowering the need for mechanical cooling, and vegetation requires water.

In the present, urban metabolism high quality energy (fossil fuels, electricity) enters the city, is used, and low quality, degraded (thermal) energy is disposed of in the surrounding environment; similarly, high quality water (pure, clean, potable) enters the system, is used, and low quality (impure, more or less dirty, non-potable) is conveyed to a nearby large water body (sea, lake, river). It is the same process: a negentropy flow enters the city, the neighborhood, the individual buildings, and is degraded into an entropy flow and disposed of into the environment. The water system mimics the energy system: centralized production distribution use waste.



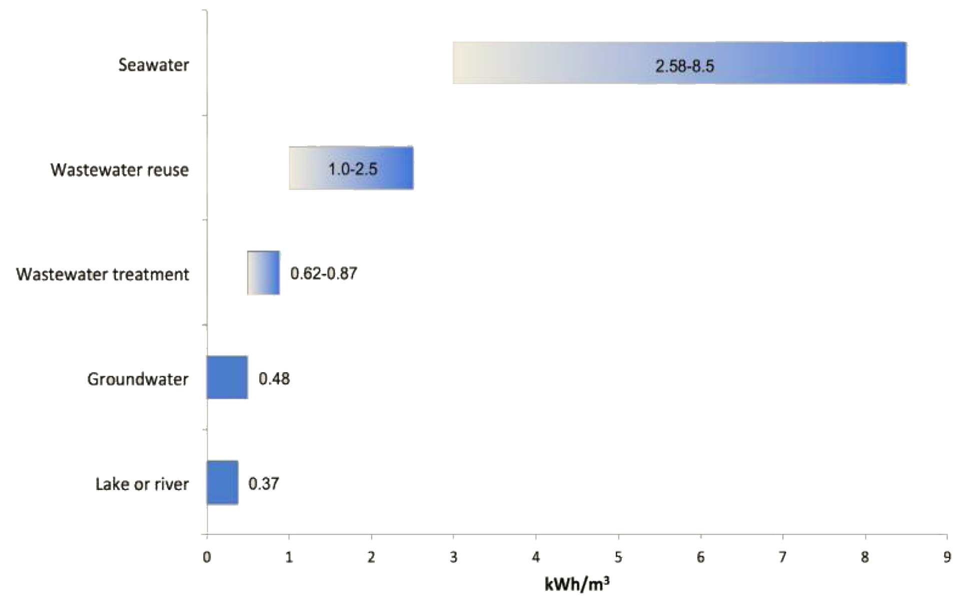



Figure 49 A Mount Of Energy Required To Provide 1m3 Water Safe For Human Consumption From Various Water Sources [21]

#### 2.2.11.1. Rainwater Harvesting

Rain is the primary source of water, followed by rivers, lakes, and groundwater. We now depend on secondary sources; however, it is often forgotten that rain is the ultimate source of all these secondary sources, and that rainfall may be gathered. Rainwater harvesting reduces the amount of energy required to raise groundwater. Rainwater can be harvested from:

- Rooftops;
- Paved and unpaved areas, i.e. storm water drains, roads and pavements and other open areas;
- Storm water drains; if properly designed and maintained they offer a simple, cost effective means of rainwater harvesting.

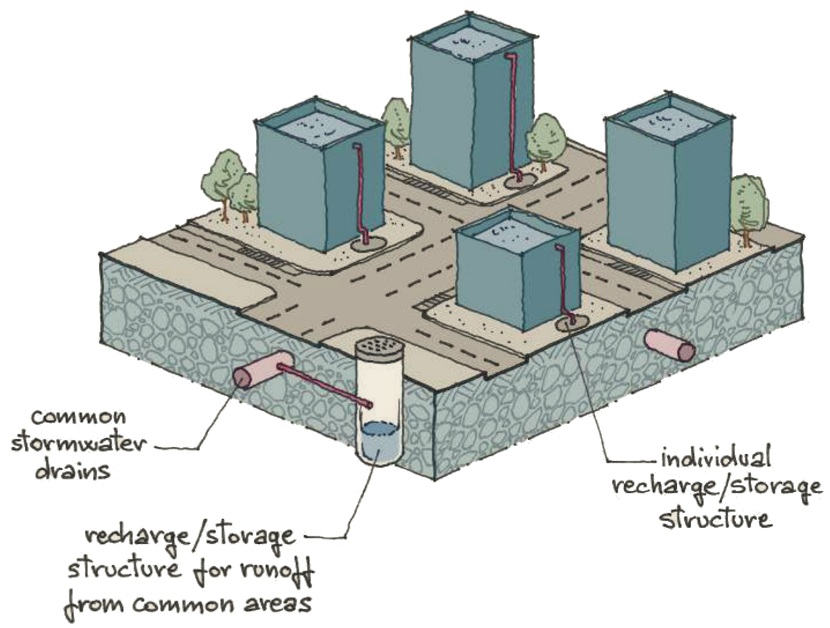



Figure 50 Example Of Rainwater Harvesting [21]

### 2.2.11.2. The Ideal Water Cycle

In underdeveloped nations, centralized wastewater treatment plants are frequently vulnerable due to insufficient updating and maintenance, as well as frequent power failures, resulting in the release of pathogenic wastewater.

Based on the cycle represented in Figure below, a safe, sustainable, and resilient neighborhood should be able to rely only on rainfall to provide all of the water required to meet the community's demands, at various quality levels.

For technological and/or economic reasons, this ideal goal is frequently unachievable. However, the urban designer should try to keep the neighborhood's reliance on centralized water supply to a minimum.

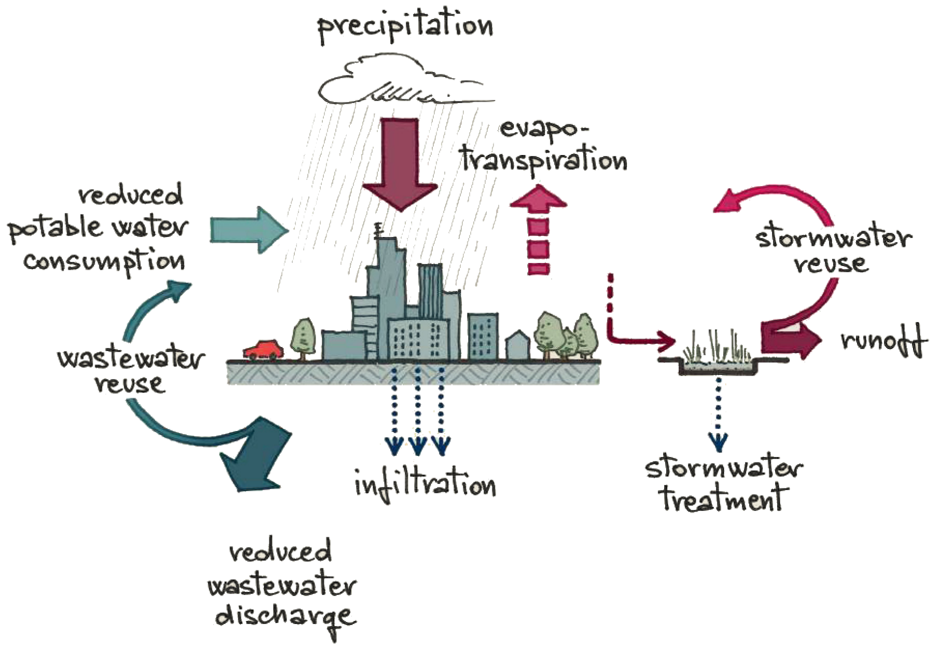



*Figure 51 The Ideal Urban Water Cycle [21]*

### 2.2.12. Improve Solid Waste Reuse and Recycling

Urban waste contributes significantly to greenhouse gas emissions and contributes to climate change. Solid waste collection and disposal is often considered to be a city governance issue rather than an issue of urban design: only the area covered by the landfill or incineration plant affects land use and space planning.

However, if solid waste collection and disposal is decentralized at the local level rather than centralized, the urban designer is directly involved.

There are numerous advantages to decentralized solid waste management. (Figure below) Localized waste collection and processing eliminate waste transportation to the far dumping locations, saving energy and emissions, as well as lowering air pollution and road maintenance expenses. It also lowers the contamination of ground water caused by landfill leachate leakage.

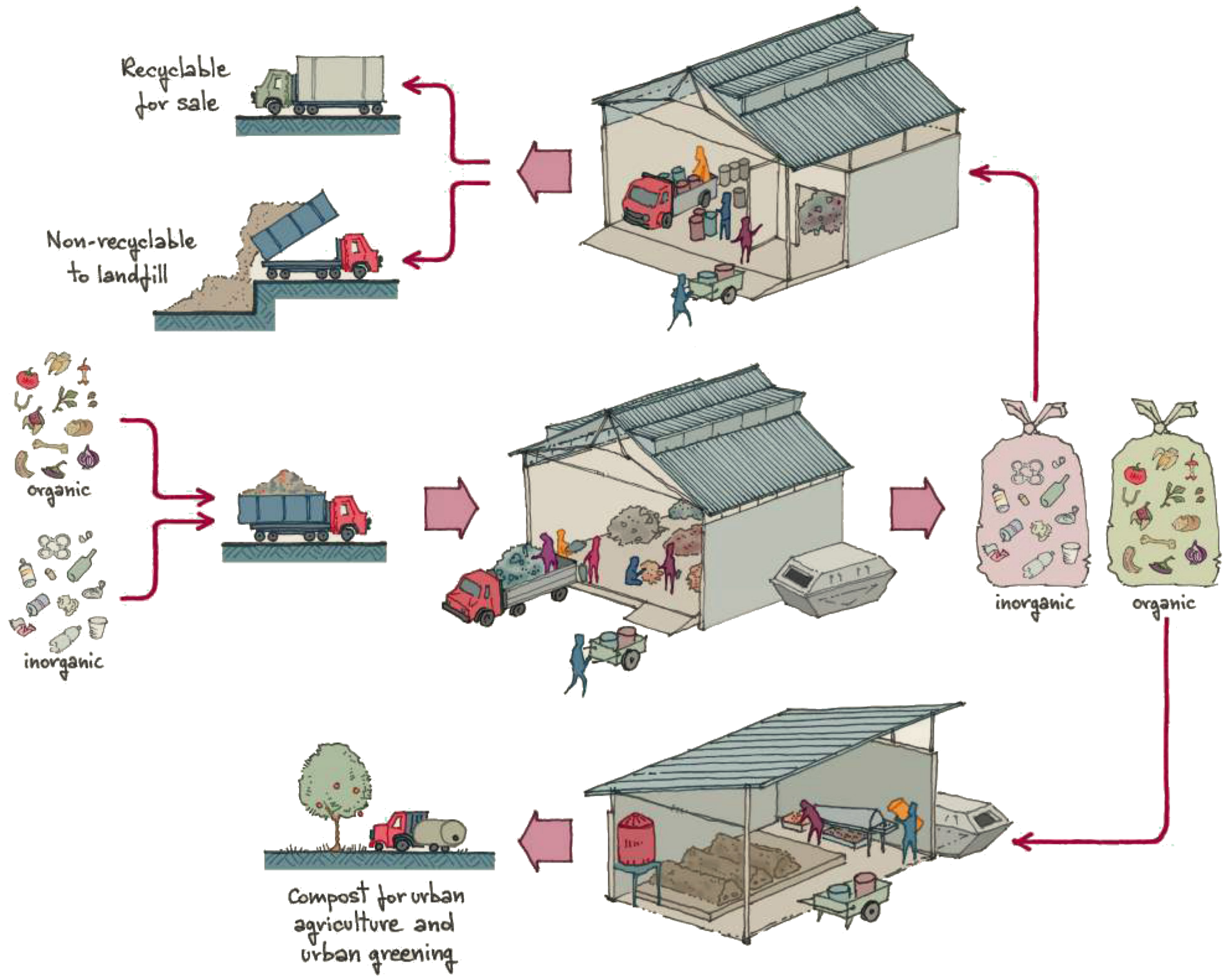



*Figure 52 Decentralized Solid Waste Management [21]*

### 2.2.13. Closing Energy, Water And Waste Cycles On Site

A sustainable neighborhood rejects the idea of waste, be it of energy, water, food or materials; instead, it seeks to transform waste into beneficial uses. In so doing, it seeks to reduce or even cut out inputs of water and energy from afar and to reduce the flow of materials. This concept leads to efforts to decentralize the production of energy and food. It also powers the three "R's" (Reduce, Reuse, Recycle) of decentralized solid waste management. [21]

The movements of energy, water, and waste are all linked (Figure below). The connections in the traditional, centralized, linear urban metabolism are one-way: the higher the standard for providing water to households, the higher the water input and the higher the energy consumption for water purification and pumping; the higher the standard of sanitation, the higher the energy consumption for wastewater treatment; and the better the solid waste collection and disposal system, the higher the energy consumption for transportation.

In the circular metabolism, however, energy is linked to water and waste in many other ways:

• Using rainwater and treated wastewater to restore water tables prevents them from becoming low, requiring less pumping power.

• Using treated wastewater for vegetated areas allows them to develop due to fertigation, which is helpful for both outdoor and indoor comfort, lowering the demand for air conditioning.

• The availability of natural fertilizers and water allows for the promotion of urban agriculture, and the use of locally produced food minimizes the amount of energy used to transport it from distant regions.

• Organic waste and wastewater can produce biogas, which can be utilized in a cogeneration system to produce drinkable water from treated wastewater via vacuum distillation, among other things.

• Digesters and/or gasifiers can supply energy from organic waste from urban agriculture and green maintenance residuals.

cThe reduction in the need for private transportation resulting from mixed use reduces energy consumption as well as the required street width due to reduced traffic, resulting in a reduction in impervious areas in favor of pervious surfaces that allow stormwater to percolate and replenish water tables.

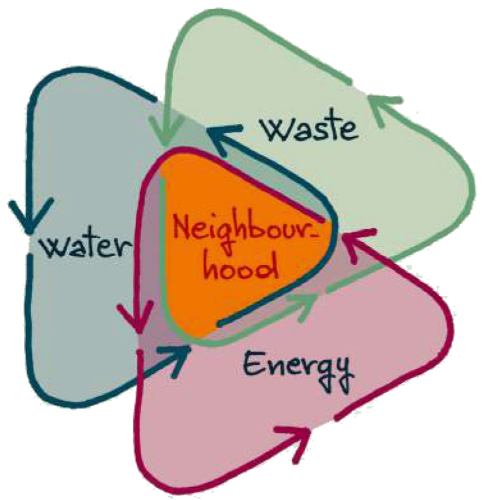



Figure 53 Water, Waste And Energy Flows [21]

Thus, in a sustainable neighborhood, linear processes are replaced by circular ones, reducing entropy production in each flow; additionally, an appropriate interconnection between flows can lead to even more entropy reduction in the neighborhood's metabolic process, making it more sustainable and reducing both direct and indirect emissions (see Figure 53).

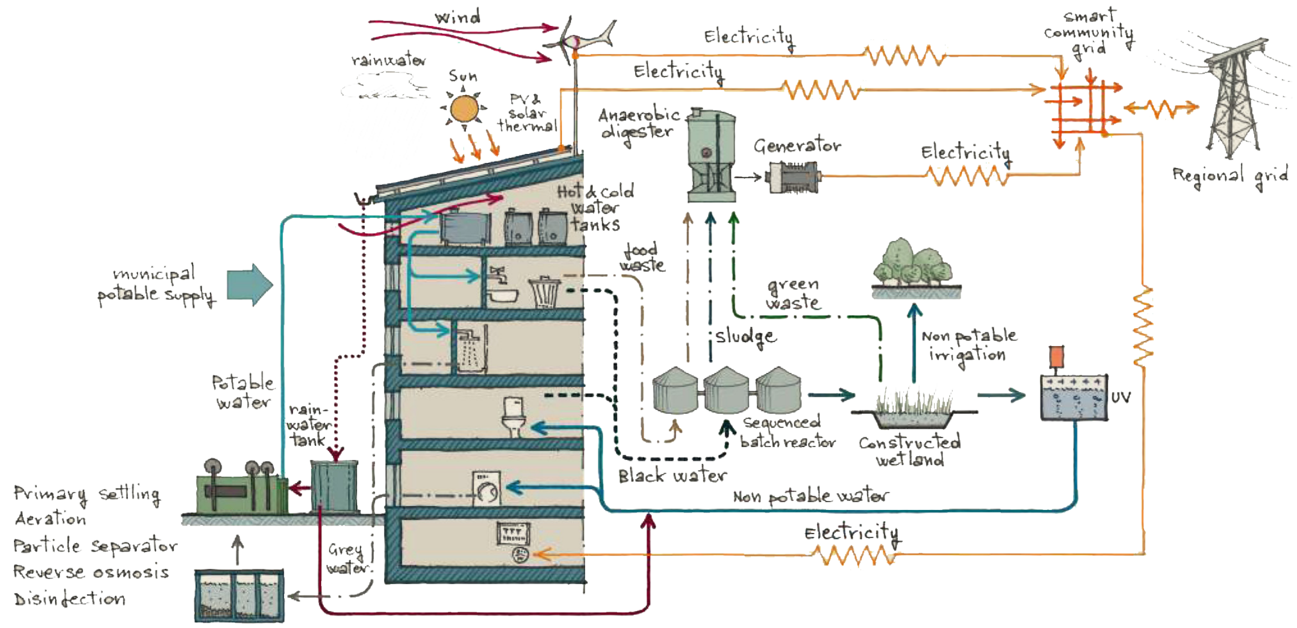



*Figure 54 Schematic Of Integrated Water, Waste And Energy Systems For A Sustainable Neighborhood [21]*

The only way to get cities to achieve their goal of sustainable development is to combine demand management with an efficient supply of energy and water based on decentralized systems and a closed cycle approach. If a sustainable community is to meet future problems, it must begin to approach zero emissions.

The interactions between structure (layout, form, land use, materials, greenery), energy, water, and waste can be used to reduce the flow of resources (or negentropy) required for a neighborhood's operation while also making it more resilient, making it more capable of coping with climate change challenges.

The neighborhood's increased resilience is mostly due to the diversity of its energy (sun, biomass, and wind, if available, fossil) and water supplies (rainwater, wastewater, well water, and water from the city's distribution system).

### 2.2.14. Minimise Indirect Ghg Emissions

GHG emissions embodied in the material flow entering the city, i.e. those related with the extraction, manufacture, and transportation of products or services entering the city, account for a major share of urban GHG emissions.

The urban designer can control a part of these embodied, or indirect, emissions, as they are affected by his/her design choices.

The manufacturing of concrete, steel, glass, and other materials used in civil infrastructure accounts for the majority of embodied emissions as a result of the urban designer's choices. Because it requires the processing of mined raw materials at very high temperatures, the production of cement, steel, glass, aluminum, and fired bricks, which are the basic building materials for most modern constructions, has a very high environmental impact, consumes a significant amount of energy, and produces the majority of the construction sector's GHG emissions.

The cement industry is responsible for ~5% of annual worldwide CO2 emissions from fossil fuels. The production of iron and steel, which is also used in reinforced concrete, is responsible for more than 4% of world total energy use and the corresponding GHG emissions. The production of glass and aluminum also causes large GHG emissions because their production is energy intensive. [21]

Building materials with low embodied emissions, such as stone, timber, bamboo, stabilized compressed bricks, and so on, should be preferred. They can also be made locally, minimizing transportation energy consumption and boosting the local economy.

An urban design that attempts to minimize the amount of resources required can also achieve a considerable decrease in indirect emissions due to building materials.

Because the lower the surface to volume (S/V) ratio of buildings, the less material is required to provide a given useful floor area, there is an inverse relationship between urban density and indirect GHG emissions: a multi-storey building has a lower S/V ratio than a detached house, and it is capable of providing more useful floor area with the same footprint (Figure below). The bigger the amount of construction material required, the more embodied GHG emissions are produced.

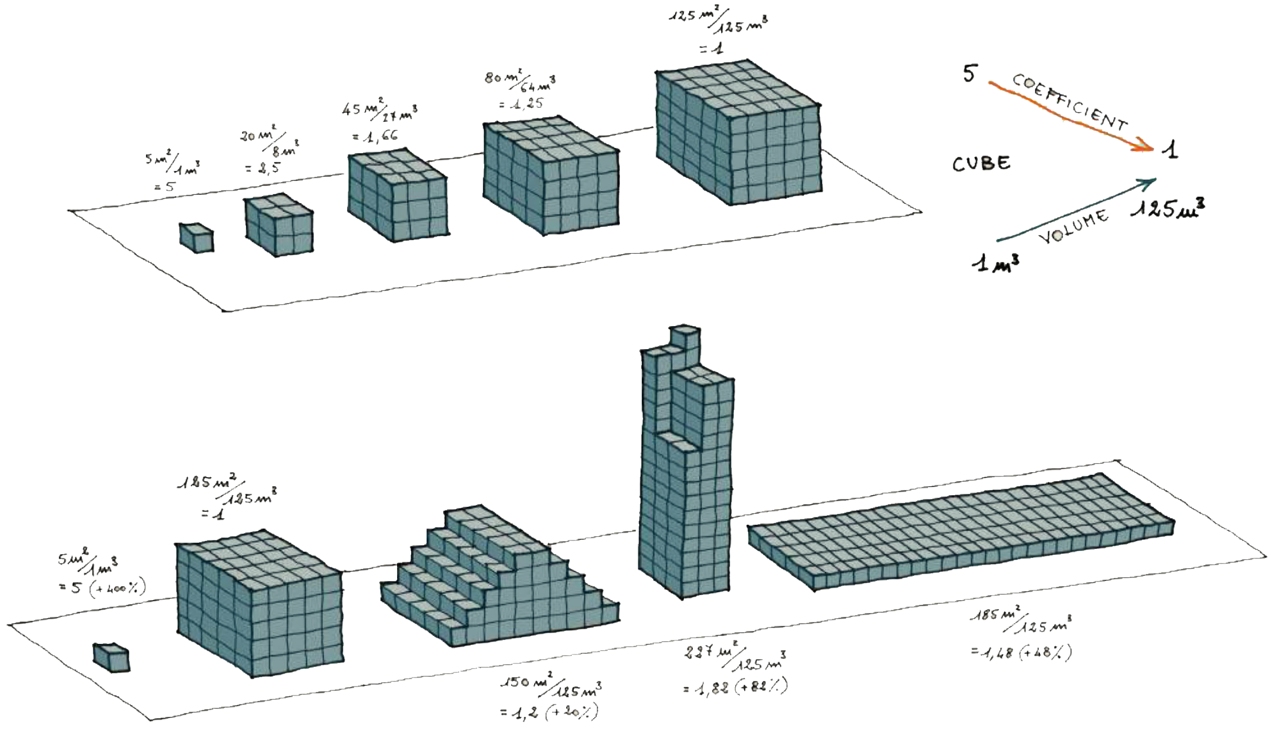



*Figure 55 Variation Of Surface To Volume Ratio (S/V)) For Increasing Volume Of A Cube. [21]*

Building materials should also be chosen based on their durability (the more durable, the lower the quantity of GHG embodied emissions spread throughout the building's whole life cycle), reusability, and recyclability.

The figure below demonstrates the components of a building's overall GHG emissions over its entire life cycle, from emissions associated with the building's pre-use phase, such as raw material extraction for metals, to transportation-related activities in vehicles at all stages of the building's life cycle, to after-use activities such as re-use, recycling, thermal recycling, and waste disposal processes.

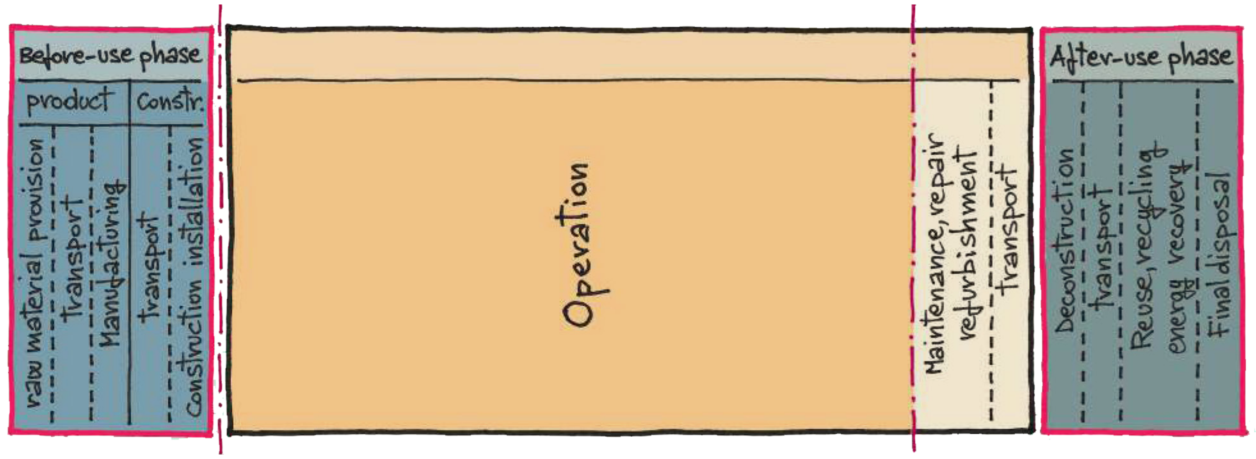



*Figure 56 GHG Emissions Of Buildings Across Their Life-Cycle [21]*

It should be emphasized that, because the goal of a sustainable city, or neighborhood, is to reduce the amount of fossil energy required for building operation to zero or almost zero, the amount of emissions generated during this phase of the building's life-cycle should be approaching zero.

### 2.2.15. Renewable Energy Technologies at Neighbourhood Scale

Renewable energy sources are considered as future in all the word to create sustainable livable area. Implementations are done not only new constructions but also are done for existing buildings in different type of systems. The most popular systems are solar panel systems which composed of solar thermal panels and photovoltaic panels, wind energy and biomass.

Solar energy can power the buildings in terms of transport and production activities. However, it is subject to daily and seasonal variations. As we can imagine, this energy source is not a continues source of energy like fossil energy sources. Solar energy is one of the most critical renewable energy implementations to reduce energy consumption in the buildings and urban areas. Solar energy production and management requires the development of grids that are capable of producing, distributing, modulating and storing energy according to variations.

#### 2.2.15.1. Solar Thermal Energy

Solar thermal systems convert solar radiation into heat, transferring heat to a fluid. The fluid can be heated at low (< 100 °C) [21] or high temperature. Low temperature heat is generally used for Domestic Hot Water (DHW) production, and less frequently for cooling. When heated at high temperature, mechanical power with a thermal engine is produced.

### 2.2.15.1.1. Low Temperature Solar Thermal Energy

The simplest solar thermal technology is the flat plate collector, for hot water production (Figure below left). However, the evacuated tubes solar collector (Figure below right) is more efficient. Even if the solar water heater includes a tank for hot water storage (Figure below), there are periods of the year in which the solar energy falling on the collector is not sufficient to satisfy the demand for hot water, hence a back-up energy source is necessary.

The easiest back-up is provided with an electric resistance. The use of a solar water heater, instead of a conventional electric water heater, allows an annual energy saving up to 70% [21].

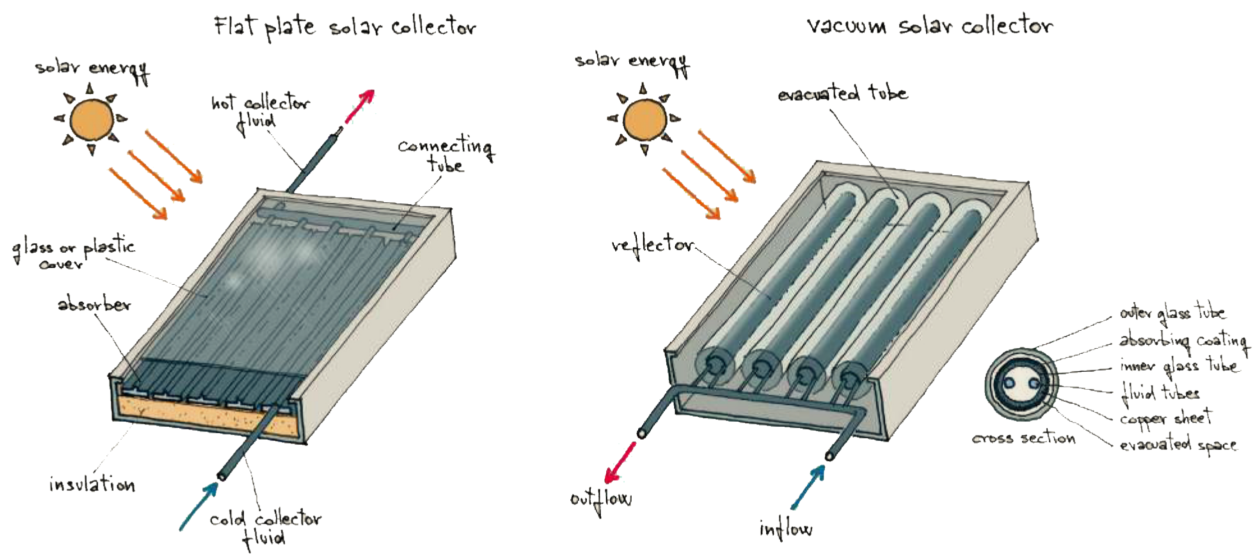



*Figure 57 Flat (Left) And Evacuated (Right) Solar Collector [21]*

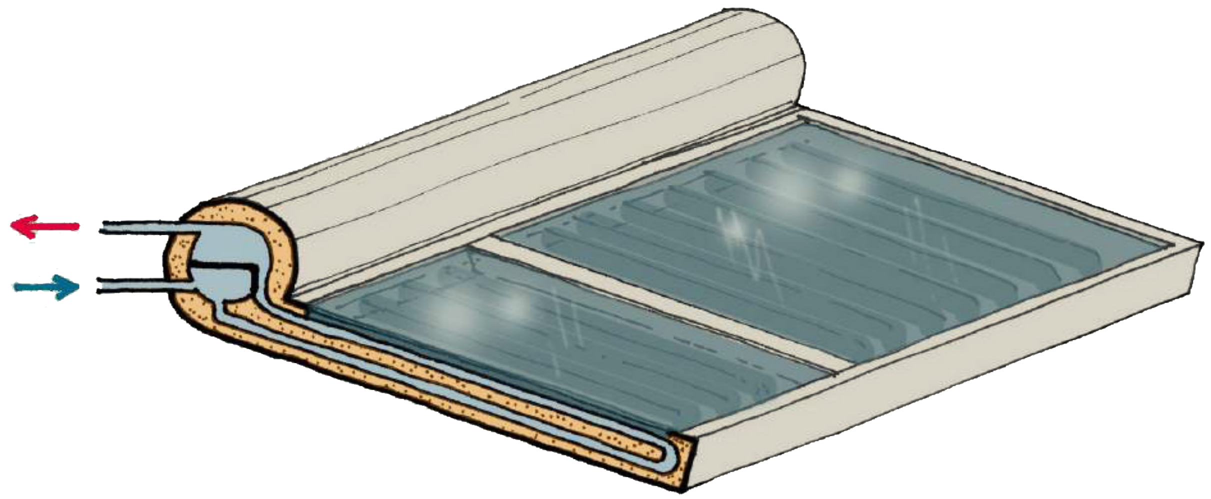


*Figure 58 Integrated Storage Solar DHW System [21]*



Solar thermal systems can be utilized for cooling by linking them with an absorption chiller (Figure below) or a desiccant cooling (DEC) unit, as it is possible to attain temperatures exceeding 85 °C with evacuated solar collectors (Figure below).

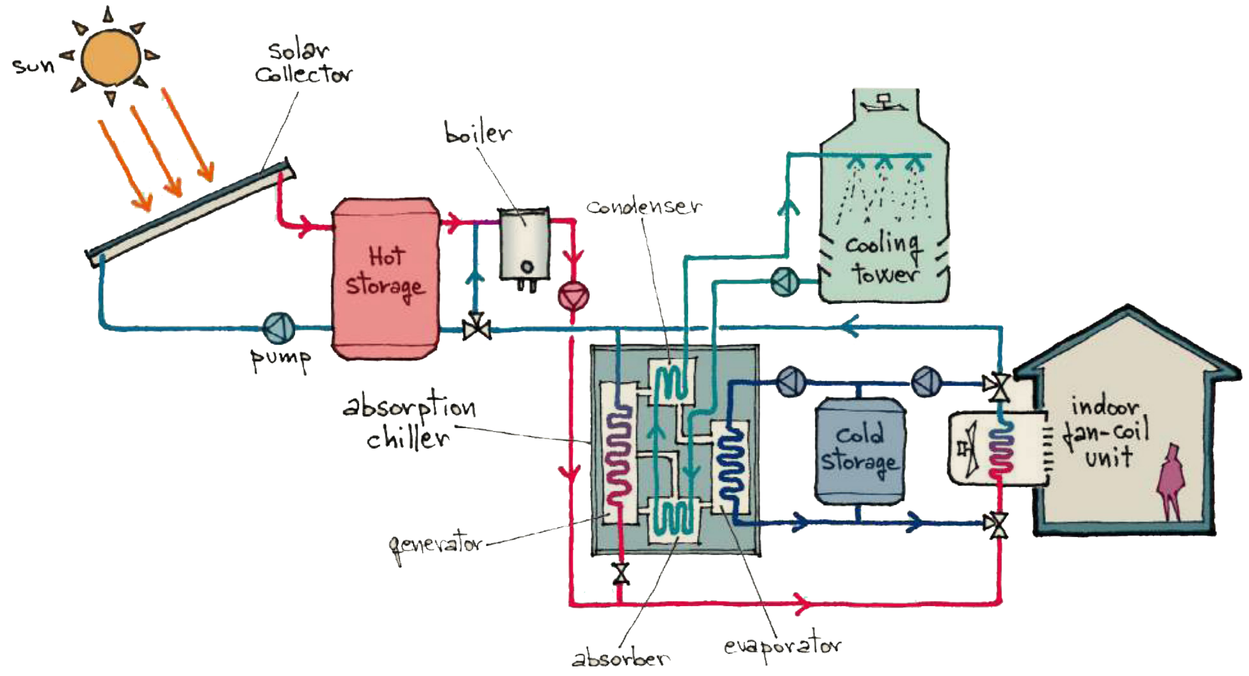



*Figure 59 Solar Powered Air Conditioning System [21]*

### 2.2.15.1.2. Solar Thermodynamic Power Stations

Solar energy converted to heat can be used to generate electricity if high temperatures are achieved, which can be done by concentrating solar rays. (Figure below).

The parabolic through, linear Fresnel, and dish/engine are the best technologies at neighborhood scale. Dish concentrating collector power plants are more easily expandable since they are made up of modular units that include the concentrator and the engine/generator unit.

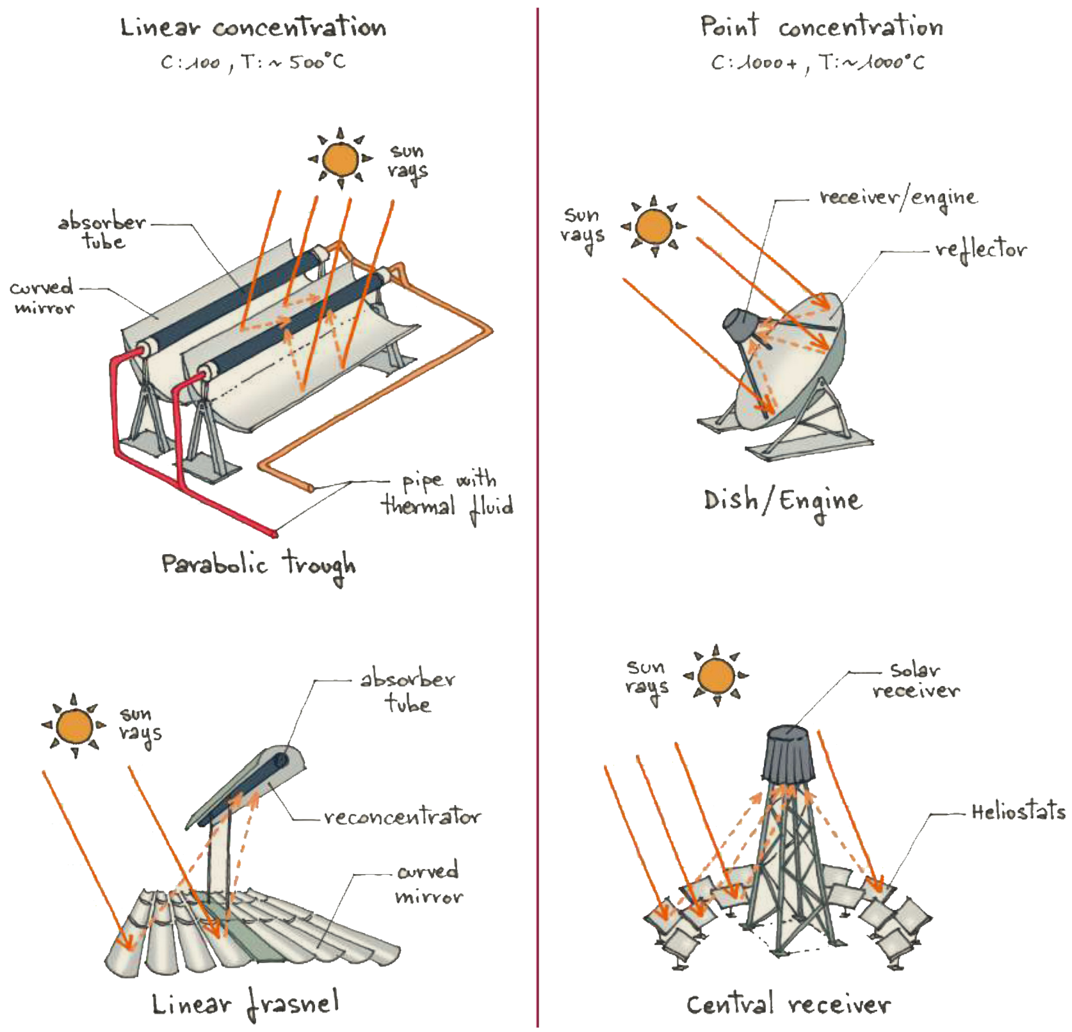



*Figure 60 Concentrating Solar Technologies: Basic Layout Schemes [21]*

### 2.2.15.2. Photo Voltaic Systems

Photovoltaic panels are capable of converting solar energy into DC current directly, without any moving parts or circulating fluid. They can be grid connected (Figure below, top) or stand-alone (Figure below, bottom), or a combination of the two, with the electric storage providing, entirely or partially, electricity when the sun is not shining or when demand exceeds production, together with the grid. Grid connected systems use the grid as storage, in the sense that the DC current is first transformed into AC, and then delivered to the grid (partially or totally). The electricity required by the user comes partially or totally from the grid. The amount of solar electricity used is given by the difference between the energy delivered to the grid and that received. If the grid is a mini grid, it can be provided with a storage system, which is a substitute for the individual storage.

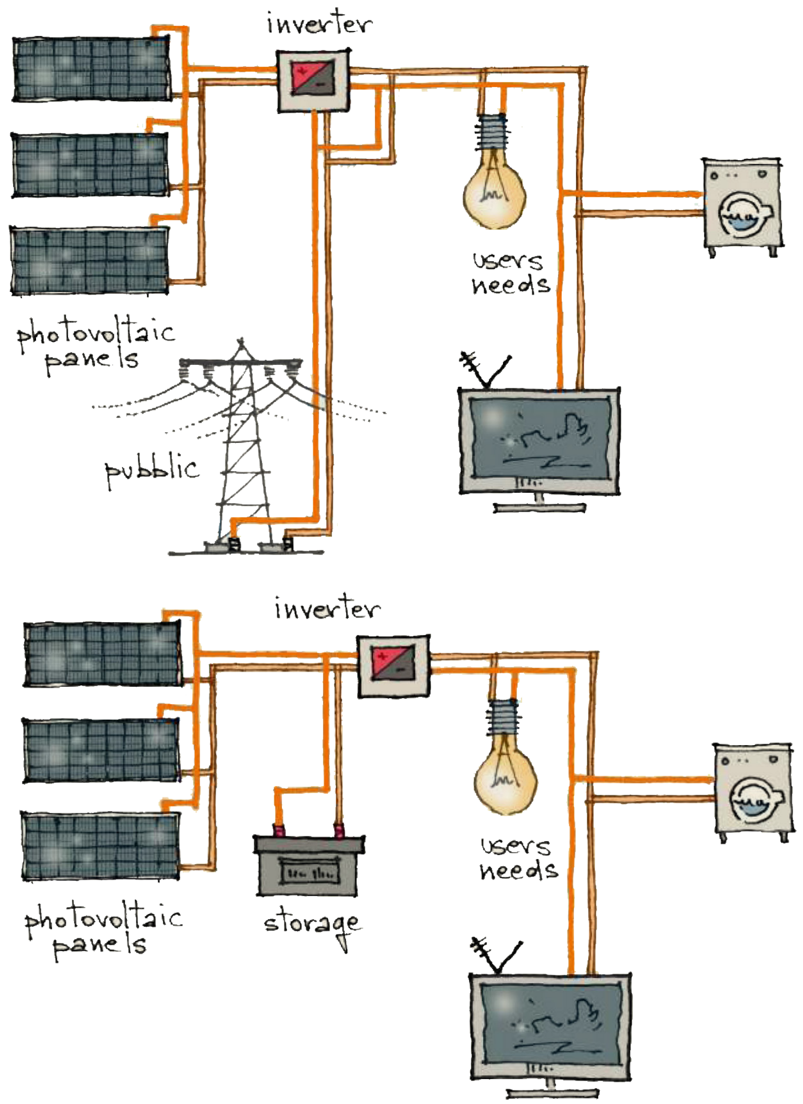



*Figure 61 Stand Alone (BOTTOM ) And Grid Connected (TOP) PV Systems [21]*

PV systems are competitive with centralized power production with fossil fuels in many circumstances, such as those typically seen in new settlements in poor nations; they are the major actors of a decentralized energy system of a low-energy urban settlement, integrated by storage systems.

The climate in which a photovoltaic system is installed has a significant impact on its productivity. In fact, the amount of energy produced is directly proportional to the amount of solar light available, and inversely proportional to the working temperature of the cells to a lesser extent. As a result, defining the optimum inclination and orientation of the modules is critical in order to optimize incident radiation and encourage heat loss.

Architectural integration is a privileged sector for PV systems, with extremely promising growth potential, even in terms of pure economics. In fact, installing the modules on the building envelope offers a number of benefits, including the use of land already occupied by buildings, cost savings on support structures, the replacement (with comparable performance) of materials and components such as traditional roof elements, and the ability to use energy generated on site according to distributed generation logic.

Figure 62 San Paolo Skyscarper made by RPBW [34]

One of the good example to the integration of PV panel systems is Torino San Paolo Skyscraper which was made by RPBW. The surface of the south-facing façade is entirely covered with 1600 square meters of photovoltaic cells for the production of electricity. [33]

PV roofs are the ideal candidates for supplying all of the energy necessary for the operation of residential buildings: lighting, air conditioning, household appliances, and even cooking if induction stoves are utilized, as they are the easiest and most dependable way to produce renewable electricity.

There are 4 different types of PV panels today in the market: monocrystalline, polycrystalline, PERC and thin-film panels. [35]



#### 2.2.15.2.1. Monocrystalline Panels

Also known as single-crystal panels, these are made from a single pure silicon crystal that is cut into several wafers. Since they are made from pure silicon, they can be readily identified by their dark black color.

The use of pure silicon also makes monocrystalline panels the most space-efficient and longest-lasting among all three solar panel types. [35] The structure of the panel is shown on figure below.

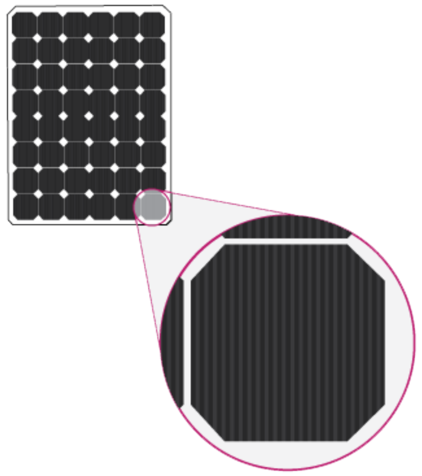


*Figure 63 Monocrystalline Panel Structure* [36]

#### 2.2.15.2.2. Polycrystalline Panels

As the name implies, these come from different silicon crystals instead of one. The silicon fragments are melted and poured into a square mold. This makes polycrystalline cells much more affordable since there is hardly any wastage, and gives them that characteristic square shape.

However, this also makes them less efficient in terms of energy conversion and space, since their silicon purity and construction are lower than monocrystalline panels. They also have lower heat tolerance, which means they are less efficient in high-temperature environments. [35] The constriction is shown figure below.

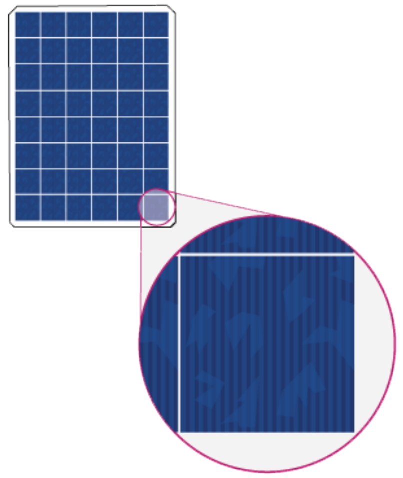


*Figure 64 Polycrystalline Panel Structure* [36]

#### 2.2.15.2.3. Passivated Emitter and Rear Cell (PERC) panels

PERC solar panels are an improvement of the traditional monocrystalline cell. This relatively new technology adds a passivation layer in the rear surface of the cell that enhances efficiency in several ways:

- It reflects light back into the cell, increasing the amount of solar radiation that gets absorbed.
- It reduces the natural tendency of electrons to recombine and inhibit the flow of electrons in the system.

PERC panels allow greater solar energy collection in a smaller physical footprint, which makes them ideal for limited spaces. They are only slightly more expensive to produce than traditional panels, due to the added materials needed, but they can be manufactured on the same equipment, and can end up having a lower average cost per watt due to their efficiency. [35]

#### 2.2.15.2.4. Thin-film solar panels

Thin-film panels are characterized by very fine layers that are thin enough to be flexible. Each panel does not require a frame backing, making them lighter and easier to install. Unlike crystalline silicon panels that come in standardized sizes of 60, 72, and 96-cell counts, thin-film panels can come in different sizes to suit specific needs. However, they are less efficient than typical silicon solar panels.

### 2.2.15.3. Wind Energy

In windy places, wind turbines are now a well-established and cost-effective technology. Wind farms are a regular thing in peri-urban regions, particularly in Northern Europe. Although wind power is not available everywhere, it is generally abundant enough to make the building of wind turbines economically viable.

In windy places, large wind turbines are not the only option to consider; compact wind generators (Figure below) with either a horizontal or vertical axis are also an alternative. Despite the fact that their cost-effectiveness is lower than that of large turbines, they are a valuable option that could make a significant contribution to the settlement's energy balance due to the large number that could be installed on building roofs and the fact that their production is not dependent on the presence of sunlight, complementing or substituting PV production and reducing the amount of back-up power required to match demand and supply.

The power generated by wind turbines installed on the roofs of buildings' usually ranges between 0.5 and 4 kW. More powerful turbines, from 20 to 50 kW (10 – 15 m rotor diameter) can be installed in open spaces, such as parking areas, urban parks or constructed wetlands [21].

### 2.2.15.4. Biomass

Biomass represents a valuable resource and an alternative to fossil fuels, for many reasons: availability, different typologies, programmability and storage, and technological maturity. [21]

Depending on the type of biomass to be processed, the end use, and the economic conditions, a variety of technologies are available. At the neighborhood level, biomass comes from urban agriculture, park and garden wastes, the organic part of solid waste, and sewage sludge.

Agriculture, parks, and gardens can use biomass either directly (as pellets or woodchips burned directly) or after gasification. Biogas can be made from the organic part of solid waste and sewage sludge.



## 2.3. Energy Efficiency Strategies In Building Scale

In recent years, significant efforts have been made to improve energy efficiency and reduce energy consumption by increasing energy saving at building scale. The concept of energy in building scale is related to energy supply needed to achieve desirable environmental conditions that minimize the energy consumption.

As a result of energy efficiency, many approaches have been developed at three levels: administration, building and architectural design. Due to the uncertainties in energy supply and global warming, many countries have introduced target values for reducing energy consumption at building scale. [37]

One of the most effective ways to cut energy costs in buildings is through proper heating and cooling design like what we discussed in the neighborhood scale. All design characteristics must be tuned to create an energy efficient building. The end user benefits from energy-efficient design strategies.

Because of its lower energy consumption, a building designed according to energy-saving standards lowers economic costs during the building's useful life, more than compensating for the higher original expenditure. Throughout the life cycle of the building, there are fewer CO2 emissions into the atmosphere, which helps society.

### 2.3.1. Building Shape And Geometry

The shape of the building is the one of the parameters when analyzing the energy at building scale. The shape of a building influences the solar energy that it receives as well as its total energy consumption. The radiation hitting a building can increase energy requirements for cooling to up to 25%. Accordingly, building shape not only determines the total area of the facade and roof that receive solar radiation, but also the surface exposed to the outside, and thus to energy losses. [38]

The variables that are related to building shape and which influence heating and cooling requirements are the following:

- compactness index
- shape factor
- climate
- the influence of shape on the life cycle of the building.

The parameters of the building envelope are critical variables to consider since they are related to the energy requirements for keeping a pleasant temperature in the building.

The compactness index is the ratio of the volume to the building facade's outside surface [38]. It has to do with the structure's ability to store heat and prevent heat loss through the facade. A highly compact building is one with a high volume/surface ratio, minimizing the surface area exposed to potential heat losses or gains. The figure depicts two identical buildings with differing compactness indices.

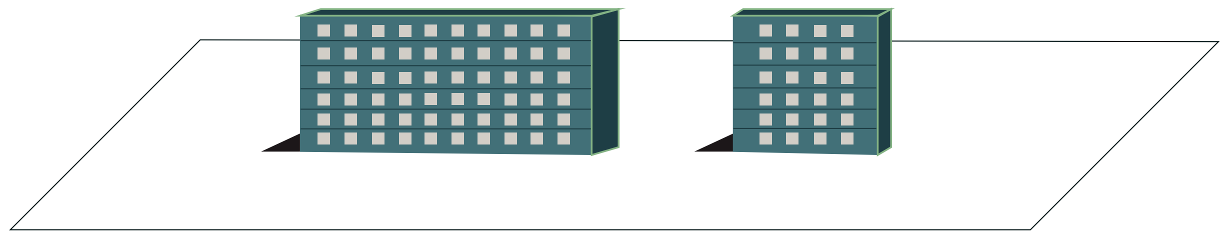


*Figure 65 Buildings with Different Compactness- Left index of 3.5 and Rigth index of 5*

The shape factor is the ratio of building length to building depth. Along with orientation, this factor defines the percentage of the facade exposed at each cardinal point. Both factors are generally studied together. By combining the optimization of shape and orientation, it is possible to obtain benefits that can lead to heat energy savings of 36%. [38]

In general, the design and form of a structure have a direct impact on its efficiency and energy consumption, as larger spaces necessitate more artificial lighting and air conditioning. In terms of building size and energy considerations, increasing the building's area will increase heat loss, which is undesirable. To limit heat loss, compact, intense, and bulk shapes are desirable. Furthermore, square or rectangular designs would conserve heat while also facilitating natural light and ventilation circulation within the structure.

In terms of climate and shape orientation, in very cold climates, more heat escapes through the building envelope than the amount of heat that can be gained by increasing the surface receiving solar radiation [39]. When a result, as the shape factor increases (more external building surface for the same volume, lower compactness index), the amount of energy required for heating increases. This proportion is not direct in warm areas, and a definite type of construction performance cannot be identified.

### 2.3.2. Settlement Standards and Orientation

The design concerns that are examined at the building scale consider not only the construction characteristics but also the location of the building. When choosing a suitable location to settle, climatic type and zone must be taken into account, as topography, sun path, humidity, and wind direction all play a role in the design process at the building size.

For example, in a hot, dry environment like that of Ankara, Turkey's capital, the best topographical grounds for settlement are the middle or lower center of the slope. [39]

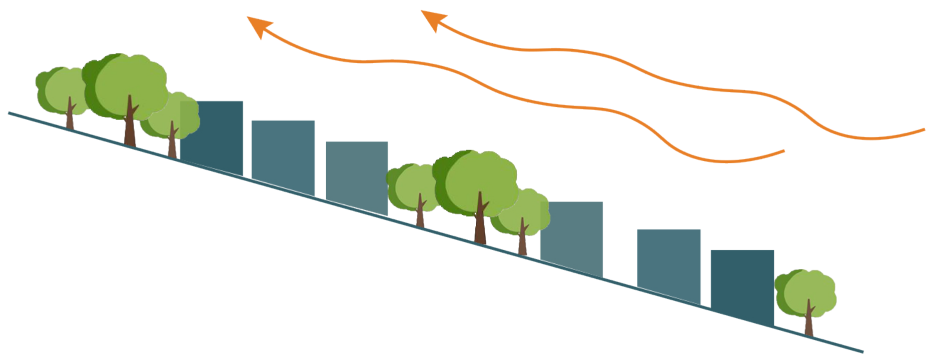


*Figure 66 Preferred Topography to Settle Up a Building in Dry Climate Temperature*



Other case in the consideration of settlement for a building is the orientation. There are relations between the building orientation and heat demand and between the building orientation and shape. For example, when the building shape is rectangular and the small portion of the building surface look east, this orientation gives more profit in terms of energy saving and lower heat demand [38]. In general, finding the best location for a building leads to increased energy savings in the structure. In the table below, an example of energy savings based on a rectangular building when the orientation is shifted to south in reference is shown.

Energy saving ($/year)

| Installation | Change in orientation ( in reference to the south) | | |
|---|---|---|---|
| | 30 ° | 45 ° | 60 ° |
| Heating | 29 | 26 | 36 |
| Cooling | 58 | 15 | 0 |
| Heating, ventilation, and air conditioning (HVAC) | 53 | 38 | 23 |
| Total | 140 | 79 | 59 |

Table 6 Energy Saving Obtained Based on The Orientation of A Rectangular Building [38]

The amounts of direct radiation hitting the building façade depends on the azimuth in the wall, and building's angle. The Southern side of a building generally receives the maximum level of solar radiation, and Northern side receives the minimum amounts of radiations. Based on this fact, a southern building orientation can be considered as an optimal orientation for receiving the highest level of sun's rays in the winter and controlling ingress lights in the summer. [40]

### 2.3.3. Thermal Insulation and Thermal Inertia

The clear areas of a structure should enable passage to solar radiation, which is good for indoor lighting and crucial for contributing to passive heating of the interiors without boosting the transmittance of the building shell.

It is necessary that the thermal layer of the envelope be continuous and characterized by low U-factor to ensure the efficiency of energy performance. Insulation is necessary to assure energy efficiency: a high mass contributing to increase the thermal inertia of the system is not sufficient to limit the thermal conductivity of the building envelope. For instance, for a natural stone wall 60 cm thick, plastered on its sides, we can assume a value of thermal transmittance of 2,20 W/m2K, about seven times higher than what would be necessary to benefit in terms of a discrete containment of energy. To limit heat transmission, the application of appropriate layers of insulating material is necessary: in general, monolayer constructive solutions do not provide sufficient insulation in cold climates, even when using efficient elements of brick. [41]

Light-technologies and insulated building envelope solutions offer strong thermal transmittance and are frequently used in cold areas. They are often realized with wooden frames and gaps filled with insulating material, thermal layers, and protective coverings. Wood's low heat conductivity is a good example.

Since recent researches have been primarily aimed at codifying appropriate construction technologies for the containment of energy during winter, it seems appropriate to focus on the climatic characteristics, in particular on the passive protection from summer heat. If heat insulation is the most important factor, and the most codified one from a regulatory point of view, as regards different climates, in particular warm ones, the role of thermal inertia of a building system gradually assumes importance. [41]

Traditional Italian architectures can represent as simple but effective bioclimatic reference models, capable of maintaining a sufficient indoor temperature without the use of auxiliary fixtures and fittings, thanks to proper architectural form, exposure, soil relationship, and, in particular, the thickness and mass of their envelope.

As a result, in addition to transmittance, it is critical to evaluate the role of massive materials in relation to higher heat capacity in order to limit the effects of external temperature changes on the microclimate indoor.

### 2.3.4. Passive Systems

The most sustainable energy technique is to conserve energy as much as possible. Passive techniques, especially in the developed countries, are growing interest in the building architecture. Generally, the passive design is the simplest and the most cost-effective strategy that architects could implement to reduce energy consumption and enhance thermal comfort and building performance. These systems especially developed for arranging the climate of the building which is passive cooling. These mechanisms are based on the natural convective movement caused by the different densities of cold and hot air. On the other hand, passive solar building can aid energy conservation efforts because building design is directly related to energy use. [38] [39] [42]

#### 2.3.4.1. Passive Cooling System

Passive cooling is defined as the limitation of heat inside buildings by means of natural processes to expel heat into the atmosphere (i.e. convection, evaporation, and radiation), or into the ground beneath buildings. The efficiency of passive cooling systems is closely related to the nocturnal and diurnal outside temperature gradient with maximum temperature peaks, depending on the location. Certain passive cooling procedures are immediately effective (e.g. natural ventilation and direct evaporative cooling). Other systems store cold energy in the structural mass of the building. The following sections are a summary of the most important types of passive cooling methods listed in the figure below. [38]

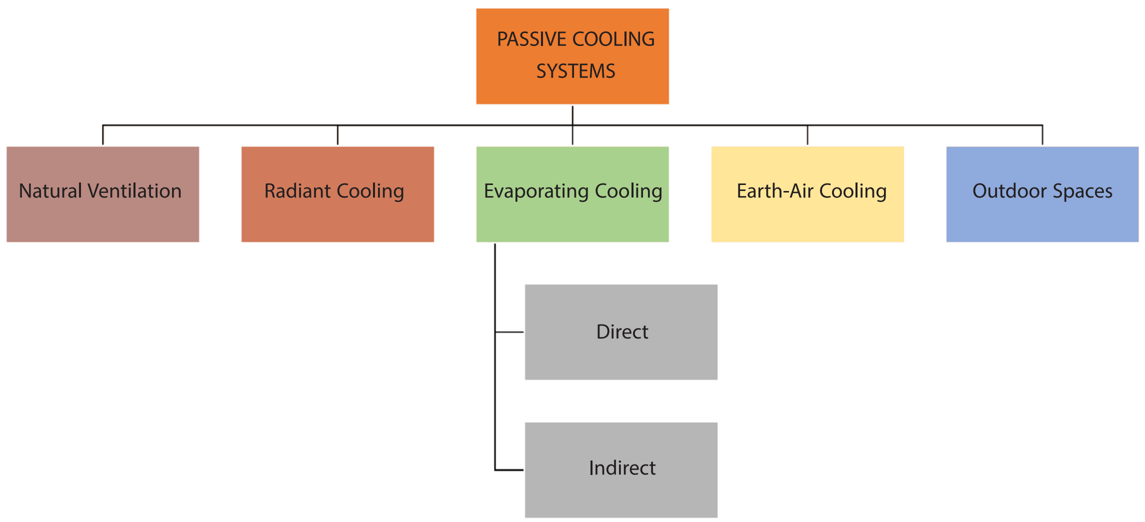



*Figure 67 Classification of Passive Cooling Systems*



##### 2.3.4.1.1. Natural Ventilation

Natural ventilation is also known as comfort ventilation and is based on the positive psychological effect of a suitable air flow throughout the building [38]. Even when the temperature and humidity of the outside air and the interior air are the same in hot humid climes, this impact significantly improves the inhabitants' feelings of well-being. As a result, daily ventilation is required to reduce the psychological effects of high humidity and increase convective heat loss. The phrase "advanced naturally ventilated building" was coined to describe structures that employ the stack effect (natural air movement caused by temperature and density differences), as seen in the diagram below.

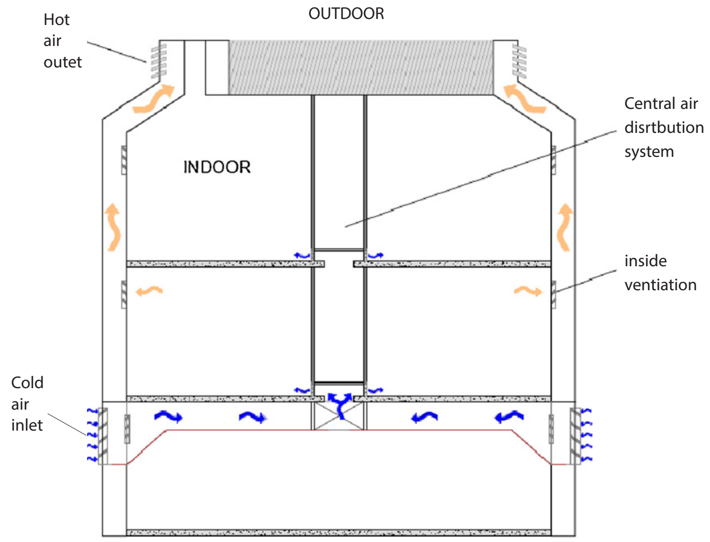



*Figure 68 Operation of A Natural Ventilation System [38]*

##### 2.3.4.1.2. Radiant Cooling

Radiant cooling requires the construction of roofs made of heavy and highly conductive material (e.g. concrete) as well as insulation material. During the day, the external insulation on the roof minimizes the heat gain from solar radiation. The cooled roof mass can then act as a heat sink, and absorb, through the ceiling, the heat penetrating into and generated inside the building during the daytime hours. This system is effective and related to radiant heat loss during the night.

##### 2.3.4.1.3. Evaporating Cooling

Evaporative cooling takes advantage of fresh air currents to cool buildings by means of the direct or indirect evaporation of the water in the air. One example of direct evaporation is the placement of wetted pads made of fibers in the windows. A drawback of this system, however, is that the pads block the view through the windows. In indirect evaporation systems, the moisture content of indoor air does not increase.

The air from the outside enters the roof, which is at a lower temperature. From there, the cool air is distributed throughout the building by means of convection. In the figure below, there is an example which shows reduction in indoor temperatures.

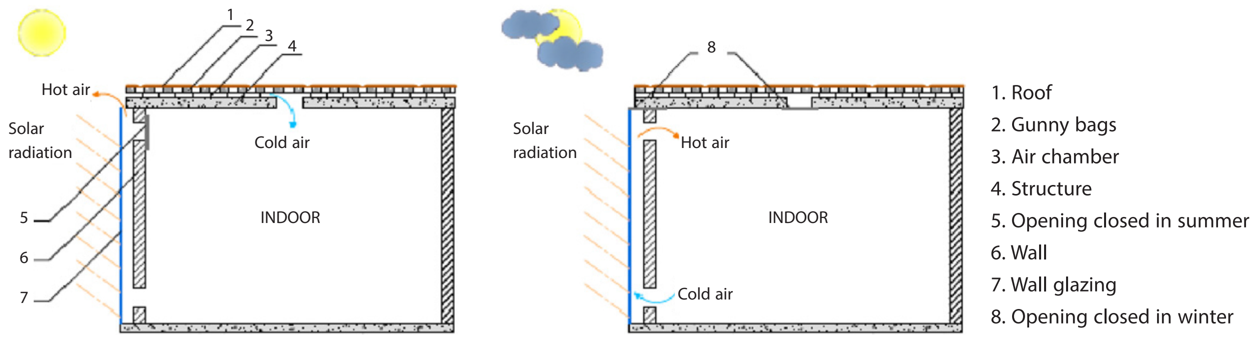



*Figure 69 Evaporative Cooling System [38]*

### 2.3.4.1.4. Earth-Air Cooling

Earth-air cooling takes advantage of the thermal inertia of earth to cool the building. In this type of system, buildings can be either totally or partially underground. Alternatively, underground air conducts can also be installed. In temperate climates, the natural temperature of the earth in summer at a depth of 2–3 m can be sufficiently low so that the earth can be used as a cooling source. In warmer climates, the natural temperature of the earth in summer is generally too high for this. [38]

### 2.3.4.2. Passive Heating System

Passive heating alternatives based on thermophysical qualities and building envelope architecture can reduce thermal discomfort by up to 2/3. The passive use of solar energy stores heat in particular building materials (walls, roofs, and glass). Climate conditions, construction materials, and the direct or indirect usage of solar energy all influence the performance of these systems.

The goal of all passive solar heating systems was to capture the sun's heat within the building's elements and release that heat during periods when the sun is not shining. At the same time that the building's elements (or materials) are absorbing heat for later use, solar heat is available for keeping the space comfortable. More research has been done on passive heating methods than on passive cooling methods. Generally speaking, passive mechanisms work better when they operate in combination with each other. There are different kind of systems for buildings. [38] [42]

### 2.3.4.2.1. Trombe Wall

A Trombe wall is a wall separated from the outdoors by glazing and an air cavity. It also has vents at the top and bottom of the interior wall, to control air flow. Solar energy is stored in the wall, and subsequently conveyed to the inside of the building by conduction. Hot air is released through upper air vents. Cold air enters the space between the wall and the glazing through the lower air vents, and comes in contact with the wall, which makes its temperature rise. Afterwards, the cycle begins again. The figure below shows various example.

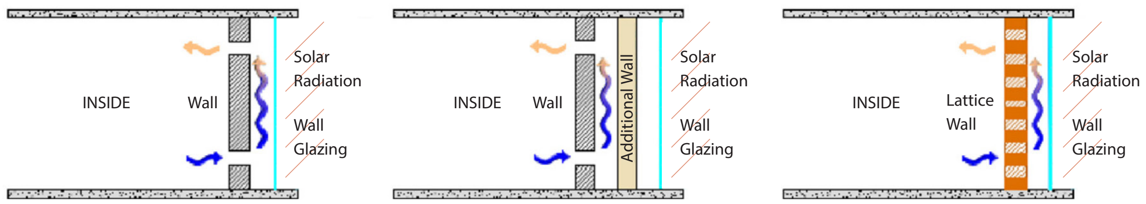



*Figure 70 Trombe Wall Examples [38]*



### 2.3.4.2.2. Solar Chimney

The solar chimney is based on natural convective air movement stemming from the variation in density of indoor air currents. In those cases in which the chimney is attached to the building wall, it operates similarly to the Trombe wall, and also provides benefits in the summer. Despite its positive results, the use of a solar chimney is not always feasible for aesthetic reasons. Depending on the distribution and opening of air vents, the solar chimney can act as a natural ventilation system, passive heating method, or thermal insulation device, as shown in the figure below.

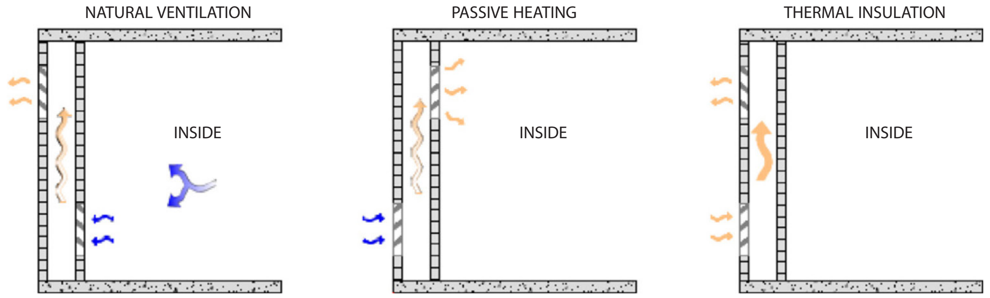



*Figure 71 Solar Chimney Models [38]*

### 2.3.4.3. Glazing

Window glazing is one of the weakest thermal control points in building interiors. In a standard family residence, 10–20% of all heat loss occurs through the windows. [38] There are different type of glazing types which  provides energy saving and it can be classified with following types:

• Heat absorbing glass, this glazing transforms solar radiation in heat energy (i.e. increasing its temperature), and distributing heat throughout the room by means of convection and radiation to reduce the direct radiation through the glass.

• Heat reflecting glass: this glazing has a coating or film that blocks the entry of solar radiation into the building.

• Low radiation glass: this glazing also has a coating or film which reduces the heat transfer coefficient. It can also facilitate energy saving in winter.

The use of double glazing is another approach to improve window performance. This approach works well in both hot and cold weather conditions. Double glazing with a film coating that limits the heating of the window surface is the best option in hot climates, while double glazing with a film coating that limits the heating of the window surface is the best option in cold climates.

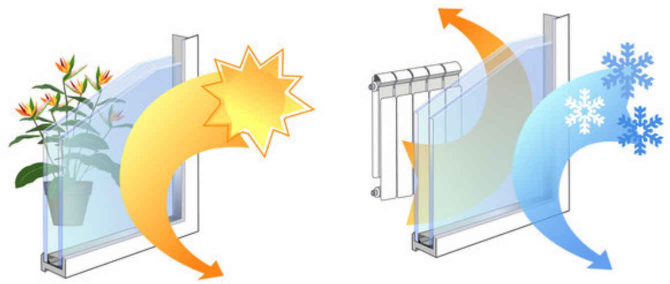


*Figure 72 Advantages of Double Glazing* [43]

## 2.3.5. Climate Mitigation and Adaption

Climate change is already affecting Europe's and the world's ecosystems, and it will continue to do so in the future, posing new challenges to biodiversity and ecosystem function. Climate change has a huge impact on society, with the greatest impacts likely to be felt in metropolitan areas. The effects of heat waves and other severe events (e.g., flooding, droughts, etc. ), changes in infectious disease patterns, and repercussions on food yields and freshwater supplies are also major concerns.

Given the growing threats to biodiversity and society, green and blue spaces within cities and at the building scale are increasingly being recognized for their ability to not only support biodiversity conservation, but also to generate additional environmental, economic, and social benefits, as well as to foster ecosystem functioning as critical backbones for climate change mitigation and adaptation.

In response to climate change, cities around the world are already implementing ambitious actions to reduce emissions (mitigation) alongside efforts to increase their climate resiliency (adaptationc), to protect citizens and infrastructure against current and future extreme weather events. [44] [45]

International efforts to tackle climate change were significantly strengthened during past decade. Another strategy to mitigate climate effect not only buildings but also in urban scale is reducing the Greenhouse Gas (GHG) emissions as.

Most of the country have already been involved to this agreement by Paris Agreement and they targeted to reduce these emissions %20 by 2020 and %40 by 2030 compared to 1990 levels. [46]

The majority of industries are required to obey these norms, and the building and construction industry plays a critical part in this agreement. As a result, increasing building energy efficiency plays a critical part in realizing the ambitious goal of carbon neutrality, while also being a vital aspect in the evaluation of sustainable living space.

Furthermore, buildings are found to be affected by global warming over time due to changes in external conditions, resulting in decreased energy performance and thermal comfort, which includes high-performance buildings. According to five major targets can be identified  in the research studies on climate change and its impact on buildings:

- evaluation of the climate change impact on building energy consumption
- adaptation and mitigation measures for buildings against adverse effects of climate change
- models for building retrofitting and renovation to cope with the changing climate
- new tools and methods for future climate projection
- uncertainty of climate projection models and their impact on building simulation results [46]

It is critical that cities make investments in the zero-carbon transition that are robust to current and future climate and extreme weather events. Cities that fail to incorporate climate change adaptation into renewable energy, buildings, transportation, waste, and other vital sectors risk underinvestment and missed opportunities. Early evaluation of climatic threats and appropriate actions can thereby reduce risk for building owners while also reducing project costs.



Cities can play a key role in ensuring that new buildings are both energy efficient and climate-adaptive. The following are critical processes to achieve integrated energy efficiency and adaptation measures when developing new building and zoning legislation, rules, and standards.

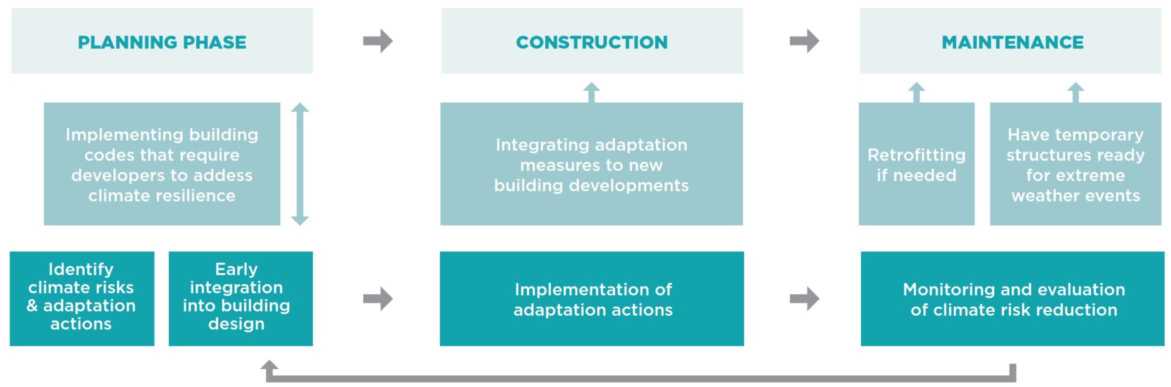



*Figure 73 New Building Development Cycle [44]*

In the planning and building site determination phase, understanding a city's climate vulnerabilities will allow cities to avoid building new developments in climate vulnerable areas. Constructing Low and Zero carbon developments with a climate adapted design and choice of materials represent a key opportunity for cities to reduce their emissions, as well as to improve their resilience. These measures are described below with some examples. [44]

### 2.3.5.1. Extreme Whether Events

#### 2.3.5.1.1. Integrated Energy Efficiency Strategy

Implement building efficiency measures to reduce reliance on energy-intensive heating, cooling, and electrical systems that are prone to failure in extreme weather. During power outages, buildings with passive design features will be more comfortable and robust.

On the other hand, other aim is integrating energy storage and microgrids to improve community energy resiliency during power outages and including robust and resistant materials choices in building standards.

#### 2.3.5.1.2. Building Design Strategies

During the design of the building, design strategies for building heating/ cooling/ventilation services are important to prevent or reduce damage from precipitation.

#### 2.3.5.1.3. Strategic Planning For New Development

When providing planning guidance for new developments, take into account future climate estimates and probable extreme weather is important key step during the design of the building.

### 2.3.5.2. Flooding

#### 2.3.5.2.1. Building Location

Most of the cities has potential risk due to flooding. In this case using city's risk assessment plan for modelling flood risks is important to avoid new building developments in flood prone areas and on natural drains. Additionally, another key is important weather conditions which gives rise to flooding. In this case, it is important to integrate effective storm water management system

#### 2.3.5.2.2. Building Design Strategies

During the design, it is important to focus on energy efficiency strategy reducing energy demand and dependence on services that can be prone to damage from flooding. Additionally, it is critical to develop guidelines for strategic design for heating/cooling/ventilation services to prevent or reduce flood damage.

Integrating flooding adaptation measures -permeable material, green areas and green roofs as repository for rainwater is another point to take into account.

When building in flood zones, require raised floor level and ban of basements to prevent flood water entering inside the building in areas prone to flooding.

#### 2.3.5.2.3. Energy Storage

Strategically place building-scale energy storage is critical to reduce the risk of damage during flood events.

### 2.3.5.3. Drought

#### 2.3.5.3.1. Focus on Water Efficiency Strategy

In this decade, the drought is strictly critical for all the word. Thus, focusing on water efficiency strategies are playing important role. As some examples to this strategies, we can develop and implement sustainability standards that address both energy and water efficiency. Using technologies and other measures like green roofs or wastewater heat recovery systems to address water efficiency and energy efficiency will help to fight with the drought. Also, when we use water efficient fittings, we can reduce water usage of buildings.



### 2.3.5.4. Extreme Heat

#### 2.3.5.4.1. Reducing Cooling Demand for New Buildings Through Building Codes and Standards

To protect building from extreme heats, reducing cooling demand is important factor when designing new building. Here there are some strategies which give profit to the building:

- Use green roofs to improve building's insulation, and to remove heat from the air through evapotranspiration.
- Increase vegetation to help reduce external surface temperatures of walls and paths through shading and evapotranspiration
- Use cool/white roofs that reduce the heat absorption of new buildings.
- Develop specific standards for glazing to wall ratios, glazing performance and blinds/fixed external shading to mitigate solar gain whilst also ensuring adequate daylighting.
- Integrate passive design measures including insulation, air permeability, orientation and shading to help maintain comfortable indoor temperatures.
- Increase thermal storage through building materials. [44]

# 3. ENERGY SAVING TECHNOLOGIES IN BUILDINGS

# 3. Energy Saving Technologies In Buildings

## 3.1. Introduction

Mankind has been forced to seek shelter behind walls and beneath a roof for centuries. Despite all of the technological advancements in design and construction, buildings have essentially the same goal, which is to offer shelter, climate control, and safety at an efficient level. Buildings are now more than just a roof and four walls. Concerns about safety, comfort, global warming, and climate change are driving technological advancements that combine ambient intelligence with home automation to make buildings safer and more comfortable to live in. The structures are now more efficient, safe, and comfortable.

All the technologies in the buildings have results in return as energy demand. The designers, engineers and architects have to create not just, comfortable, safety and more optimized buildings but also they have to create the buildings together with the technologies which are saving the energy usage. [47]

Some of the famous and emerging technologies in the field of energy saving in a building are:

- Connected and Smarter Homes
- **Building Envelope Technologies**
- Light Pipe Technologies
- Next Generation Insulation
- Cogeneration
- Reflective Roof
- Advanced Window Control System
- HVAC systems and Controls [48]

## 3.2. Connected and Smart Homes

Most countries in the world have a good stock of old and historic buildings which are highly energy intensive. This means that mostly the buildings are energy inefficient. Even if all new buildings were to be built as net zero energy (structures that produce the amount of energy they consume) from today on, it would take decades to have an appreciable effect on overall energy consumption.

In addition, the building sector is growing at an unprecedented rate and consume about 40% [47] of global energy for lighting, cooking, heating, cooling, ventilation, and operating electric and mechanical devices. Therefore, sustainable architectures which produce minimum carbon footprint and offer higher comforts have become a global priority. Around the world, a number of building regulations are enforced to reduce energy consumption in built environments in the framework of climate change.

Smart Homes Architecture is automated intelligent buildings that allow their devices and environments to be controlled either locally or remotely via internet. Smart management solutions are used to automate and optimize the building operations. These functions not only make buildings energy efficient but also allow itself to adapt to certain situation to enhance the occupant' convenience and comfort. Also using ICT and IoT systems help reduce energy consumption via better management of devices, remote maintenance, and accurate and timely prediction of weather. Smart homes can also adjust lighting and temperature controls automatically depending upon the weather conditions. At the below figure, there is an example of a smart home which connected to the smart grid made by Schneider Electric.

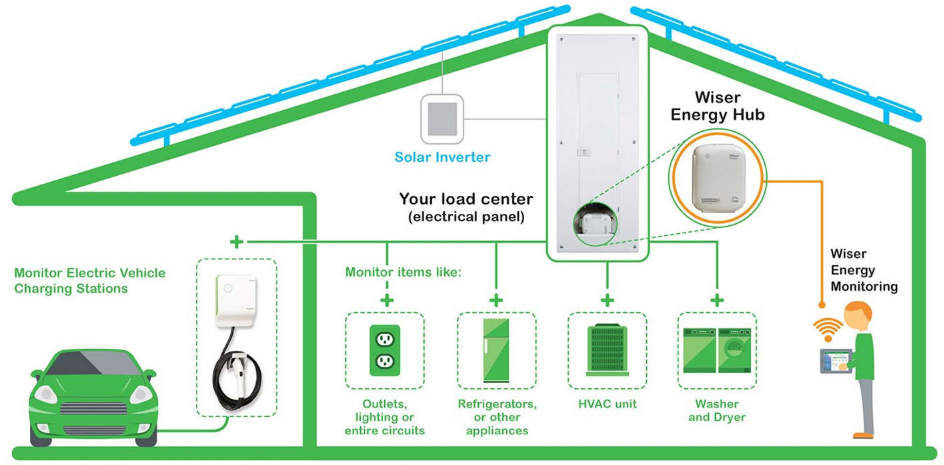



*Figure 74 Smart Home Solution by Schneider Electric* [49]

## 3.3. Building Envelope Technologies

The building envelope is considered the first line of defense against environmental impacts on the building. The main functions of the building envelope are to provide shelter, security, thermal, solar control, indoor air quality and moisture control, access to daylight, fire resistance, views to outside, acoustical control, aesthetical value to a building. [50]

The essential components of a typical building envelope are depicted in the figure 78. Building type, climate, geographic location, building materials, and construction method, among other factors, have a significant impact on a building's energy performance during its lifetime and occupancy.

The building envelope performs regulatory activities such as temperature control, moisture control, and indoor air quality control to reduce environmental impacts on the indoor environment of structures. It interacts with three main parts of the building, which are:

- Exterior environment including external environment and geo-environmental.
- Interior environment.
- The envelope system itself.

New technologies are developed to increase the efficiency of the building envelope. Mainly windows of the building structures are improved by the following methods:

- The properties of the windows can be changed according to the temperature and light-level conditions i.e during day and night by providing chromogenic glazing.
- Optimisation of solar gains and the shading effects can be done by using spectrally selective glasses for the windows.
- Photovoltaic panels can be used to generate electricity by absorbing the solar radiation. This also helps to reduce the heat moving through the building envelope. [48]

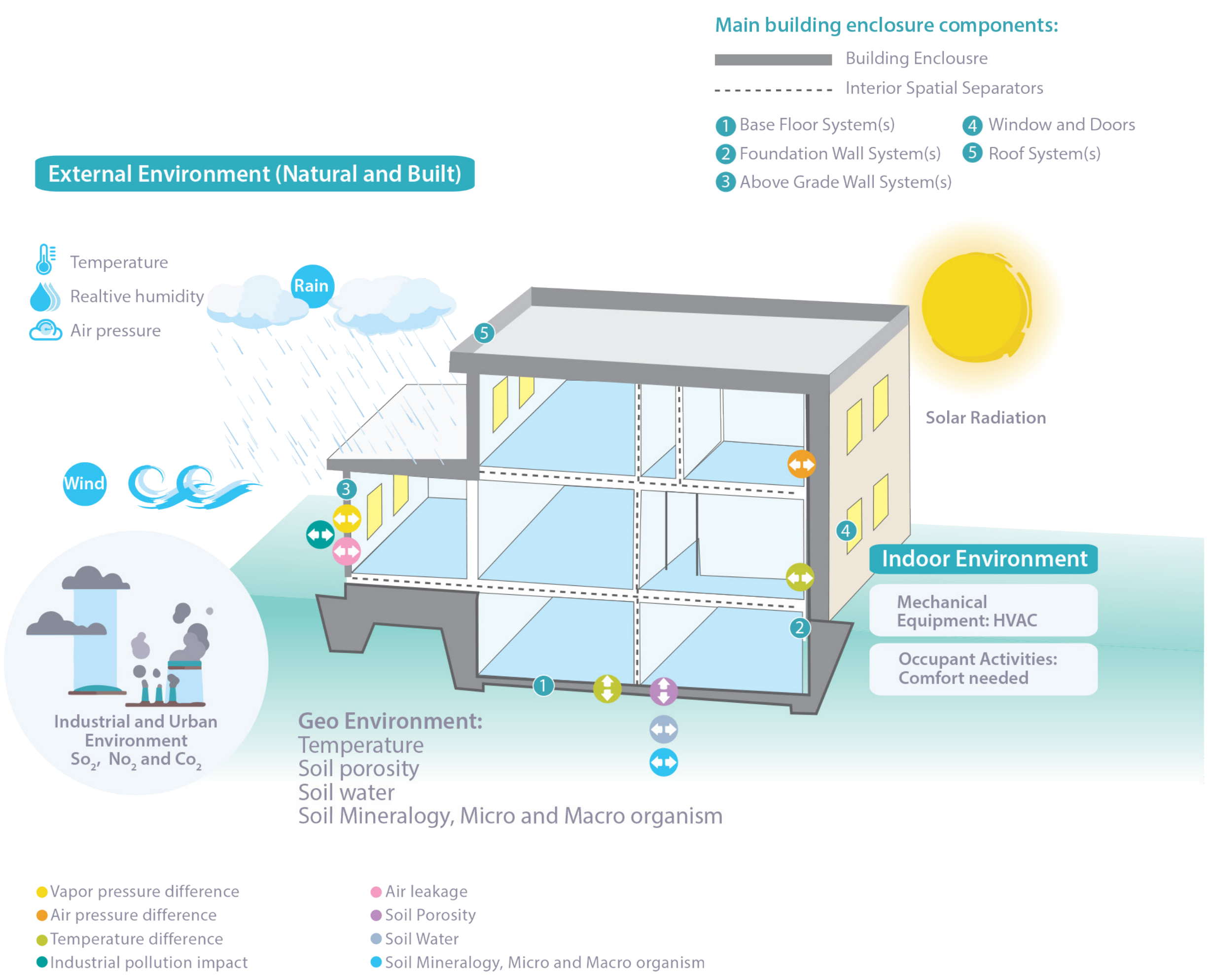



*Figure 75 The Main Building Envelope Components and Environmental Loads on The Building Envelope* [50]

In general, the building envelope is critical in determining the amount of energy required for heating and cooling. As a result, while retrofitting an existing building, it should be optimized to develop a long-term energy reduction strategy by lowering heating and cooling loads. Retrofitting an existing building envelope to make it more energy efficient is an important part of increasing building sustainability.

Buildings are the single largest energy consumer in Europe, accounting for approximately 40% of the EU's energy consumption. Nearly 35% of the buildings in Europe are more than 50 years old and almost 75% of the building stock is considered as non-energy efficient. [51]

At the same time, the building renovation rate stays rather low, averaging around 1% per year. [51] Increasing the rate of refurbishment can lead to more efficient energy consumption and lower CO2 emissions while also enhancing indoor thermal comfort.

On the one hand, several energy retrofit solutions targeting the building envelope and the building's thermal and electrical systems can be explored.



Additionally, the connection between building envelope and building sustainability is one of the key factor during building design and building retrofitting.

It is difficult to achieve building sustainability, especially when dealing with existing structures, because numerous elements must be considered. As shown in the following diagram, external and internal environmental factors have a substantial impact on building sustainability, followed by other aspects such as the building envelope, building elements, material qualities, and thermal processes.

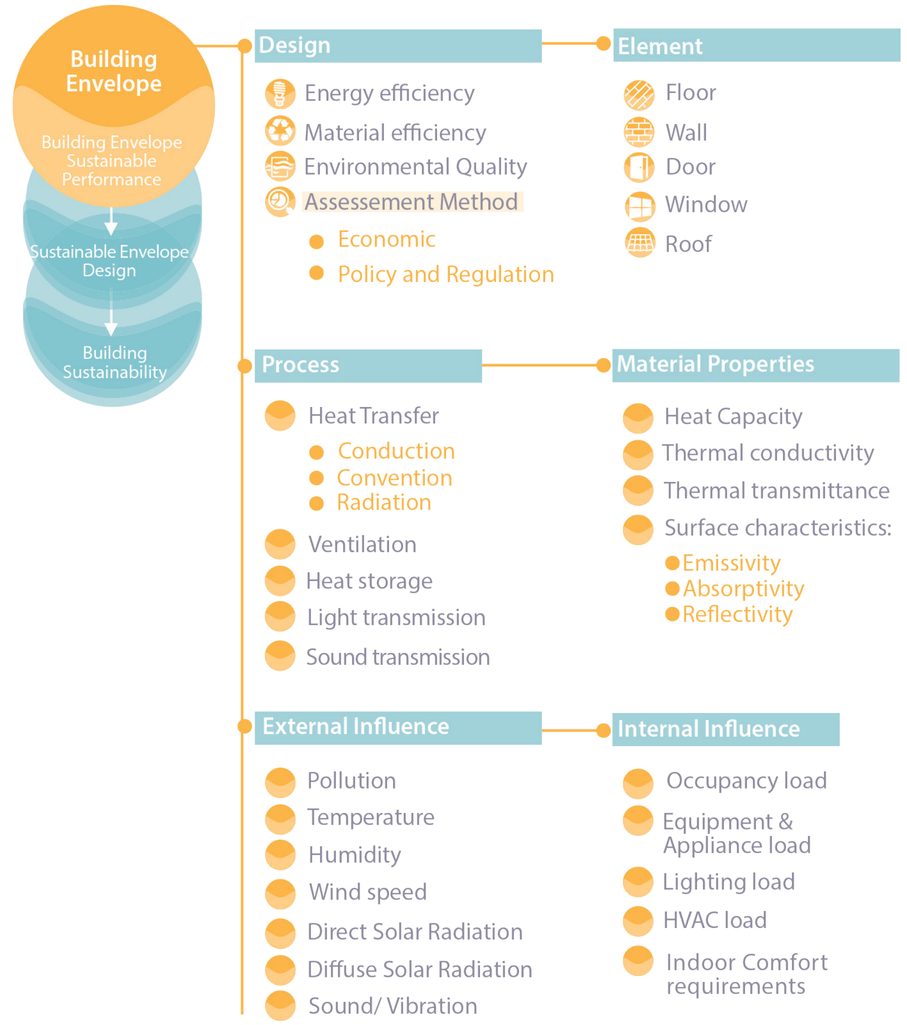



*Figure 76 The connection between building envelope and building sustainability* [52]

### 3.3.1. Retrofitting The Building Envelope Optimizes

Retrofitting the building envelope to reduce thermal losses through transmission and infiltration is a logical and effective first step. The first step in creating an energy efficient structure is to reduce heat (or freshness) losses from the conditioned interior space to the outdoors.

To affect the retrofitting in the building envelope,  the solutions to increase energy efficiency classified in 3 steps. [51]

1. Reduce the overall energy demand of the building by measures such as good insulation.
2. With the energy demand being reduced to an acceptable level, the next step is to use as much sustainable energy sources (e.g. solar, wind, geothermal…) as possible to supply the remaining demand.
3. If sustainable energy sources are not available, fossil fuels should only then be used and in the most efficient way possible.

On the other hand, retrofitting the building envelope will achieve many benefits, but with the focus on energy, the main benefits would include:

- Optimizing energy efficiency in the building as a whole and reducing energy bills related to the Cooling and Heating of the building.
- Improving the thermal comfort for occupants.
- Enhancing the health and increasing the productivity of occupants.
- Reducing maintenance costs related to the decaying of the building structure.

For better understanding the retrofitting in the building envelope before going to the strategies, we should understand the importance of energy use in the buildings, indoor air quality and thermal comfort in the building.

#### Energy Use In Buildings

The building envelope has a significant influence on the heating and cooling demand of buildings. Therefore, enhancing the energy efficiency of the building envelope reduces the energy costs on the building scale by reducing the need for heating, cooling and ventilation. [52]

#### Indoor Air Quality

The comfort of the building's occupants is influenced by the building envelope. Improving the condition of an existing building envelope to improve ventilation could increase their productivity while also lowering the influence of the indoor environment on their health and lowering the requirement for artificial ventilation.

#### Thermal comfort

Increasing the thermal insulation of an existing building envelope reduces heat loss in the winter and heat gain in the summer, improving the thermal comfort of the occupants.

An Energy Efficient Building Envelope improves both indoor air quality and thermal comfort while using less energy.

The following pictures illustrate simplified graphical methods for evaluating thermal comfort inside buildings according to the local Thermal Insulation Guide, with the effect appearing on both thermally insulated and non-insulated walls. [52]



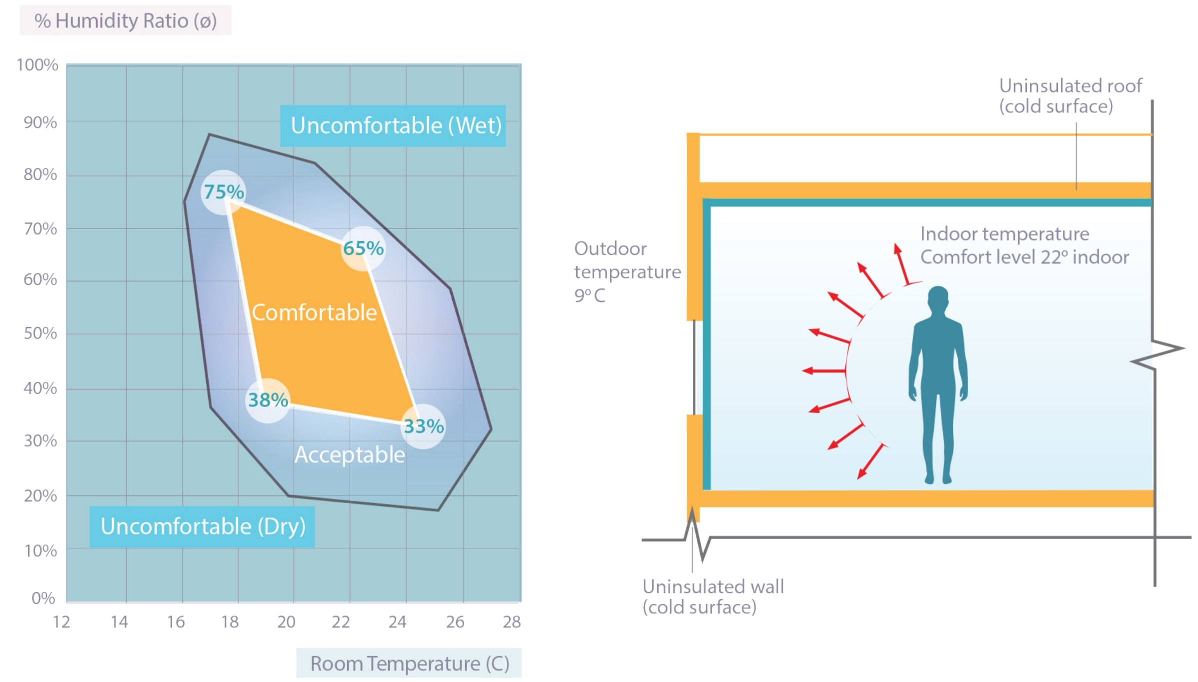



*Figure 77 The Relation Between Humidity And Room Temperature Showing The Uncomfortable, Acceptable And Comfortable Areas* [52]

Even when the indoor temperature meets the comfort zone's requirements, the temperature of the room surfaces has an impact on the occupants' thermal comfort. The reason for this is that, even when the room is heated and at a comfortable temperature level, the occupant's body will radiate towards the cold room surfaces, which are not thermally insulated, in the winter. This would make the occupants uncomfortable, requiring the discharge of more heat into the room, increasing the energy requirement for heating. The following figure illustrates the relation between the temperature of the room surfaces and the indoor temperature to achieve thermal comfort.

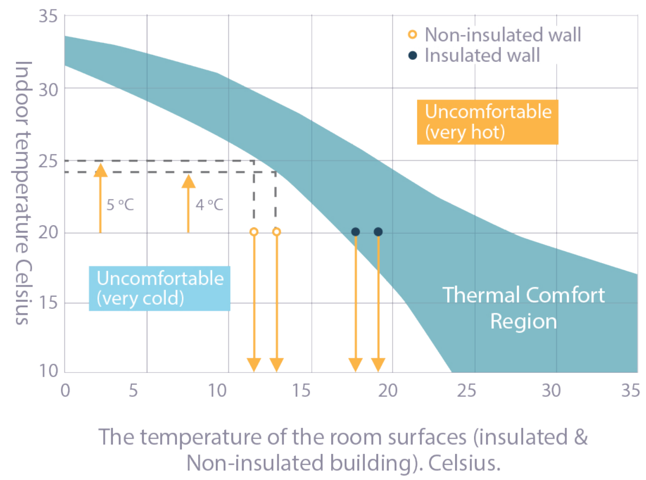



*Figure 78 The Relation Between The Temperature Of The Room Surfaces And The Indoor Temperature To Achieve Thermal Comfort* [52]

### 3.3.2. Retrofitting The Building Envelope Strategies

#### 3.3.2.1. Thermal Performance Paramaters

**Thermal Conductivity (K-Value)**

The basic measure of how much heat energy is conducted by any building material, including thermal insulation materials, is thermal conductivity. It is characterized by the lambda ($\lambda$) value, or k value (unit: W/m*K). As a rule of thumb, the lower the thermal conductivity the better, since the material conducts less heat energy. 'k' and '$\lambda$' are material characteristics, whereas 'R' and 'U' as discussed below are building component characteristics. [51] Typically this is important in assessing the potential for heat transfer between the inside and outside of a building. [53]

**Thermal Resistance (R-Value)**

Thermal resistance is a measure of how well a two-dimensional barrier, such as a layer of insulation, window or a complete wall or ceiling, resist the conductive flow or heat. It is also known R-Value in the buildings. [54]

Basically, thermal resistance is the inverse principle of conductivity. The lower the conductivity, the higher the resistance. To compare the relative performance of different thicknesses of materials (and composite building parts consisting of several layers of different materials) implies assessing their thermal resistance (unit: m2*K/W).

Thermal resistance is calculated by dividing the thickness of the material by its thermal conductivity, giving an R value specific to that thickness. As a rule of thumb, the higher the thermal resistance the better, as there is a greater resistance to heat transfer. Resultantly, the thermal resistance can be increased by selecting a material with a lower conductivity and/or by providing a thicker layer of that insulation material. In a composite wall, the thermal resistances of the different layers add up. [51]

**Thermal Transmittance (U-Value)**

The growing attention to energy savings in the building sector has led to more and more performing walls characterized by very low values of thermal transmittance. A U-value is a measure of thermal transmittance, or the amount of heat energy that moves through a floor, wall or roof, from the warm (heated) side to the cold side (unit: W/m2*K). As a rule of thumb, the lower the U-value the better. In this way, U is the inverse of R. Basically, this parameter describes the insulating capacity of a wall; it depends on its global layout and on the characteristics of the single layers. [51] [55]



#### 3.3.2.2. Facades/External Walls

The building envelope is the physical interface between the indoor and outdoor environments of a building, and it is responsible for much of the energy balance that occurs in the building. As a result, the type of construction used in the facade is a key factor in determining the energy performance of a building and therefore its level of sustainability.

For example, the extensive use of glass (very common in office buildings of large European and North American cities) directly affects the energy needs of the building and its level of internal thermal comfort. [56] For facades, the insulation layer can be placed externally, internally or in the wall cavity.

##### 3.3.2.2.1. External insulation

External insulation implies that one or more insulation layers are applied to the external surface of the wall. The extent to which the existing wall is dismantled depends on its state of conservation and on the type of insulation. The existing rendering or cladding of the external surface sometimes needs to be removed before putting the new insulation layers. [51]

On top of the newly additional insulating layer, a new facade finishing is usually required. Rendering is a classic example, but light facade systems and even a new outside stone or brick blade are also viable with the correct support systems in place (support frames attached to the existing facade or new foundations).

External insulation is the preferred option from a building physics point of view because: it provides the most guarantees for achieving a continuous insulation coat around the building without 'thermal bridges' (interruptions in the insulation that cause accrued thermal losses and lead to risks such as condensation); and it completely 'packs' the thermal mass of the building structure so that it can work as a heat (or cold) storage within the protected volume, reducing the risk of condensation.

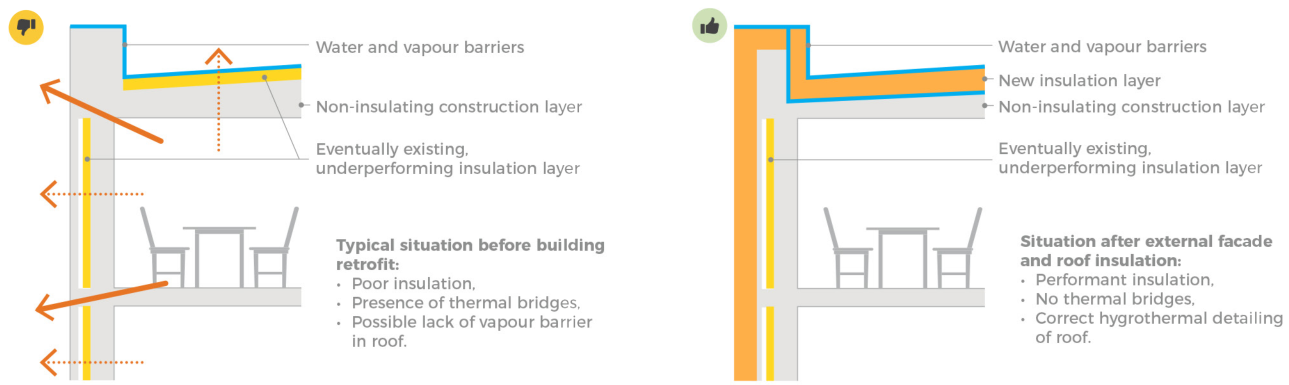



*Figure 79 Wrong(Left) and Correct(Right) External Isolation Examples [51]*

### 3.3.2.2.2. Internal insulation

Internal insulation means adding an insulation layer on the inside of the external wall. The most common method is to build a new stud wall and to add the insulation layer into its structure. [51] Internal insulation, on the other hand, might be inconvenient because it necessitates the removal and reinstallation of indoor goods or equipment. It is also sub-optimal in terms of building physics.

Furthermore, the internal insulation package reduces the usable floor area. Internal insulation must therefore be considered as a viable alternative when other options are unavailable or deemed too complex or costly to implement.

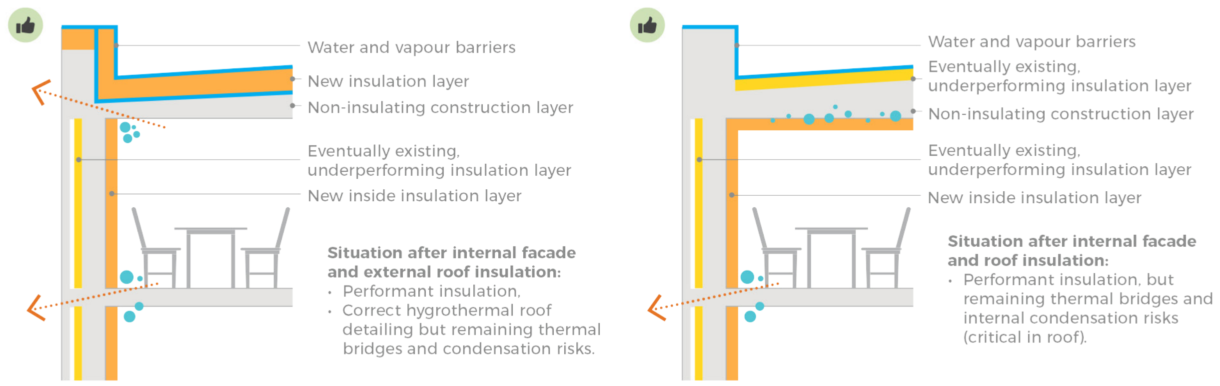



*Figure 80 Internal Facade and Roof Insulation Examples [51]*

### 3.3.2.2.3. Cavity wall insulation

A cavity wall is made of two separate thin walls (usually built of brick, and known as 'skins' or 'leaves') with a gap (or cavity) between them. They are usually held together by metal wall ties. This insulation idea was started to implement to the buildings after 1920s. This insulation type helps to get more cost effective way to retain heat at the buildings and save more energy. Another good benefits of this methodology is  also to reduce carbon emissions at the building. [57]

If the external wall has an empty cavity and the cavity is wide enough (at least 50 mm [51]), the latter can be filled with an appropriate insulation material in order to improve the thermal properties of the external wall.

By replacing the air layer with a more efficient insulation material, the insulation layer lowers heat losses through the cavity. Although this is a very convenient solution (few interruptions, low cost), it does have some drawbacks, such as internal insulation.

Thermal bridges are an unavoidable problem with this method, depending on how continuous the internal cavity is. The breadth of the cavity also limits the potential improvement in thermal performance. The thickness will, however, be sufficient to counteract the typical thermal discomfort associated with chilly external walls.

For any of the above insulation measures, it is strongly recommended to get advice from a building expert in order to realize a durable set-up that fulfils the proper hydrothermal prerequisites.



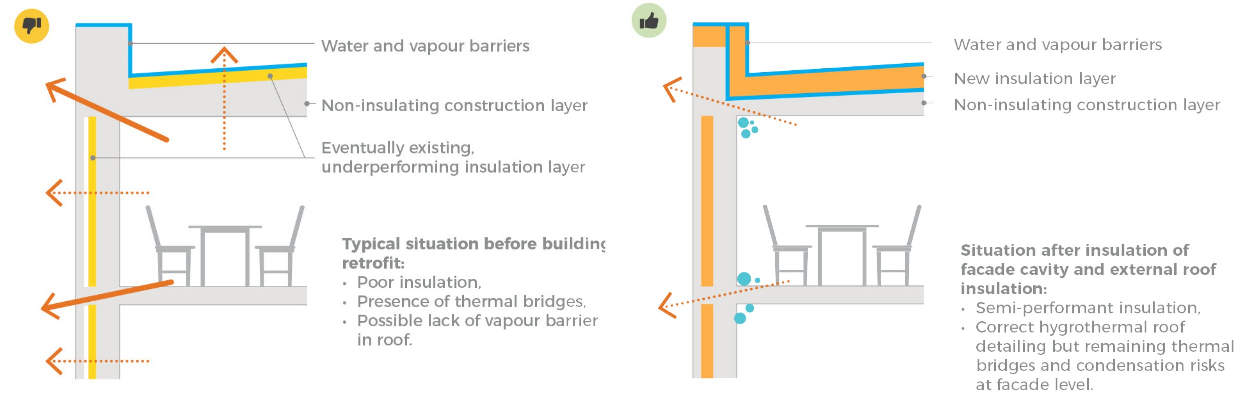



*Figure 81 Insulation of Facade Cavity and External Roof Insulation Example [51]*

### 3.3.2.3. Roof/Attic

### 3.3.2.3.1. Roof insulation

Roof insulation method to prevent heat penetration from the outside environment to inside of the building. The method provides temperature stability and prevents unwanted noise penetration. The importance of thermal insulation has increased recently mainly due to changing insulation standards worldwide, which put higher demands on the thermal resistance of building structures to reduce energy loss for heating or cooling. [58]

Roof insulation is typically more important than wall insulation, and it will be the first measure implemented when prioritizing retrofit interventions. At the same time, roof insulation has a significantly quicker payback time than wall insulation.

The type of roof determines how it is insulated. The proper approaches for flat roofs differ significantly from those for pitched roofs. In order to minimize internal condensation in the roof structure, vapor barriers must be installed where needed and in the proper position while insulating a roof.

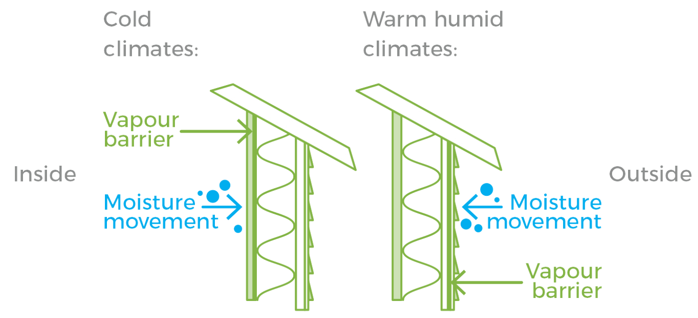



*Figure 82 Installation of Vapour Barriers [51]*

#### 3.3.2.3.2. Attic insulation

A significant amount of the cooling load in residential buildings is the result of heat transfer across the ceiling from the attic space. The ceiling heat flow originates with the incident solar radiation that is absorbed by the roof. [59]

There are two types of attic: cold and warm. In the cold attic, insulation is placed on the attic floor rather than in the roof structure and keeping the loft cold. This may be a viable solution where the attic is not used, or only as a storage space for materials that can resist heat and cold shocks. When storing materials in such attic, attention must be paid in order not to damage the insulation layer in the use phase.

In the warm attic, thermal insulation is placed in the roof structure. In this way, the attic can be used as a living space rather than as a storage space solely. [51] Warm roof solutions are generally more costly to achieve because the slopping area to be treated is greater than cold attic area, but they provide more greater level of heat retention. [60]

### 3.3.2.4. Windows/Doors

Replacing old single- or double-glazing windows with energy efficient glazing and profiles (e.g. low-E glazing, up-to-date double/triple glazing, window frames with double or triple thermal chambers) can significantly increase the energy performance of the building. Indoor comfort will increase as well, as the cold radiation from windows in winter will substantially decrease.

Depending on the thermal properties of the other parts of the building envelope, there may be a restriction to set on the thermal performance of the windows. Installing double-glazed or even triple-glazed windows in inadequately insulated walls might lead to wall condensation.

#### 3.3.2.4.1. Low-emissivity windows (Low-E windows)

Low-E glass windows have a special glass surface coating that minimizes the amount of infrared (IR) and ultraviolet (UV) radiation passing through it, without preventing most of the visible light to come through. The long wave infrared radiation, which is heat, emitted from the room to the outside is reflected back by the coating. [51]

#### 3.3.2.4.2. Double-glazed windows

These windows feature two panes separated by an air or noble gas filled layer. The fenestration system is airtight. A spacer is in place to separate the panes and seal the gas inside.

#### 3.3.2.4.3. Triple-glazed windows

The concept is the same as with double glazing, however, with three glass panes and two layers of gas (either air or noble gases). Triple glazing will result in better thermal properties compared to double glazing. The thermal transmittance of windows includes both the glass and the frame. Correct installation of the glass is crucial in order not to create leaks and draughts near the frame. Commercially available glazing often combines the above characteristics, e.g. coatings and air/gas chambers.

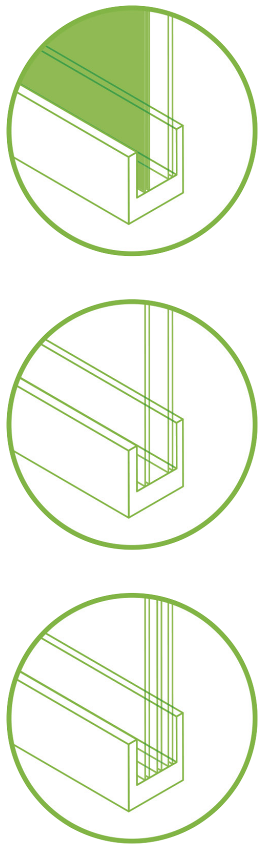


*Figure 83 Energy Efficient Glazings* [51]

#### 3.3.2.4.4. Door replacement

Replacing an old exterior door with an energy efficient door with lower u-value will both reduce the energy consumption and increase the air-tightness of the building.

### 3.3.2.5. Other Measures

#### 3.3.2.5.1. External/Internal shading

The most recent buildings are often characterized by an extensive use of glazing façades. The presence of large transparent components and the application of shading devices have been usually object of analysis because of the large influence of solar gains on the building thermal energy performance, in both summer and winter seasons, on the lighting energy demand and on thermal and visual comfort. In general, all the literature on solar shading devices is oriented to the evaluation of the strategies for the daylight harvesting in order to reduce lighting consumption, for the cooling or heating energy saving and for the indoor thermal and visual comfort. [61]

Shading devices can limit the amount of undesired solar radiation entering the building. They can be either external or internal, either fixed or dynamic. [51] External shading is more effective than internal shading because it prevents solar radiation from entering the interior space, where it will be absorbed and converted from light to heat. Fixed shade can be precisely arranged so that in the winter, low solar altitudes allow sunlight to enter the structure and provide free heat gains, while in the summer, high solar altitudes block the radiation.

#### 3.3.2.5.2. Green roof

A green roof is a vegetative layer on top of the roof. It can improve the roof's thermal and acoustic features, including thermal capacity and heat and noise insulation, as well as retain, collect, and utilize storm water, improve local air quality, lessen the urban heat island effect, and increase biodiversity. A green roof is also more appealing to the eye than a black polymerous surface.

Green roofs help the environment while also lowering energy use. They can reduce heat island by boosting evapotranspiration and adding mass and thermal resistance value. In the winter, green roofs can help to reduce heat loss and energy use. A dense concentration of green roofs in a city can even lower the city's average summer temperatures, reducing the urban heat island effect.

Traditional building materials soak up the sun's radiation and re-emit it as heat, making cities at least 4 °C (7.2 °F) [62] hotter than surrounding areas.

#### 3.3.2.5.3. Insulation materials

The external envelope of a building is critical because it has a significant impact on the surrounding microclimate and serves as a barrier between the internal and external environments, influencing the residents' thermal comfort as well as energy losses during the operation phase.

In the context of sustainability, Life Cycle Assessment of buildings components and of entire buildings has become more and more important, in order to take into account, the whole energy uses starting from the construction up to the demolition. So, using of adequately insulated walls has become more essential. [63] The insulation material, in this context, is the layer that primarily contributes to the overall thermal behavior of opaque walls over the winter and summer seasons, responding to external conditions with its specific thermophysical qualities. Insulating materials must provide acceptable performance throughout the building's life cycle, but thermal performance isn't the only factor to consider when choosing an insulator. Other factors that influence this decision are sound insulation, fire resistance, water vapor permeability, environmental effect, and human health.

Various materials can be used in different components of the building envelope depending on the building envelope retrofit method. The following are the properties of the most commonly used thermal insulation materials:

- Inorganic materials:
    - Glass wool, mineral wool.
- Organic materials:
    - Natural: cork, cellulose, cotton, hemp, straw
    - Synthetic: expanded polystyrene (EPS), extruded polystyrene (XPS), polyurethane (PUR), polyisocyanurate (PIR), etc. [51]

When choosing thermal insulation materials, many factors should be considered, including thermal qualities, cost, simplicity of installation, building code requirements, durability, acoustic performance, air tightness, and environmental impact. When it comes to thermal performance and energy conservation, however, the thermal resistance of insulation materials remains the most essential attribute.

### 3.4. Light Pipe Technologies

This technology allows to "pipe" the light falling on the roof or on a wall-mounted collector to the interior spaces of the building. These interior spaces are spaces not located near to the window or the skylights. [48]

Light pipe is one of the effective ways to reduce electricity consumption for lighting; it can transmit light from outdoor to the room without generating excessive heat. [64] Reduced electricity consumption due to lightning is of particular importance in most cities. Light pipe technology is one of the most effective ways to address these consumption issues in buildings by using more sustainable solutions. Furthermore, light pipe technology may not only cut electricity consumption but also improve the quality of the indoor atmosphere in buildings.

The light pipe technology can used in two different purpose and these are side light pipes and top light pipes. Both of them are used for lighting in different environment. Inside the design of them, there are different type of methods to transmit the light to the building.

In technology, different ways serve different purposes. For example, lenses and mirrors can be utilized to convey light inside a pipe, increasing lighting efficiency. Angled light transportation is aided by prismatic pipes and mirrors.

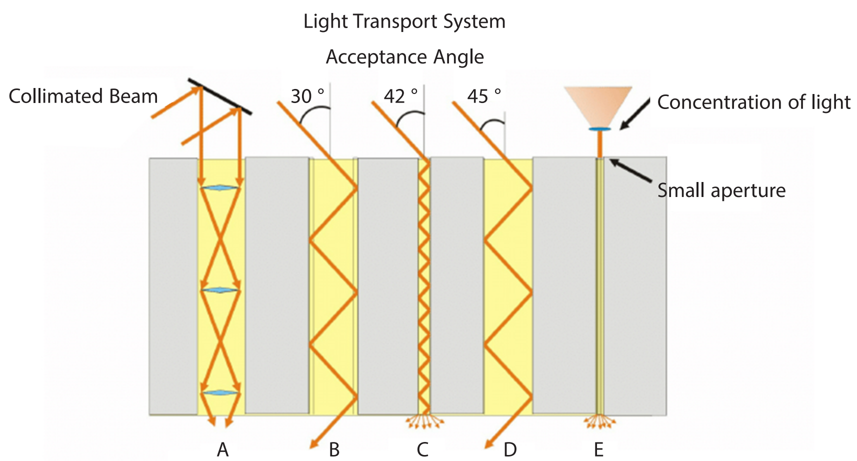



*Figure 84 Different Light Pipe Technologies A:Lenses, B:Hollow Prismatic Pipes, C:Light Rods, D:Mirrored Light Pipes, E:Fiber Optics* [64]

### 3.5. Next Generation Insulation

This is a type of foam insulation developed by the Industrial Science and technology for the windows. These insulations are made of environmentally friendly and advanced series of composite materials. These help to restrict the heat escape from the walls, attic areas, and other spaces during colder climates. [65]

This advanced technology can improve the thermal insulation around 30% [48] by comparing the traditional insulation systems. Also the system aims to develop an environmentally clean, cost effective building insulation with superior performance comparing to other solutions on the market.

### 3.6. Cogeneration

Because of the high cost of electricity, businesses and commercial buildings are forced to minimize their electrical energy consumption and demands or implement energy-saving measures such as self-generation.

Co-generation, the simultaneous generation of electrical power and thermal energy from a single fuel source, has made this concept of self-power generation even more attractive. Cogeneration is well known technology for energy conservation in industry and in commercial buildings. It shows a great potential for energy and monetary savings in buildings energy management utilizing the rejected heat from comfort-cooling purposes. [66]

With the discovery of the double-effect absorption chiller with low-grade waste-heat recovery equipment, which eliminates the use of a waste heat boiler and heat exchanger, the idea of cogeneration in buildings has expanded: it has better performance, lowers investment costs, and provides more financial benefits. Comfort air-conditioning accounts for a significant portion of electrical energy usage in both commercial and institutional buildings. In general, storing electrical energy is extremely expensive; but, cooling or heating energy can be cheaply stored to reduce peak demand, so moving peak load from a peak to an off-peak period, lowering demand charges and eliminating the larger chillers.

### 3.7. Reflecting Roof

The design of the building envelops like roof always try to achieve energy saving by helping reduce building operating loads and thus the energy demand for energy over time. When solar energy hits to building roof, a part of solar energy is reflected, and the other part is absorbed. The absorbed part represents part of solar energy which cause the increasing temperature on the surface of the building roof. Typically, reflective and white roofing systems are used for reflecting significant portion of incident short wave solar radiation which lowers the surface temperature compared to conventional roofing system. [67]

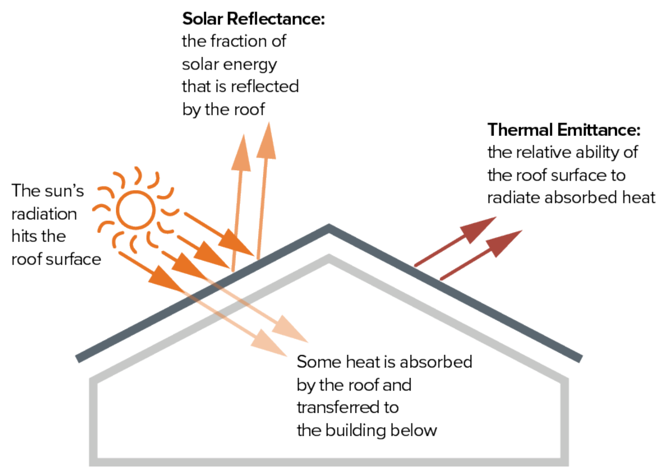



*Figure 85 How Solar Reflectance Helps Moderate Temperatures, Resulting In Lower Demand On Cooling Systems* [68]

### 3.8. Advanced Window Control System

This energy efficient system makes use of microprocessors and sensors along with insulated windows. This helps to automatically adjust the shading based on the sunlight and the time of the day. This provides proper comfort, lighting, saves energy and money. [48]

### 3.9. Hvac Systems And Controls

To achieve energy efficient building level, Heating, Ventilation and Air Conditioning (HVAC) systems are essential to catch energy requirements. In this system , it has various mechanical and electrical components and to control and to operate buildings optimally. More efficient HVAC systems lead to a significant reduction in power consumption in buildings, which is significant bearing in mind that buildings consume over 40% of the total power consumption in many developed countries.

The building needs heat pumps, water heating and cooling systems, efficient air conditioning systems, efficient component designs, and energy storage and regeneration equipments for HVAC systems. [69]

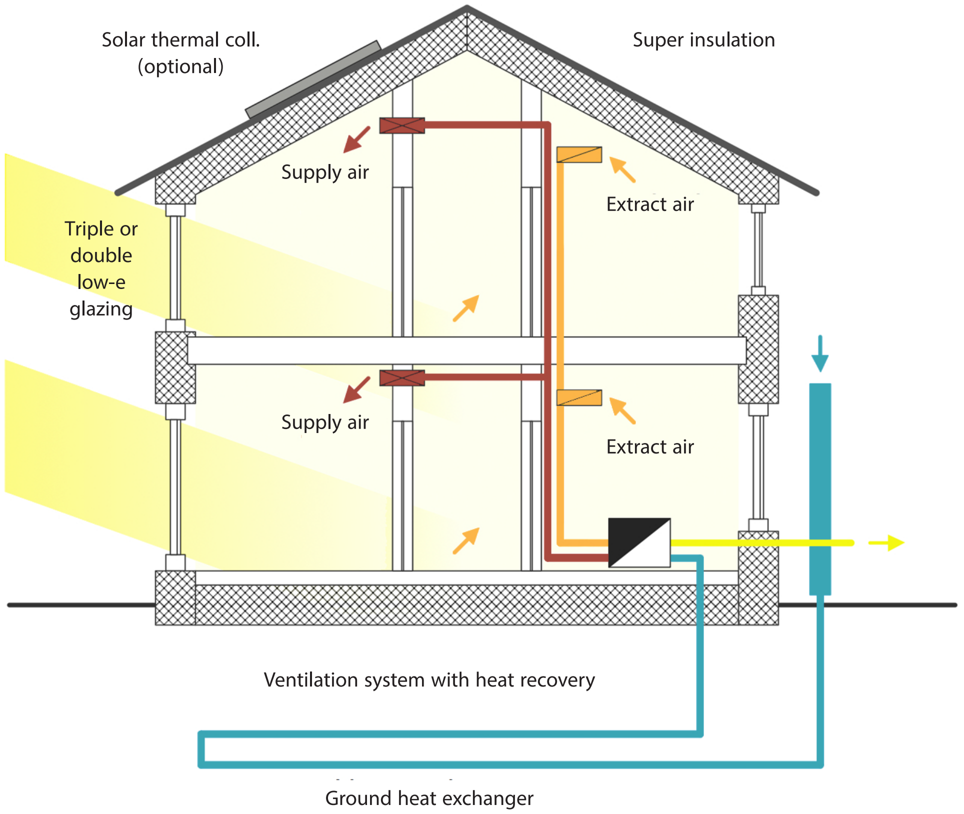



*Figure 86 HVAC Systems for Energy Efficient Homes [70]*

# 4. PRACTICE EXAMPLES

CASE STUDY 1 - SCIENCE IV DEEP ENERGY RETROFIT / RENOVATION IN BINGHAMTON UNIVERSITY

CASE STUDY 2 - SHELTER HOME “VEILIGE VESTE,” LEEUWARDEN ENERGY RETROFITTING PROJECT

CASE STUDY 3 - THE MILDMAY CENTRE ENERGY RETROFITTING PROJECT

CASE STUDY 4 - HARWARD HOUSEZERO ENERGY RETROFITTING PROJECT

CASE STUDY 5 - FUTURE LIVING BERLIN

**Case Study 1**

**Science IV Deep Energy Retrofit / Renovation in Binghamton University**

**Location:** Binghamton, NY

**Architects:** Ashley Mcgraw

A science facility of 77,000 SF and four stories of reinforced concrete, the Science IV building at Binghamton University was built in 1973. The Science IV building's energy performance was appalling, especially in terms of efficiency and thermal comfort. The best way to improve the thermal performance and airtightness of the chronically leaky exposed concrete facade was to wrap the exterior in insulation. A metal rainscreen system was also installed to both protect and refresh the exterior. Original windows were also replaced with dual-pane, thermally broken units.

A two-part retrofit's first phase was finished in the summer of 2018. A defined direction and goals for the building and its future were developed through thorough visioning and programming processes involving important campus stakeholders.

- Redesign the campus's main entrance by transforming the current structure into a warm, opulent, energy-efficient landmark that highlights the psychology department.
- Incorporate lightness and transparency to both contrast and complement the existing structure, improving the campus's relationship to nature.
- Through enhanced spatial linkages and adaptable design, cultivate an atmosphere that encourages creativity in the field of cognitive and behavioral research.

*Figure 87 Binghamton University Science IV - Before*



**1. Envelope**

In this instance, it was decided to totally re-clad the building in order to address the deterioration in the façade as well as greatly increase thermal efficiency and thermal comfort. Air tightness and insulation should be the primary issues addressed by envelope solutions for extensive energy retrofits. There are two main types of insulating: insulating from the inside and insulating from the outside. At Science IV, insulating from the outside was the greatest option because of the need for a new aesthetic, masonry deterioration, and severe thermal bridging. The installation of new windows and rainscreen cladding. Additionally, the roofing system was changed. In addition to giving the building a much improved thermal performance, the re-cladding radically changed the appearance of the structure while maintaining its original shapes and proportions.

**2. MEP Systems**

The building's mechanical and electrical systems were also updated. The outcome was to redesign the school entrance and transform the old structure into a warm, opulent, energy-efficient landmark that highlights the psychology department. More than halfway through Phase 2 design, current modeling for Science IV predicts that EUI will drop from 160 to 60 and carbon emissions will drop from 1,250 to 604 metric tons, exceeding the SUNY targets of 50 and 25 percent, respectively.

**3. Interiors**

On the inside, the renovation sought to update faculty offices and psychology labs in ways that encouraged more interaction among students and instructors. "Ashley Mcgraw added more collaboration space, nooks and crannies where people can linger and meet before and after meetings," said Jason Evans, Associate Principal / Project Manager of the project. "There are more places for interaction to happen."

Many of the labs have window walls constructed to promote an atmosphere of openness and transparency and to let those outside see what is happening within. Revitalized midcentury academic buildings can contribute to campus life for decades to come by modifying the interiors of these facilities to create exciting new learning settings and changing the building envelopes and mechanical systems to drastically lower operating costs.

*Figure 88 Binghamton University Science IV - After*

**Case Study 2**

### Shelter home “Veilige Veste,” Leeuwarden Energy Retrofitting Project

- **Location:** Leeuwarden, The Netherlands
- **Architects:** KAW architectenhttps://www.archilovers.com/projects/120565/opvanghuis-veilige-veste.html
- **Year of construction:** 1975.
- **Year of previous major retrofit:** No retrofit.
- **Year of renovation:** 2012.
- **Total floor area (m2):** 5340 m2.

*Figure 89 Facade Before Retrofit*

### 1. Project energy goals

The former police station in the Dutch town of Leeuwarden was completely renovated and now serves as a shelter for women. It is the first repurposing of an office of this size in accordance with Dutch passivhaus criteria. It was determined to upgrade the structure to passivhaus standards and make it more energy efficient. Passivhauses have substantially superior energy ratings and more agreeable indoor climates.



### 2. Project description

The “Veilige Veste” is a huge office building that was restored in accordance with the Passive house standard, making it a groundbreaking structure. The term “passive house” refers to a requirement for a building’s energy efficiency that lessens its environmental impact. Buildings made of ultra-low energy use less energy to heat or cool their interior spaces. The substructure of the former police station was located outside the building in this instance, which created a significant energy waste. The substructure built a thermal bridge that draws in the chilly outside air just like a tunnel would. The foundation is now enclosed within the building, and the entire structure is wrapped in a thick layer of insulation thanks to the diamond-cut square panels. The facade has grown nearly 3 feet thicker in certain places. The “Veilige Veste” uses incredibly little power because of its superior insulation, draft-proofing, and use of little, highly energy-efficient equipment.

### 3. Energy saving/process improvement concept and technologies used

### 3.1. Building envelope improvement

The structure was wrapped to Rc values of 10.0, which is three times the norm for new structures, to address the thermal bridge issue. The concrete structure’s elements have been meticulously covered up. Then a concrete and timber frame retention wall is built along. This hides the taped seams from view and stops air leakage while driving in screws. The German triple-draft-proof, triple-glazed Passivhaus window frames are installed in the timber frames. More than 10 inches of insulation cover the floor. Blower testing reveals that the structure is airtight.Thermal images demonstrate how effectively insulated the facade is. The building’s actual use will be assessed after a year, but calculations show that the annual heat demand is 15 W/m2, which is significantly less than the passivhaus standard of 25 W/m. A lovely view can be enjoyed from the higher floors thanks to the inner roof on the first floor that is partially filled with sedum. It also serves as a heat and water buffer at the same time.

### 3.2. New HVAC system or retrofits to existing

All new heating, ventilation and air-conditioning system. Old systems were 35 years old and nearly “dead.”

### 3.3. New lighting system

With LED light with “occupancy sensors.”

### 3.4. New generation/distribution system

Three modest central heating boilers have been installed in the building, with one of them being in charge of providing the majority of the building’s heating needs throughout the year. When demand is higher during the colder months, the other two boilers are used. Heat recovery and a mechanism for summer night ventilation are used in the ventilation system. The ventilation for the offices uses the current cooling system. The building also has occupancy sensors on its energy-efficient lights.

### 3.5. Renewable energy

The building is equipped with solar boilers that heat the tap water and a heat recovery system for air ventilation.

### 3.6. Daylighting strategies

All exterior frames on the facades that receive sun are fitted with automated solar protection. H.1.14.

## 4. Energy consumption

### 4.1. Pre-renovation energy use (total and per m2/year)

210,000 m3 natural gas.

### 4.2. Predicted energy savings (site, source, GHG), total and per m2 /year

25,000 m3 natural gas.

### 4.3. Measured energy savings (thermal, electrical), total and per m2/year

21,000 m3 natural gas.

### 4.4. Annual energy use reduction

An enormous 90% heating energy can be saved, relative to buildings that have little insulation.

*Figure 90 Facade After Retrofit.*

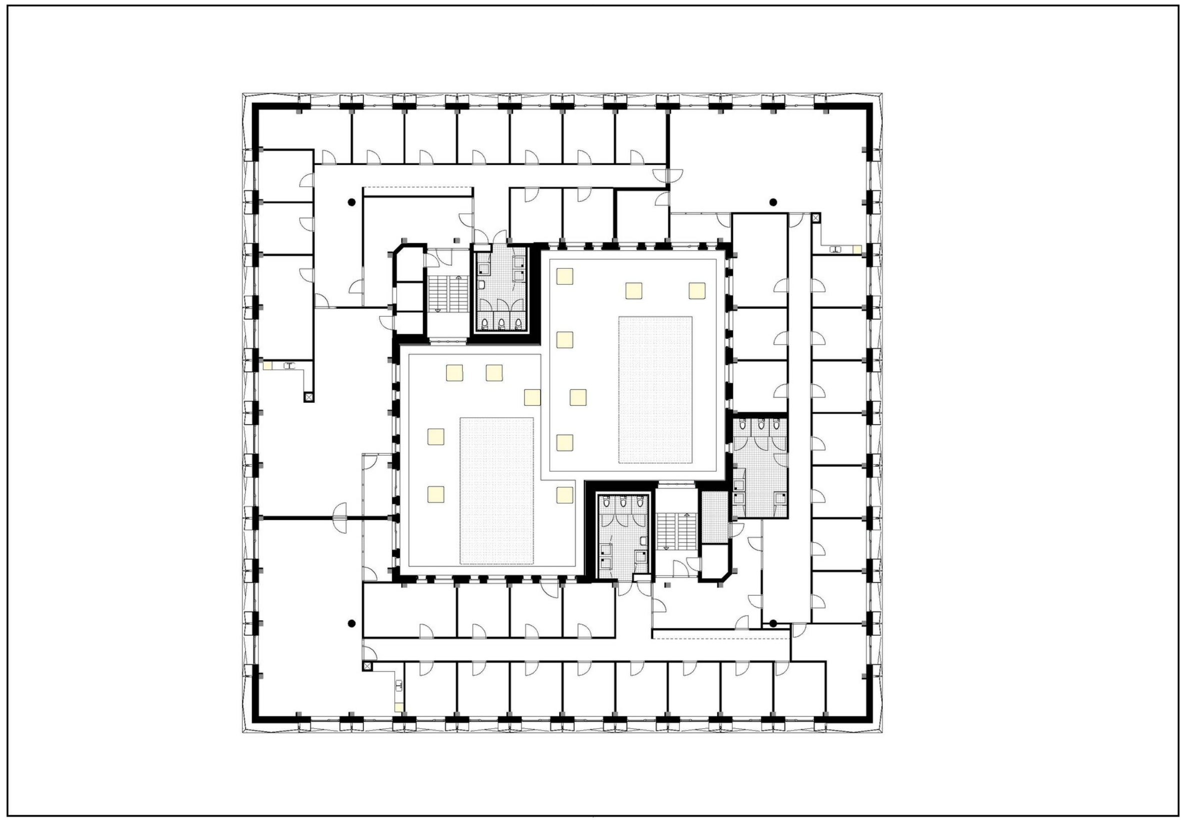


*Figure 91 Plan of Veilige Veste*

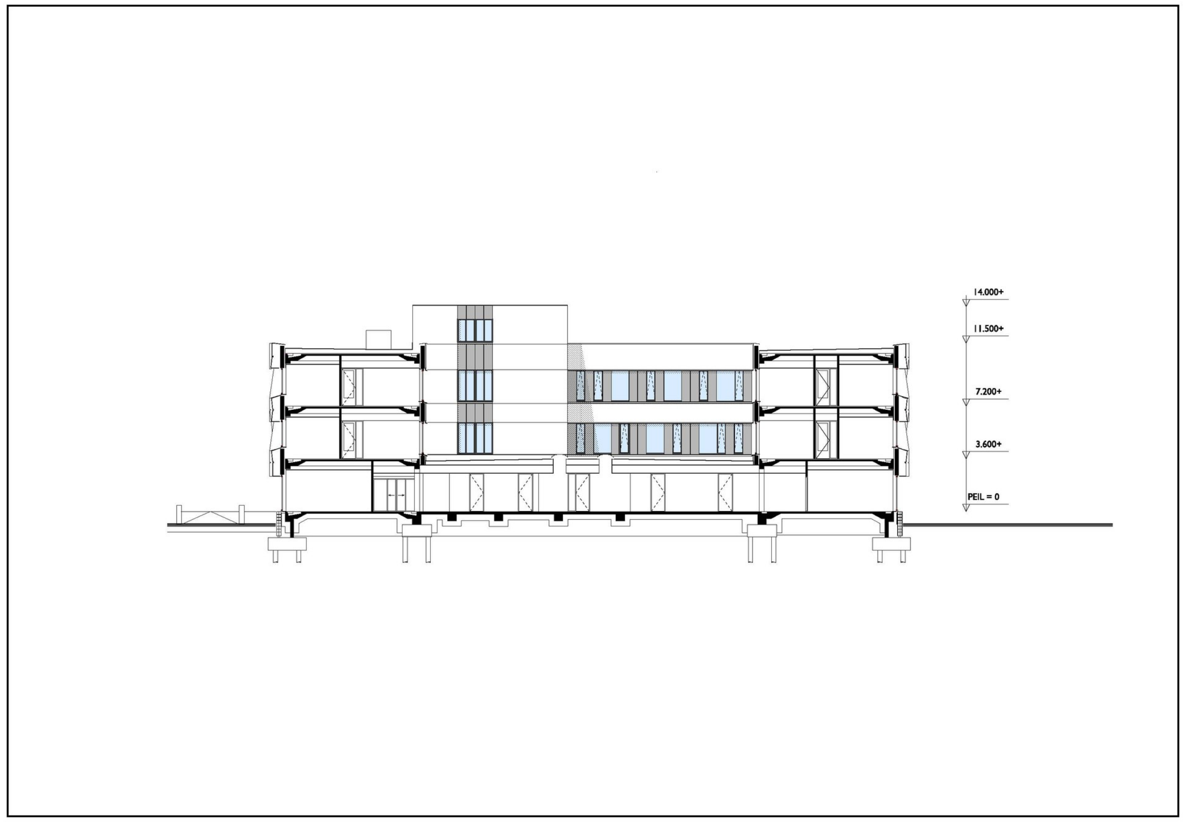



*Figure 92 Section of Veilige Veste*

**Case Study 3**

**The Mildmay Centre Energy Retrofitting Project**

- **Location:** London, UK
- **Architects:** Bere:Architects
- **Year of construction:** 1890.
- **Year of previous major retrofit:** 1973.
- Year of renovation: 2010-2012.
- **Total floor area (m2):** 665.

*Figure 93 Facade of The Mildmay Centre*

## 1. Project description

The first non-domestic retrofit in the UK to be accredited to the complete Passivhaus criteria is the all electric Mayville Community Centre (formerly known as the Mildmay Centre). 2011 saw its certification. It may have been the first Passivhaus in the UK to utilise a ground source heat pump, enabling the removal of the gas supply and the avoidance of using fossil fuels. It was renovated for just 7% more than it would have cost to meet the minimum building regulations, but throughout the course of its first winter of operation, it saved an amazing 95% on energy.

When it was transformed into a community center in the 1970s from its original use as a brick and concrete energy generating station for the North London tram network, it served as a focal point for the neighborhood's people and a crucial community resource.

Bere: To create extra usable space, architects insulated the 19th-century building's exterior and opened up the basement. Improvements included draught-free building, triple-glazed windows, and on-site renewable energy sources. All connection features adhere to the Passivhaus Planning Package (PHPP) energy calculations and are intended to prevent or minimize thermal bridging.

126m2 of photovoltaic panels on the property produce 18kWp of electricity, 3m2 of solar thermal panels provide hot water, and a ground source heat pump heats the radiators to meet the minimal space heating demand. Rainwater collection, two native wild flower meadow roofs, and an ecologically conscious garden for community food producing projects are additional features.

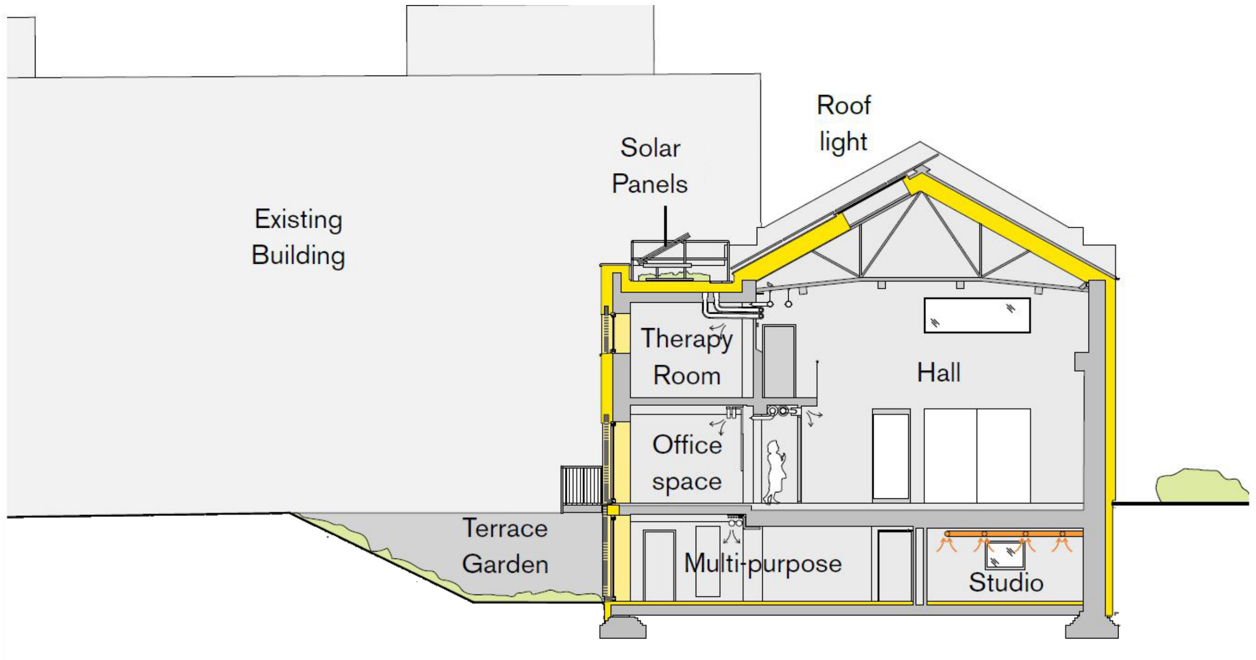



*Figure 94 Section of The Mildmay Centre*

## 2. Pre-renovation building details

### 2.1. Envelope details

Walls: solid brick 475-595mm thick.

Roof: corrugated asbestos sheeting, twin layer with 20mm unidentified fiber between layers.

Windows: steel framed, single glazed Crittal windows. Insulation levels: no insulation.

### 2.2. Heating, ventilation, cooling, and lighting systems

- Heating: large gas boiler supplying hot water radiators.
- Ventilation: opening windows.
- Cooling: none.
- Lighting systems: Fluorescent and incandescent.

## 3. Description of the problem: Reason for renovation (non-energy and energy related reasons)

- Users found the old building cold, draughty, dark and uninviting.
- Energy bills of the old building amounted to £10,000 a year, which formed a large proportion of the Centre's annual turnover of £60,000.

## 4. Energy saving/process improvement concept and technologies used

### 4.1. Building envelope improvement

• Expanded polystyrene insulation measuring 290mm is typically used as external wall insulation above ground (external).
• Insulation for single-story extensions with external walls above ground: 320mm expanded polystyrene insulation (external).
• 200mm extruded polystyrene insulation is used for external wall insulation below ground (external).
• Mineral wool insulation 400 mm thick for sloping roofs.
• 300mm Foamglas insulation for flat roofs.
• Basement slab insulation made of 75mm polyurethane foam (internal).
• 300mm Foamglas insulation for ground slab additions to single stories (beneath slab).
• New windows with insulated timber frames and triple glazing for passive houses. A tilt-and-turn opening mechanism allows for safe night-purge ventilation in the summer.
• Over the main hall, three newly installed triple-glazed Velux Passive house roof lights that are electrically powered for night-purge ventilation in the summer. Additionally, the primary recreational space has two sizable new triple-glazed fixed roof lights.
• Secure manual air intake panel for secure summer night-purge ventilation.

### 4.2. New HVAC system or retrofits to existing

• Installation of a new Paul Maxi heat recovery ventilation system. Constant pressure system with direct ventilation valves opened if $CO_2$ levels above 1100 ppm in the two variable-occupancy leisure areas and cascade air delivery to the two recreation areas.
• Installation of a new Viessmann ground source heat pump (8kWp).

### 4.3. New lighting system

Compact fluorescent lighting throughout.

### 4.4. Renewable energy

• 1no. Viessmann 3m2 vacuum tube solar thermal panel.
• 77no. Sharp NU-E235E1 photovoltaic panels, power output 18kWp.

*Figure 95 Solar Panels of The Mildmay Centre*

## 5. Energy consumption

### 5.1. Pre-renovation energy use (total and per m2/year)

More than 270 kWh/m2/yr and the building was still freezing in Winter!.

### 5.2. Predicted energy savings (site, source, GHG), total and per m2/year

The renovation provides energy savings of 80%, while at the same time ensuring warm and comfortable winter temperatures.

### 5.3. Measured energy savings (thermal, electrical), total and per m2/year

The evaluation team analyzed the cost of bills before (in 2009) and after the upgrade in terms of energy savings (Sept 2012 to Sept 2013). Despite a significant rise in the occupancy level of the post-retrofit building, the energy required from the grid after the refit (electricity only, all-electric building) is 85.5 percent lower than before the retrofit (gas plus electricity).

Due to lower energy use, the bills indicate a 58.5 percent decrease both before and after the refit. The current bills represent savings of 72.7 percent when compared to the energy used before to the retrofit (in kWh) at current energy rates (if the retrofit had not taken place). Again, this is despite a significant rise in the building's occupancy level following the retrofitting.

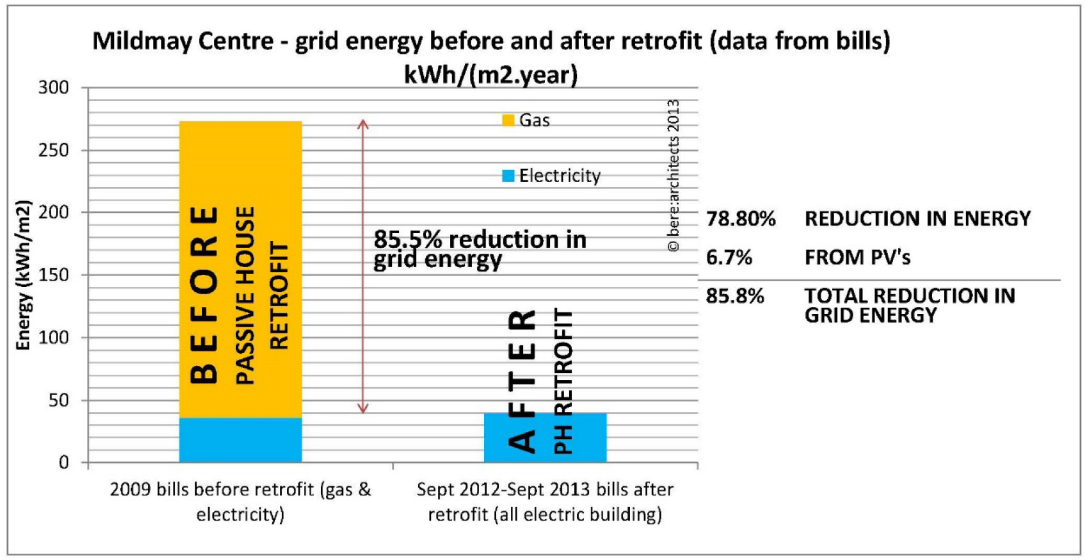



*Figure 96 Electrical Energy Before and After Retrofit.*

**Case Study 4**

## Harward HouseZero Energy Retrofitting Project

- **Location:** Cambridge, Massachusetts, USA
- **Architects:** Snøhetta
- **Client:** Harvard Center for Green Buildings and Cities (CGBC)

- **Year of construction:** pre-1940s
- **Year of previous major retrofit:** No retrofit.
- **Year of renovation:** 2016-2018
- **Total floor area (m2):** 428

*Figure 97 View of Harward HouseZero*

With the cooperation of Harvard University, Snhetta, and Skanska Technology, a historic house has been retrofitted to show how existing structures can be made more energy-efficient to help combat climate change.

The center is housed in a more than 80-year-old pitched-roof home with cedar siding. The three-story, timber-framed structure was bought by GSD in 2011 and is situated on a residential street close by.

The project's objective is to show how existing structures can be improved to use less energy.



According to the team, which consists of Harvard University, the architecture firm Snhetta, and Skanska Technology, "HouseZero attempts to address the global environmental challenge of climate change by focusing on existing buildings, which account for energy inefficiency and carbon emissions on a vast scale worldwide."

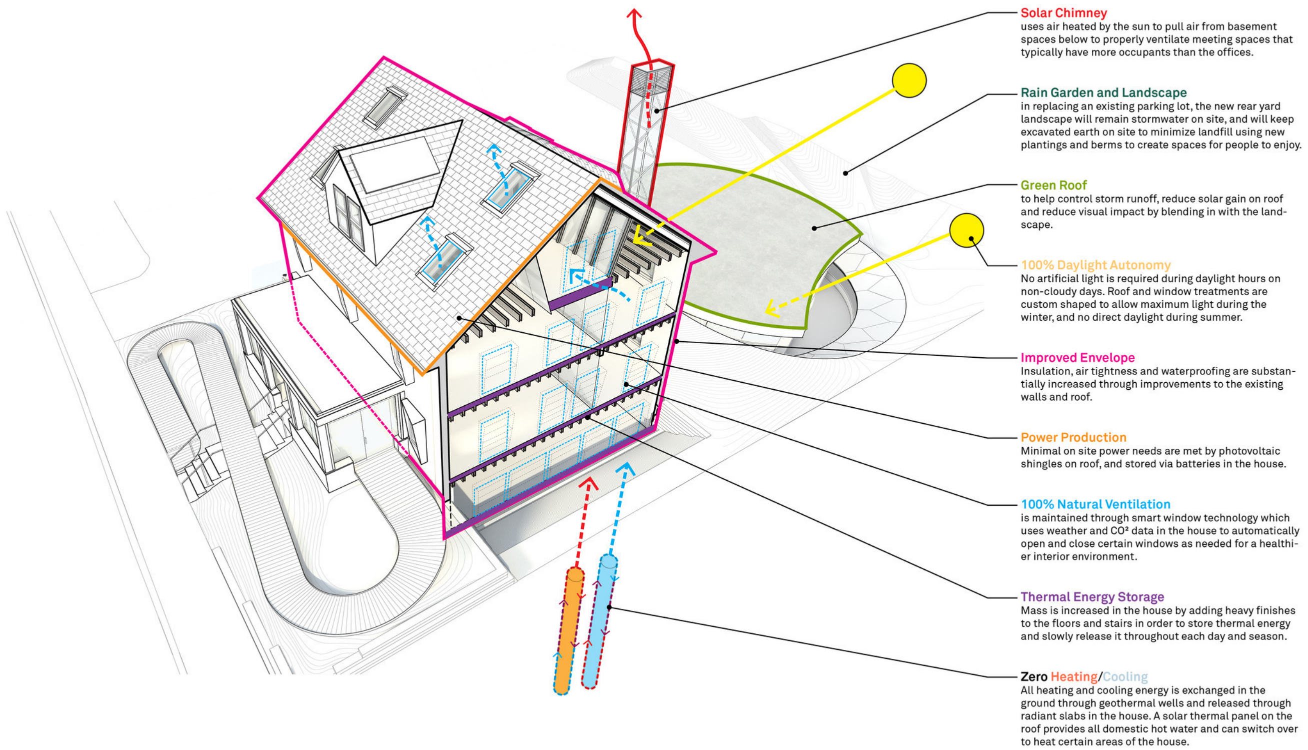



*Figure 98 Energy Efficiency Strategies of Harward HouseZero*

HouseZero's performance targets include the strongest efficiency standards ever attained by a building retrofit:

1. Heating and cooling require almost zero energy (No HVAC system)
2. Ventilation that is entirely natural
3. Complete daytime autonomy (No daytime electric light)
4. Zero carbon emissions, including materials' embodied energy

To meet thermal comfort goals for its occupants, the building will modify itself seasonally and even daily. Every day, 285 embedded sensors in the structure gather roughly 17 million data points. This data architecture enables the building to instantly self-adjust in reaction to both internal and exterior factors including inside CO2 levels and air temperature, as well as outdoor air temperature or rain.

**Case Study 5**

**Future Living Berlin**

- **Location:** Adlershof, Berlin, Germany
- **Architects:** UGK BERLIN
- **Project sponsor:** of Future Living Berlin is GSW Sigmaringen .

- **Year of construction:** 2017-2019
- **Covers an area:** of 7,604 $m^2$.

## 1. Project description

A new multigenerational residential area in Berlin-Adlershof makes it feasible to live in the neighborhood of the future at ordinary market rents. Future Living Berlin deals with social concerns such changing demographics, the use of renewable energy, and new modes of transportation.

Berlin's southern region contains the smart city district. The region, known as "Adlershof," is getting ready to emerge as the biggest technology centre in Germany. Currently, the 17 hectares of the region are home to 1,200 businesses, 20 research facilities affiliated with the Technical University of Berlin, and individuals with experience in industry and R&D. Because of this, Future Living Berlin (FLB) blends seamlessly with the neighborhood's forward-thinking vibe.

*Figure 99 Render of Future Living Berlin*



Future Living Berlin (FLB), which was inaugurated in July 2017, has 90 residential units and 10 commercial units spread across a 7,604m 2 space. Solar panels and air-water heat pumps were installed in July and December of 2019 respectively.

The district of the smart city strives to reflect the same enthusiasm with regard to technology and research as the industrial and academic innovation areas that surround it. The initial concept was to create a vision of what life would be like in the future, which will eventually become the norm: to live in the future now.

To encourage social interactions among the residents, the residential buildings were planned and constructed using open architectural models without walls. 11 out of the total 90 apartments in Future Living ® Berlin are equipped for wheelchair users or residents with physical disabilities. The investing company and project owner, GSW Sigmaringen GmbH, adhered to the Universal Design and accessibility principles to facilitate multigenerational peace and cooperation.

*Figure 100 Render of Future Living Berlin*

## 2. Energy management system

Around 80% of the energy used in a typical household is utilized for heating, therefore there is a significant opportunity to reduce emissions. Panasonic sought to optimize energy use for apartment heating and energy-efficient hot water production as a result when searching for an energy-efficient solution for this residential project.

In order to do this, Panasonic's European R&D facility created a smart energy management system to optimize energy utilization. It was decided to place Panasonic photovoltaic (PV) panels on the rooftops for the purpose of producing power. These panels are the best in the business in terms of performance. Due to a seamless alignment of the interfaces, the combination of PV panels and Panasonic air-water heat pumps related power with heating. The software approach begins by calculating the energy output from the PV panels and the corresponding energy surplus produced but not immediately utilised in the building.

Depending on many variables like the season, the time of day, etc., the control system then determines what to create with this energy—heating or hot water. These kinds of smart controls and algorithms enable substantial energy savings as well as flexible response to the needs of the residents of Future Living ® Berlin.

Additionally, the efficiency of using PV electricity is increased by the energy management software. It is based on algorithms that regulate the PV system's output so that heat pumps may use it most effectively. The comfort of the residents is actually the algorithm's top priority, so if the system detects a surplus, the energy is first used to heat the rooms, and then it is directed toward producing hot water for domestic use.

The objective is to increase self-consumption from an average of 30 to 40 percent to 50 to 60 percent. Different seasonal effects are also taken into consideration; in the spring and fall, the algorithm maximizes the usage of space heating and hot water generation and is linked to the biggest efficiency gains. Since there is no need for space heating during the summer, the excess PV energy can only be used to produce domestic hot water, which lowers the average efficiency. Due to reduced sunlight and the accompanying lower PV generation, particularly from December to February, the advantage of the energy management solution is lower even in winter.

The energy research team of Panasonic has been collaborating with many partners to improve the use of green energy, especially in decentralized settings, for many years. The PV electricity and storage systems were tested as the initial step.

Systems with a 156 KW capacity are another crucial component of Panasonic's energy solution for FLB since they let you store some of the excess energy for times when there isn't enough sunlight to generate the "electricity." Storage of energy helps maintain a balance between electricity production and consumption, making the energy supply more effective and environmentally friendly.



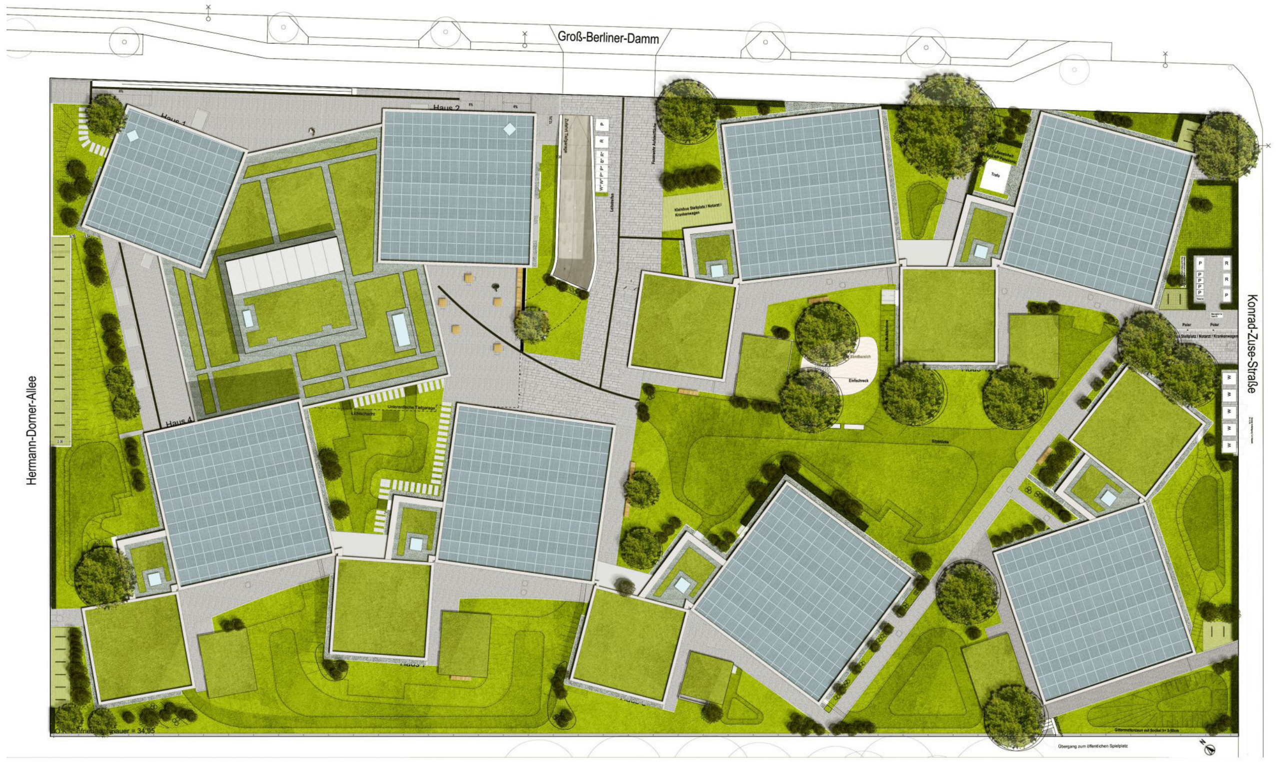



*Figure 101 Plan of Future Living Berlin*

*Figure 102 Plan of Future Living Berlin*

# 5. METHODOLOGY

## 5. Methodology

### 5.1. Introduction

The aim of this study is to develop an architectural project through the use of TABULA webtool and QGIS software in order to demonstrate the effects of the correct retrofitting strategies to the residential building in Corso Taranto, Torino, Italy by dedicated from ATC Torino. Also together with the study research, the importance of energy saving in the building is pointed out.

The start point of the methodology is defining the correct building types in the TABULA webtool. In order to choose the building type, the country selection is made as Italy firstly and then the next step becomes to choose the building from Building Type Matrix.

The next step is defining the system type from System Selection. In the webtool, different system types are present. In this section, there is the existing state for the buildings. Here, to make estimations, the existing state is defined as scenario-0 of the project.

According to TABULA, there are different building typology classifications which used in many European countries at the national or regional level. For each building typology, different statistical data are present in the webtool. These statistical data are referring to specific building types, so they have specific dimensions. In this case, to continue in the project, the real building volumetric information will be needed to make correct energy estimations. For this reason, QGIS software is used to take the building dimensions of Corso Taranto.

After defining all selections and then making integration with QGIS Software, the estimations are made with TABULA Calculator for scenario 0. Finally, after obtaining all the energy estimation results, the design proposals will be made for the building to demonstrate the effect of the design proposals in terms of energy saving.

To describe the project methodology, the summary of the methodology is shown in the figure below.

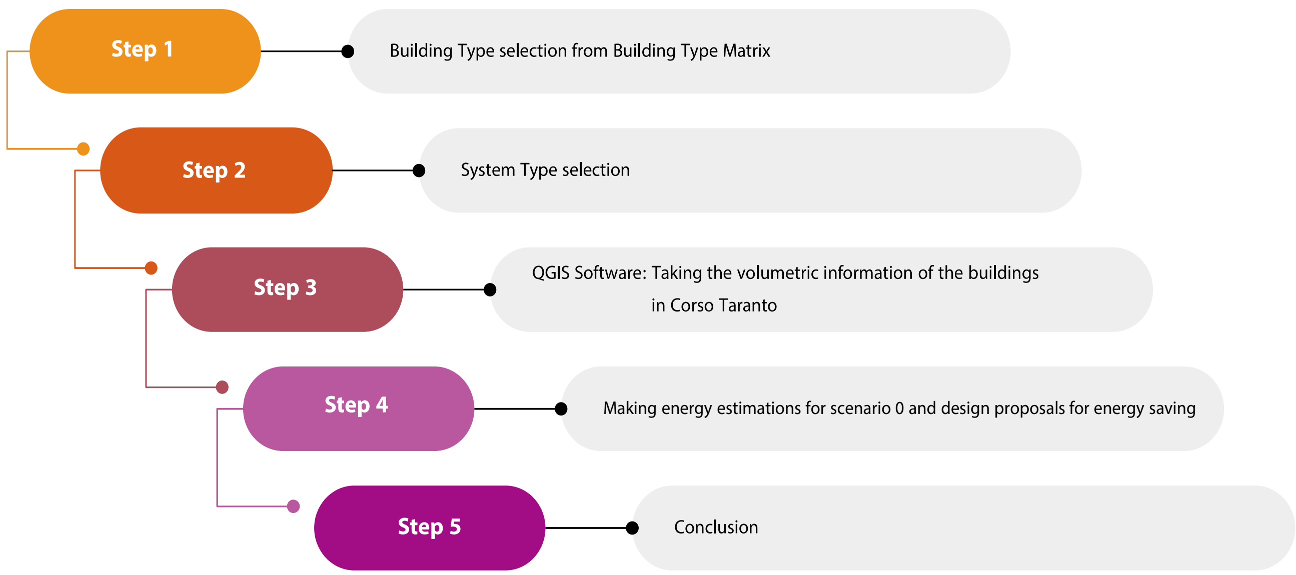



*Figure 103 Methodology Flow Chart*



## 5.2. Definition of IEE TABULA Project

### 5.2.1. Objectives of The IEE TABULA Project

The IEE TABULA Project was born out of a necessity to assess the energy consumption of national building stocks and, as a result, predict the impact of energy efficiency measures in order to choose appropriate retrofit solutions for existing structures. The concept of "building typology" lies at the heart of the investigation.

The "building typology" classification is a concept already used in many European countries at national and/or regional level. [71] However, some issues remain, such as a lack of a common definition of building typology, unknown or out-of-date building typologies, and difficulties understanding the concept of "building typology," all of which contribute to the classification's lack of application. Furthermore, we can think that without uniform terminology, it is impossible to compare the building typologies of European countries.

The objective of TABULA is the creation of a harmonised structure for European Building Typologies and each participating country developed on that basis a National Building Typology, that is a set of model buildings (named "building-types") with characteristic energy related properties. [71] Each building style symbolizes a certain country's construction period as well as a specific building size. In each country, typical buildings have been used as a showcase to demonstrate the energy performance and energy savings potentials that may be realized by upgrading the thermal envelope and supply system. There are two levels of building retrofit: "standard refurbishment," which uses measures that are common in the country, and "advanced refurbishment," which uses measures that represent the best available technologies.

The demonstration calculations have been performed in each country by using the national EPBD (Energy Performance of Building Directive) asset rating method and by showing the energy performance before and after the refurbishment and, the results have been published by each partner in National "Building Typology Brochures". [71]

The use of the typology as a model for assessing the energy performance of the entire national building stock has been made possible by the addition of statistical information on the frequencies of construction and system types.

The project's major output is a webtool that offers thermal envelope areas, U-values, supply system efficiency, and other indicators for representative buildings in each of the participating countries. Experts from all European nations can use the provided data to assess national building stocks, make cross-country comparisons, and calculate scenarios (evaluations for energy saving policies, programmes or projects, e.g. in the frame of the Energy Services Directive implementation). Apart from publishing building data and statistics, the webtool also serves as a demonstration tool: for each typical building, an online calculator shows the potential energy savings that can be achieved through various refurbishment measures of varying quality (categories "standard" and "advanced").

National building typologies can be utilized as data sources in the long run to estimate and evaluate energy savings and $CO_2$ emission reductions for each European country.

### 5.2.2. Italian Contribution to The IEE TABULA Project

The TABULA Project's goal in Italy was to improve the existing residential building typology and adapt it to a more unified approach. As a result, a technique was developed that allowed building types to be defined as reference buildings for assessing the energy performance of the building stock and evaluating the impact of energy conservation scenarios at the national, regional, and local levels.

In particular, the italian contribution point out some ideas ın TABULA webtool. First point is the creation of a harmonised structure for the Italian typology, as well as the supply of input data on buildings, structures, and systems (heating and DHW), which serve as the webtool's primary data. Then second point is through the calculation of the energy performance of the building-types, the application of the typology concept for the assessment of the energy performance of residential structures and the evaluation of the impact of energy conservation measures. The third and last point is the application of the typology idea to the development of a model for estimating the national energy balance of the residential building stock using national statistical data.

The main outcome of the research at national level is the "Building Typology Brochure", a project deliverable that contains information on the Italian residential building typology, its classification, the definition of building-types, the representation of types of construction elements and systems, the identification of refurbishment measures to be applied to the building envelope and systems. [72]

At the national level, the research could have a wide range of implications. It can be used by consultants to present house owners with a short review of the energy performance of a building identical to their own. Moreover, the typology can be utilized as a set of sample buildings, for example, in software comparison studies or for subsidy program evaluation.

The building typology can be a useful tool for housing businesses to measure the energy efficiency of their portfolio of buildings. It allows you to provide a wide range of data for particular reference buildings, assess its importance by projecting it to the entire stock or subsets of the stock, and quantify the potential for energy savings as a result of refurbishment operations. It could address energy policy at the national or local level in this way.

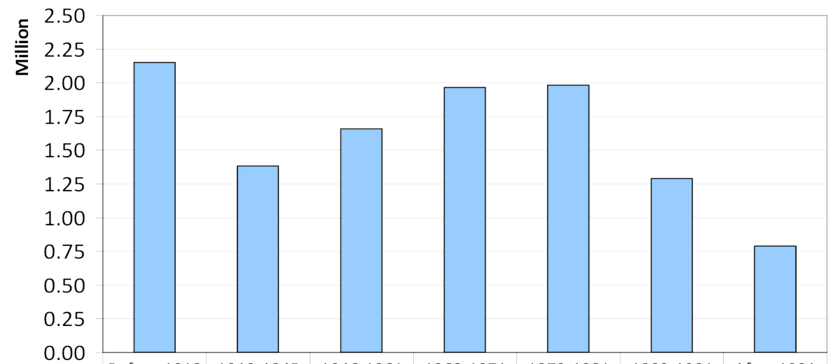
### 5.2.3. Italian Building Stock

#### 5.2.3.1. Statistical Data

Statistical data on the frequency distribution of residential buildings, number of apartments in buildings by construction period, frequency of building construction and system typologies, most used energy carriers, and so on were used to classify the Italian residential building typology and identify building types. These informations are taken from ISTAT which is the National Institute of Statics, CRESME-Centre Economical, Social and Market Surveys in building sector and the National Agency for new technologies.

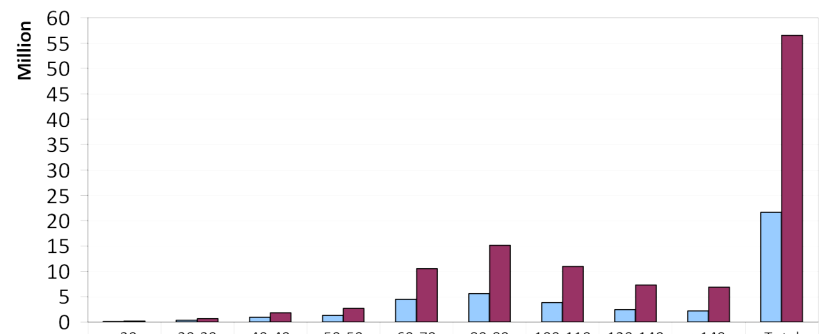
The most critical statistical data are reported in the webtool. These are frequency of buildings, building constructions typologies, technical system typologies, refurbishment actions in buildings and energy consumption and energy carriers.






| | Before 1919 | 1919-1945 | 1946-1961 | 1962-1971 | 1972-1981 | 1982-1991 | After 1991 |
|---|---|---|---|---|---|---|---|
| Buildings | 2,150,259 | 1,383,815 | 1,659,829 | 1,967,957 | 1,983,206 | 1,290,502 | 791,027 |

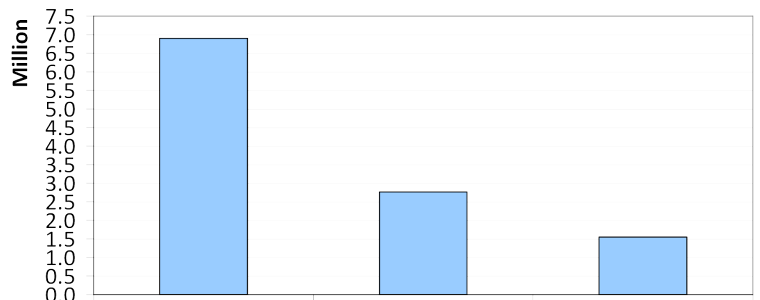
*Figure 104 Number of Italian Residential Buildings by Construction Period [71]*




| Dwelling surface [m²] | <30 | 30-39 | 40-49 | 50-59 | 60-79 | 80-89 | 100-119 | 120-149 | >149 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Apartments | 122,355 | 427,850 | 1,015,341 | 1,366,838 | 4,492,284 | 5,648,248 | 3,848,577 | 2,479,085 | 2,252,710 | 21,653,28 |
| People | 160,072 | 717,024 | 1,869,271 | 2,757,264 | 10,531,47 | 15,200,25 | 11,005,78 | 7,358,065 | 6,923,630 | 56,522,84 |

*Figure 105 Number of Apartments and People in Italy by Living Surface [71]*

The figures above are the example graphs regarding frequency of buildings. First one shows the number of Italian residential buildings by construction period while other one is showing the number of apartments and people in Italy by living surface.




| | Brick Masonry | Reinforced Concrete | Other |
|---|---|---|---|
| Buildings | 6,903,982 | 2,768,205 | 1,554,408 |

*Figure 106 Number of Italian Residential Buildings by Construction Typologies [71]*

This figure above shows the number of Italian residential buildings by contruction typologies and it is an example to understand the statistical data for building construction typologies.

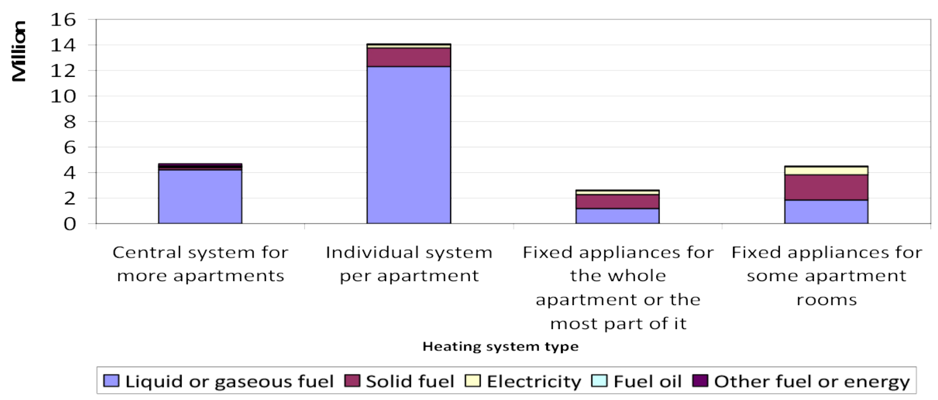



*Figure 107 Number of Italian Apartments with Heating System by Fuel Type or Energy Carrier and Heating System Type [71]*

The figure above is an example for technical system typologies and it demonstrates the number of Italian apartments with heating systems by fuel type or energy carrier and heating system type.

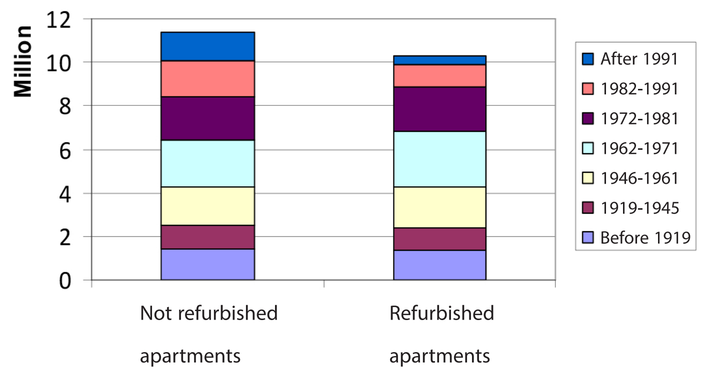



*Figure 108 Number of Italian Refurbished and Not Refurbished Apartments by Construction Period [71]*

This figure above helps to understand how much refurbishment actions needed by showing the number of Italian refurbished and not refurbished apartments by construction period.

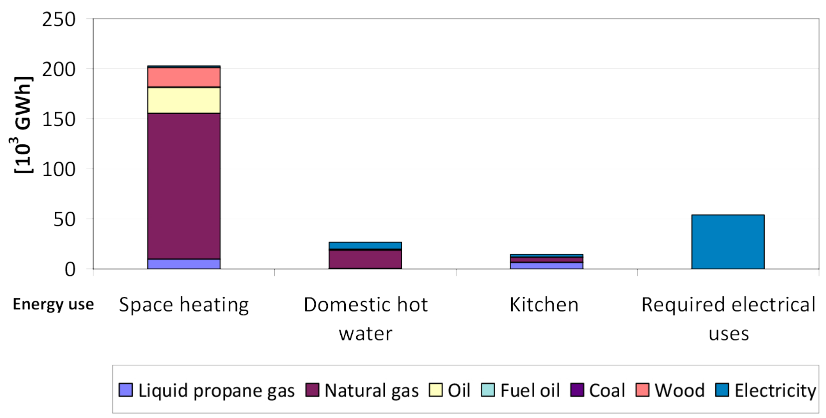



*Figure 109 Energy Consumptions for Final Energy Uses in The Italian Residential Sector [71]*

The figure above demostrate the energy consumption for final energy uses in the Italian residential sector and it point out the statistical data for energy consumption and energy carriers.



#### 5.2.3.2. Italian Buildings Construction Elements

The varieties of building construction elements and types of building systems were used to characterize the residential Italian building stock. The types of Italian building construction elements were determined based on experience (e.g., sector-specific recommendations), scientific-technical literature, statistical data, and technical norms. The building envelope technologies that are reported in this Section are those that are considered typical within a given historical period. In different tables in the webtool, the description of each building construction element, the period of highest diffusion, and its thermo-physical parameter values (i.e. U-value for opaque and transparent envelope components) are displayed.

In the webtool, the building envolope components which are considered as main parameter for calcualtions are  roofs, ceilings, walls, floors, doors and windows.

On the other hand, to clarify the classification criteria for building construction elements and their thermo-physical properties, the following specifications are required:

• The Italian constructions are typically massive structures.

• The traditional materials which constitute the building components are usually bricks (hollow and solid bricks) and concrete.

• The construction period is closely related to the thermal insulation level of the building envelope components. According to the evolution of the national regulations on energy efficiency of buildings, some assumptions were made up in the webtool. [71]

### 5.2.4. Italian Building Typology

According to Italian building types, the Italian building typology is developed in TABULA webtool. In particular, the following items are illustrated:

• The common TABULA structure is used to classify the Italian building typology.
• Building types definitions
• Building Typology Matrix
• Constraction elements of each building types
• DWH (Domestic How Water) system types and general heating types
• Refurbishment measurements on constructions and systems

#### 5.2.4.1. Italian Building Typology Classification

The typological concept focuses on building characteristics related to energy consumption because the TABULA Project is focused on measuring and improving the energy performance of existing structures. The region and climatic area, building age and building size are used to classify the national "building typology".

Italy is characterised by six different climatic zones according to Presidential Decree no. 412/1993, ranging from "A zone" to "F zone" according to the number of heating degree-days. [71] In TABULA, Middle Climatic Zone (E zone), Alpine Zone (F Zone) and Mediterranean Zone (A-B-C-D Zones) are used to classify the National building types.

For each climatic zone, eight construction age classes were determined. [71] From an energy perspective, each construction age class defines a specific historical period that reflects major geometrical and construction typologies. The following are the construction age groups:

- Class I, up to 1900 – the Nineteenth Century;
- Class II, from 1901 to 1920 – the beginning of the Twentieth Century;
- Class III, from 1921 to 1945 – the period between the two World Wars;
- Class IV, from 1946 to 1960 – the Postwar period and the Reconstruction;
- Class V, from 1961 to 1975 – towards the oil crisis; - class VI, from 1976 to 1990 – first Italian regulations on energy efficiency;
- Class VII, from 1991 to 2005 – recent regulations on the energy performance of buildings in Italy;
- Class VIII, after 2005 – more restrictive energy performance requirements. [71]

Building size classes represent each construction age class. They refer to distinct dimensional typologies, or buildings with specific sizes and shapes. Single family house, terraced house or apartment block are one of the examples to this calssification.

The axes of the so-called "Building Typology Matrix" are made up of features that help classify building typologies. Each climate zone is represented by a matrix, which is made up of rows that represent building age classes and columns that indicate building size classes. Each cell in the matrix is filled with a "building-type," or a structure that is indicative of that circumstance (climatic zone, construction age, and building size).

The Italian "Building Typology Matrix" has been developed for the E zone (Middle climatic Zone) that represents 4250 Italian municipalities on a total number of 8100. [71] At the figure below, there is Italy map together with indications of climatic zones within national territory. Each colour refer to different climatic zones.

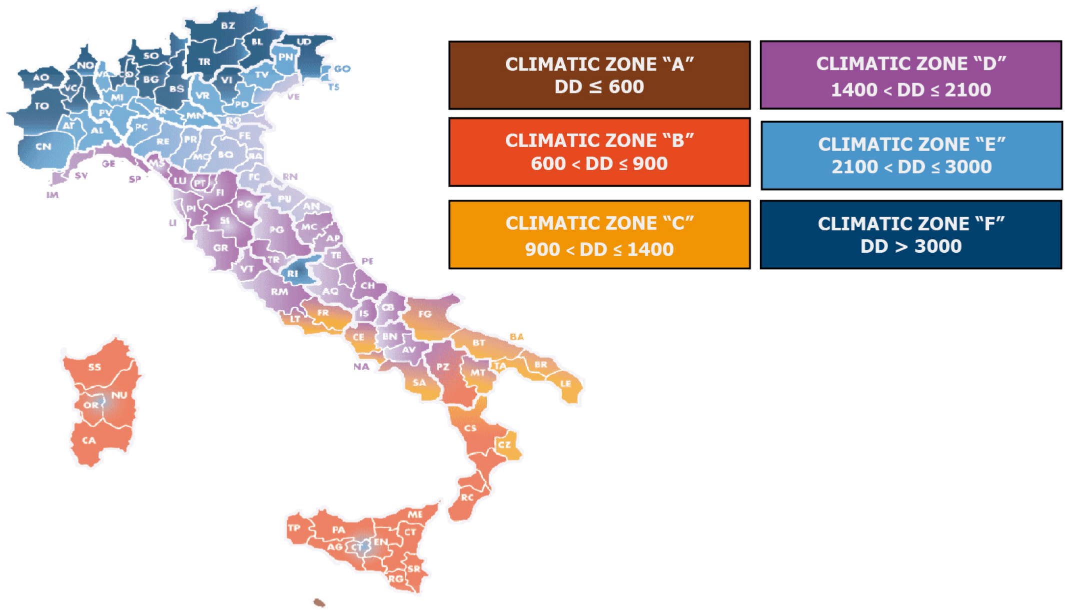



*Figure 110 Indication of Climatic Zones Within The National Territory [71]*



#### 5.2.4.2. Italian Building Typology Matrix

The identified building-types constitute the so-called "Building Typology Matrix", which was developed for the Italian E zone and it is represented in figure below. [71] To use the TABULA webtool correctly, this matrix explains every step by its classfications. The most important thing is that the example of buildings have actual data in the webtool.

Building Type Matrix

| | Region | Construction Year Class | Additional Classification | Italy<br>SFH<br>Single-Family House | <br>TH<br>Terraced House | <br>MFH<br>Multi-Family House | <br>AB<br>Apartment Block |
|---|---|---|---|---|---|---|---|
| 1 | Middle Climatic Zone (Zona climatica media - ZONA E) | ... 1900 | generic | IT.MidClim.SFH.01.Gen | IT.MidClim.TH.01.Gen | IT.MidClim.MFH.01.Gen | IT.MidClim.AB.01.Gen |
| 2 | Middle Climatic Zone (Zona climatica media - ZONA E) | 1901 ... 1920 | generic | IT.MidClim.SFH.02.Gen | IT.MidClim.TH.02.Gen | IT.MidClim.MFH.02.Gen | IT.MidClim.AB.02.Gen |
| 3 | Middle Climatic Zone (Zona climatica media - ZONA E) | 1921 ... 1945 | generic | IT.MidClim.SFH.03.Gen | IT.MidClim.TH.03.Gen | IT.MidClim.MFH.03.Gen | IT.MidClim.AB.03.Gen |
| 4 | Middle Climatic Zone (Zona climatica media - ZONA E) | 1946 ... 1960 | generic | IT.MidClim.SFH.04.Gen | IT.MidClim.TH.04.Gen | IT.MidClim.MFH.04.Gen | IT.MidClim.AB.04.Gen |
| 5 | Middle Climatic Zone (Zona climatica media - ZONA E) | 1961 ... 1975 | generic | IT.MidClim.SFH.05.Gen | IT.MidClim.TH.05.Gen | IT.MidClim.MFH.05.Gen | IT.MidClim.AB.05.Gen |
| 6 | Middle Climatic Zone (Zona climatica media - ZONA E) | 1976 ... 1990 | generic | IT.MidClim.SFH.06.Gen | IT.MidClim.TH.06.Gen | IT.MidClim.MFH.06.Gen | IT.MidClim.AB.06.Gen |
| 7 | Middle Climatic Zone (Zona climatica media - ZONA E) | 1991 ... 2005 | generic | IT.MidClim.SFH.07.Gen | IT.MidClim.TH.07.Gen | IT.MidClim.MFH.07.Gen | IT.MidClim.AB.07.Gen |
| 8 | Middle Climatic Zone (Zona climatica media - ZONA E) | 2006 ... | generic | IT.MidClim.SFH.08.Gen | IT.MidClim.TH.08.Gen | IT.MidClim.MFH.08.Gen | IT.MidClim.AB.08.Gen |

*Table 7 "Building Typology Matrix" for The Italian Middle Climatic Zone*

### 5.2.4.3. Definition of Refurbishment Measures

Except for those in the eighth building age class, some refurbishment procedures were considered for the building types (built after 2005). The retrofit operations on the building exterior were examined separately from the retrofit actions on the thermal systems (heating and domestic hot water). On two levels, the energy-saving measures were assessed. These are "standard" and "advanced" respectively.

"Standard" refurbishment, taking into account the usage of measures that are common in the country. On the other hand, "advanced" refurbishment, which takes into account the use of the most up-to-date technologies.

Standard and advanced refurbishment methods take into account different measurements like U-value according to the building envelope. As an example, if an application of insulation material on walls to reach an U value of 0.33W/m2K, it is standard refurbishement while this value is 0.25W/m2K for advanced refurbishment. [71]

In the webtool, the DHW system refurbishment has been hypothesized considering different measures like insulation of the distribution subsytem or according to high insulation level for both standard and advanced refurbishment.

### 5.2.5. Energy Calculation Methods

The energy performance of the building types has been determined using two separate calculation methodologies, the common calculation procedure and the national calculation procedure, both in their original state and after the implementation of standard and advanced refurbishment procedures.

According to the scope of the project, both techniques allow for the calculation of the net energy need for space heating, primary energy for space heating, primary energy for domestic hot water, and CO2 emissions. The standard calculating process is used in both the "Excel Workbook" and the webtool. Instead, the "Building Typology Brochure" was written using the national calculation procedure.

The common calculation of energy use and provided energy by energy carriers should be a relatively basic technique in order to achieve calculation transparency (understandable in each country/comprehensible online calculation) and ease of use (Excel calculation for a large number of buildings). The calculating technique has been established as closely as feasible in compliance with the relevant CEN requirements and takes into account national standard climatic and usage data. Existing harmonised definitions (CEN, DATAMINE, etc.) have been taken into account in general.

On the other hand, there are some other assumptions in the TABULA which adopted for calculations [71]:

- Climatic data of the city of Turin (for Middle climatic Zone) from a national technical standard (UNI 10349);
- Natural ventilation rate fixed according to the use (residential, in this case);
- Simplified calculation of internal heat gains;
- Simplified calculation of building internal heat capacity;
- Simplified calculation of thermal bridges; - simplified calculation of indoor air temperature of unconditioned spaces;
- Neither shading devices nor shutters installed on windows;
- Fixed value of the reduction factor for shading by permanent obstructions;
- Fixed value of the reduction factor for window frame (frame factor).



### 5.3. Definiton of QGIS Software

QGIS is a free and open-source cross-platform desktop geographic information system (GIS) application that supports viewing, editing, printing, and analysis of geospatial data. [73]

QGIS is a geographic information system (GIS) program that allows users to analyze and update spatial data as well as create and export graphical maps. Raster, vector, and mesh layers are all supported by QGIS. Point, line, and polygon features are used to store vector data. The software can georeference images and supports multiple raster image formats.

### 5.3.1. QGIS for Expeditious Data Collection

As described the TABULA project Italian database is defined based on building use, year of construction, building typology, heated floor area, thermal transmittance and type of thermal systems.

To start energy consumption estimation, a graphic plan and volumetric data which is the square meters of the buildings on the project site should be taken from the QGIS software for usage in the Tabula project web tool and for the final step Excel Workbook.

In the figure below, there is the urban plan of Corso Taranto which is the case study of the thesis. At the same time, the volumetric units are showed in the software.

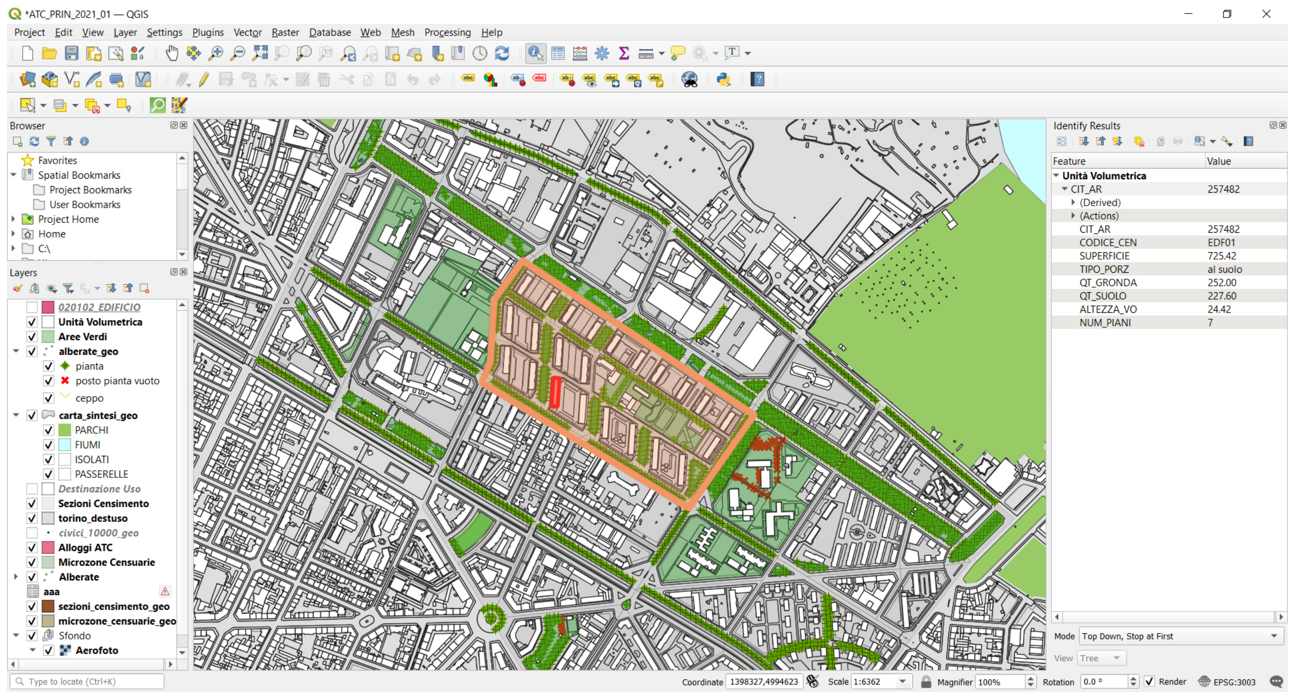


*Figure 111 Site Plan of Corso Taranto*

## 5.4. Choices Made During Energy Estimation

To make an estimation in TABULA webtool by the help of QGIS Software, the steps are defined according to the study methodology. In the steps, some choices were done according to the Corso Taranto area. By doing this, estimating the energy parameters of the buildings to be studied is aimed.

Generally, the most important choices which are, building type selection and system selection are explained in this chapter.

### 5.4.1. Building and System Type Selection

After the selection of the country as Italy, the next step is the selection of Building Type from the Building Type Matrix in TABULA webtool. When we compare the case study buildings in Corso Taranto and TABULA webtool Building Types, to make the closest energy estimation, IT.MidClim.AB.05.Gen building type was chosen. During the selection, the year of construction, the type of building (Apartman Block), and similarities of Building Data (roof detail, floor detail, detail plan) were effective. The selected building type is shown in the figure below.

Building Type Matrix

| | | | | Italy | | | |
|---|---|---|---|---|---|---|---|
| | Region | Construction Year Class | Additional Classification | SFH Single-Family House | TH Terraced House | MFH Multi-Family House | AB Apartment Block |
| 5 | Middle Climatic Zone (Zona climatica media - ZONA E) | 1961 ... 1975 | generic |  IT.MidClim.SFH.05.Gen |  IT.MidClim.TH.05.Gen |  IT.MidClim.MFH.05.Gen |  IT.MidClim.AB.05.Gen |

*Table 8 Building Type Selection for Case Study of Corso Taranto*

In this section, the Existing State of the building is chosen as scenario-zero of the energy estimation of the project. According to our building type and TABULA webtool systems, the chosen scenario have some particular system properties to make our energy estimation. These are:

- There is no ventilation system.
- The building has central heating system.
- The building has individual DHW (Domestic Hot Water) system.



**Region / Climate zone:** Medium climate zone

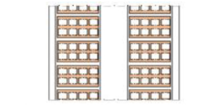
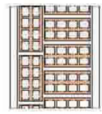
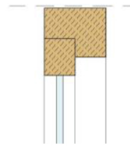
**Period of construction class:** 5 (1961-1975)

**Building size class:** Block of flats

| $V$ $[m^3]$ | $S/V$ $[m^{-1}]$ | $A_{f,l}$ $[m^2]$ | Number of Apartment | Number of Floor |
|---|---|---|---|---|
| 9438 | 0,46 | 2869 | 40 | 8 |

**EXISTING STATE**

**CONSTRUCTION TYPE**

| Coverage | Walls | Roof | Floors | Windows |
|---|---|---|---|---|
|  Pitched brick roof [non-air-conditioned attic] |  Hollow wall brick masonry (40 cm)  Hollow brick masonry (40 cm) |  Ceiling with reinforced brick-concrete slab |  Floor with reinforced brick-concrete slab |  Single glass, wood frame |

| Coverage | Walls | | Roof | Floors | Windows |
|---|---|---|---|---|---|
| $U$ $[W/(m^2K)]$ | $U_1$ $[W/(m^2K)]$ | $U_2$ $[W/(m^2K)]$ | $U$ $[W/(m^2K)]$ | $U_1$ $[W/(m^2K)]$ | $U_1$ $[W/(m^2K)]$ |
| 2.20 | 1.10 | 0.91 | 1.10 | 1.30 | 4.90 |

**SYSTEM TYPE**

**Heating System**

-Gas central heating, non-condensing boiler (forced draft burner) in thermal plant, insulated pipes

**Domestic Hot Water System**

- Individual dhw system (per apartment)
- Gas-fired instantaneous water heater (sealed combustion chamber without standing pilot)
- Separate dhw distribution without circulation

*Figure 112 Selected Building Type in Tabula Webtool*

## 6. Plot Area - Corso Taranto, Torino

### 6.1. Historical and Territorial Framework of Corso Taranto

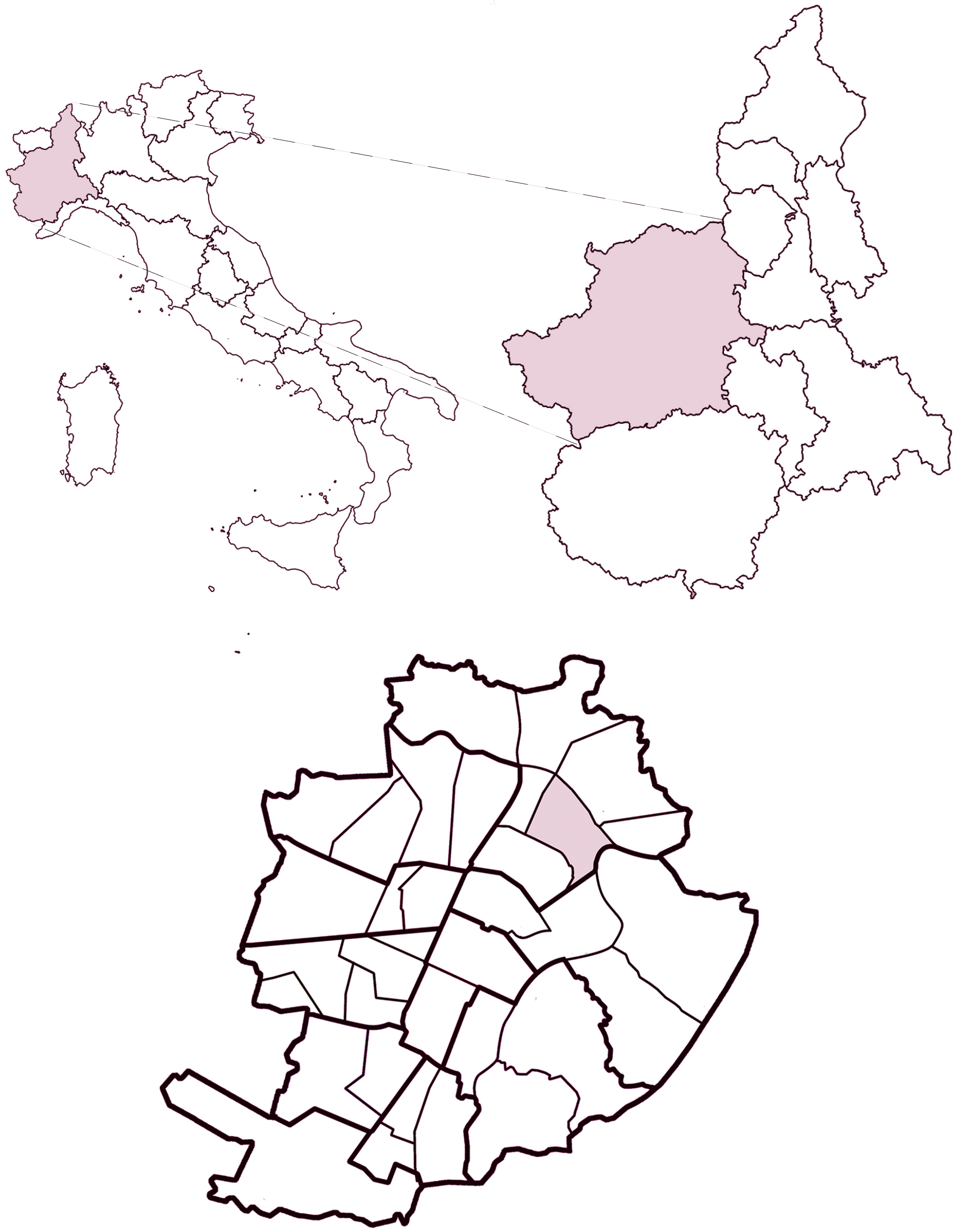


*Figure 113 Map of the Districts of Turin with Indication of the Regio Parco District*


*Figure 114 The Case Study Area in Corso Taranto*

The plot area is located in the Regio Parco district in the city of Turin in the piemonte region of Italy. The exact location of the plot area is between Via Corelli, Via Pergolesi, and Via Mercadante, where there are sixteen buildings of Corso Taranto.

Project what emerges from the study conducted on the sixteen buildings of Corso Taranto is that a third of the resident population is over 65 years old. The elderly of Corso Taranto are, in most cases, the young southerners who came in the 1950s.

In the last decades, in the Piedmontese capital, following the economic boom and immigration, especially from southern Italy, there was a need to build quickly in every available area, to the detriment of the agricultural land present around the city. Turin population has started to increase year by year.

The history of the buildings of Corsa Taranto intersects with the neighborhood of Barriera di Milano. The Regio Parco and also including the Barriera di Milano areas had grown around 10% from 1936 to 1951. Instead, in the decade between 1951 and 1961, the number of inhabitants had increased by 40%, and in the decade from 1961 to 1971 there was an increase equal to 25%, for a total of 105,905 inhabitants. It is evident that the most significant growth took place starting from the 1950s, especially because of new opportunities. [74]

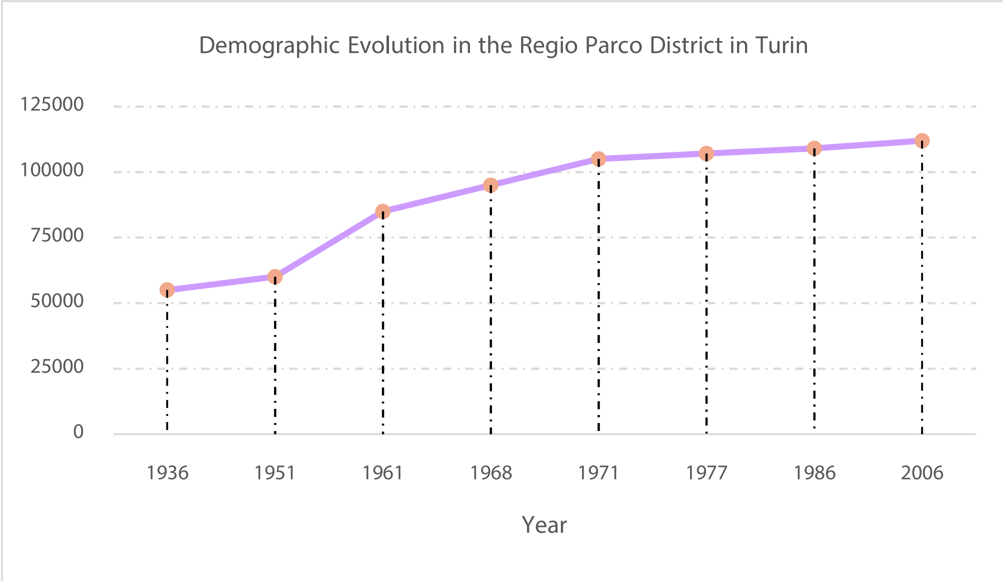



*Figure 115 Demographic Evolution in the Regio Parco District in Turin*

The growth was due on the one hand to the continuing migratory flows that caused an increase in the population density, and on the other to the transfer of the population from other areas of the city following the considerable number of new homes, including social housing they were built in more recent decades.

The data shows that in the span of twelve years, from 1951 to 1963, 7198 dwellings were built in the Regio Parco. The peak was reached in 1968, with the construction of 2667 dwellings built in the popular economic building district of Corso Taranto. [74]

The average age of the inhabitants was around 30 which compose of young couples often with four children. According to the stories of Giuseppe Marino, an elderly resident of the neighborhood and President of the Tenants Committee of Corso Taranto, the neighborhood of the 70s was a lively, young, safe neighborhood where children could play outdoors and parents could count on the supervision. They had neighborhood dynamics that were the same as those of the southern cities from which they came.

In 1975, the first Tenants Committee of Italy was established. [74] the committee and the residents came together and cooperated. And they fought for the good of the neighborhood. Then, the construction of other buildings was blocked, and football fields, markets and a church were built.

There was a sense of public affairs: in fact, even though they were aware that the houses they lived in were not their property, in 1987 the inhabitants of Corso Taranto, headed by Giuseppe Marino fought and succeeded to allocate 12 billion to renovate the buildings, for example by replacing the PVC eaves and creating adequate shelters at the entrance. Starting from 1971, due to the evident saturation of the available territory, the number of houses built began to decrease and almost disappeared between the years 1974 and 1977. At the threshold of 1979 in the territory of Barriera di Milano there were no more building areas available. [74]

From that moment, the phenomenon of population decline began. The population was slowly beginning to shrink both as a result of the demographic decline and the decrease in internal immigration, but also because of the changing economic conditions. For the Barriere di Milano, the minimum number of inhabitants (46,720 [74]) was reached, in 2000, then started growing again slowly during the following years.



### 6.2. Demographic Analysis of the Popular District of Corso Taranto

Nowadays, mostly elderly people stay in the Corso Taranto area. Their children live in different areas, often more central, they are divided between family and work, and do not have much time available to visit their parents. In the other hand today there are numerous family members, often made up of foreign immigrants. The atmosphere of friendship and reciprocity of the Sixties seems to have vanished: mistrust and indifference reign, so much so that the meeting centers where the elderly met up to a few years ago, today only welcome non-EU citizens. The elderly keep their distance from other types of frailty, taking refuge in the solitude of their homes.

The data relating to over 65-year-olds is equal to 27.5% of the population of Corso Taranto and the data are not far from the percentage of elderly people living in the city which is 25% of the total population. It follows, therefore, that in the district the percentage of over 65s exceeds the percentage of the city by 2.5%. [74]

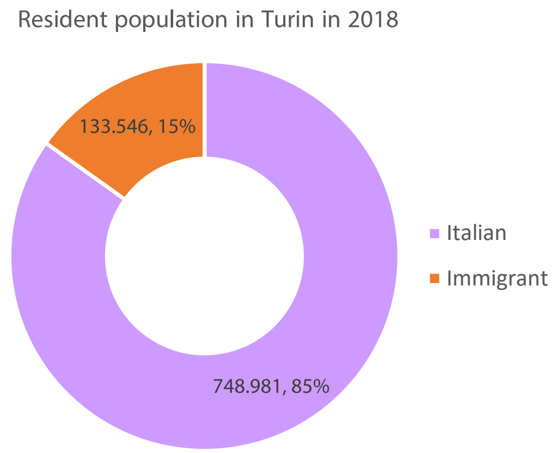



*Figure 116 Resident Population in Turin in 2018*

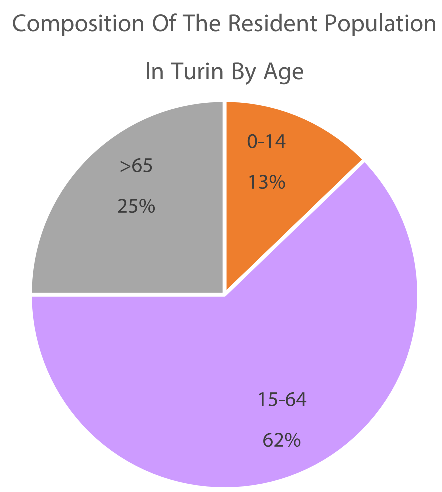



*Figure 117 Composition of the Resident Population in Turin by Age*

As can be seen in the graph below which shows the distribution by age of the population residing in public housing in Corso Taranto, out of a total of 738 resident people attributes 27.5% to over 65s (201 corresponding people). Specifically, the highest percentage which is 19.1% is given by people with an age range from 65 to 85 years.

Of the 738 residing in the accommodation in Corso Taranto, 41 elderly people live alone in large apartments which are between 76 and 87 m2. On the other hand, there are 78 apartments in which people live together and most of the time they are households of at least five members. And also 82 people live paired with a spouse in their apartments. [74]

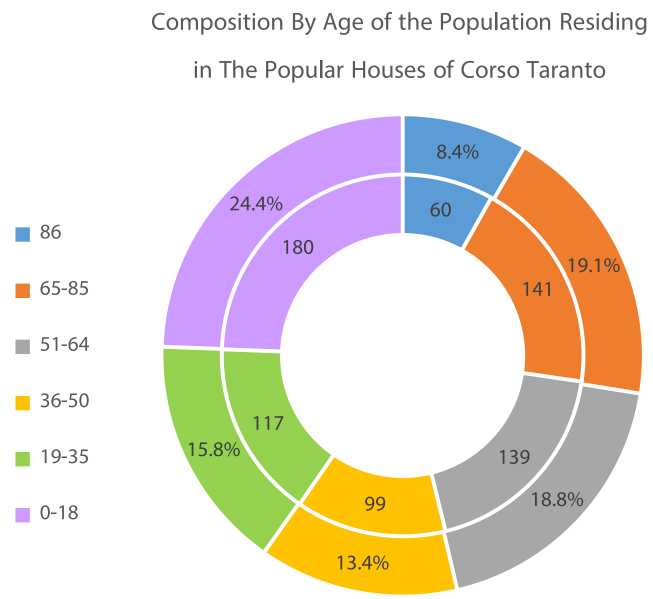



*Figure 118 Composition By Age of the Population Residing in Corso Taranto*

## 6.3. The Services in Corso Taranto


*Figure 119 Services Spots in Corso Taranto*

The Corso Taranto district was born with a severe lack of services. The residents who determined to demand better housing conditions fought to obtain the construction of the kindergarten of the sports center on a lot intended for new housing construction, and of the shopping center. But the fulcrum of the district, as well as the symbol of the first conquest of the inhabitants and the main meeting place, is the prefabricated wooden church. The only building intended to serve the community, existing even before the construction of public housing, was the San Giovanni Bosco Hospital which together with the public housing houses of Corso Taranto in the 1960s and 1970s represented one of the focal points of the neighborhood development.

The hospital, which consists of nine floors above ground, was designed before the outbreak of the Second World War and was built by the architect Ettore Rossi in the years from 1958 to 1962. [74]

To date, the situation of abandonment and lack of services does not appear obvious. Eco-selection made for the San Giovanni Bosco Hospital and the health unit of the ASL of Turin between Via Coreli and Via Botticelli, the rest of the offer of services is almost completely non-existent in the immediate vicinity. The services are mainly distributed to the southwest at Barriera di Milano, and to the east at Barriera di Stura. In these two districts, there are restaurants, pharmacies, supermarkets, post offices, churches, and cultural centers. The houses in Corso Taranto, on the other hand, are served by a single large supermarket.

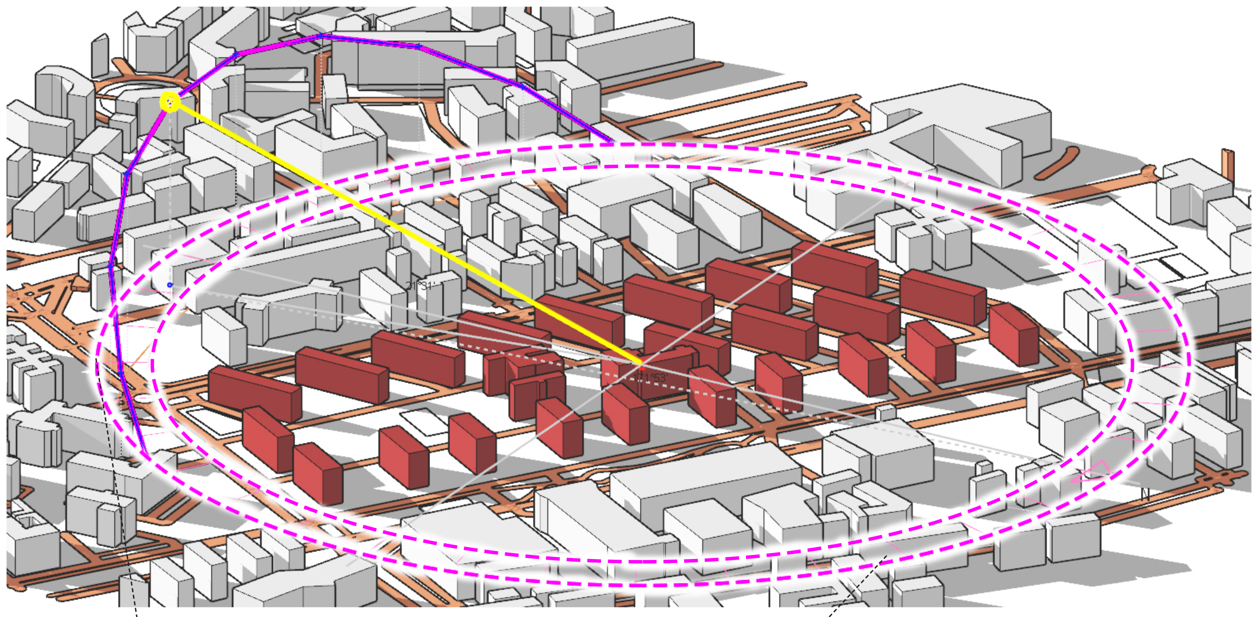
There was a whole other part of the city that is not reached before, areas like the Vanchiglia area, Via Po, Corso Vittorio San Salvario, and Crocetta. With the new line constructions, there are many connection is available. The bus lines which exactly pass through from Corso Taranto or very closely are 8, 62, 27 and 57 [75].

From this, it is deduced that reaching the most important parts of the city by public transport is possible and we can assume that the elderly do not must move to another line to go to the place where they want. But still, there are southern parts that people can not reach directly and they need to change their transportation at least one or two times.

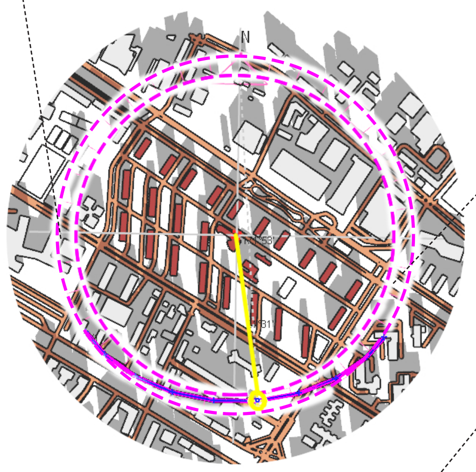


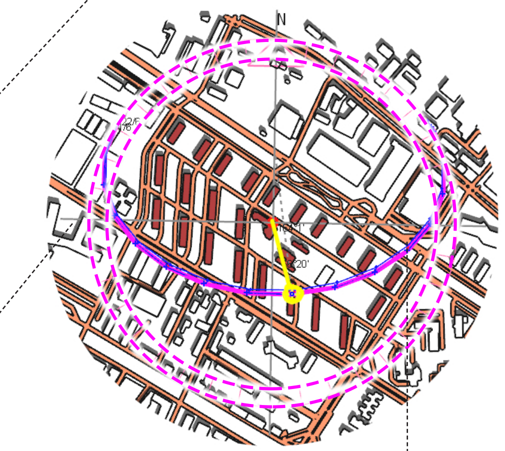
## 6.4. Site Analysis

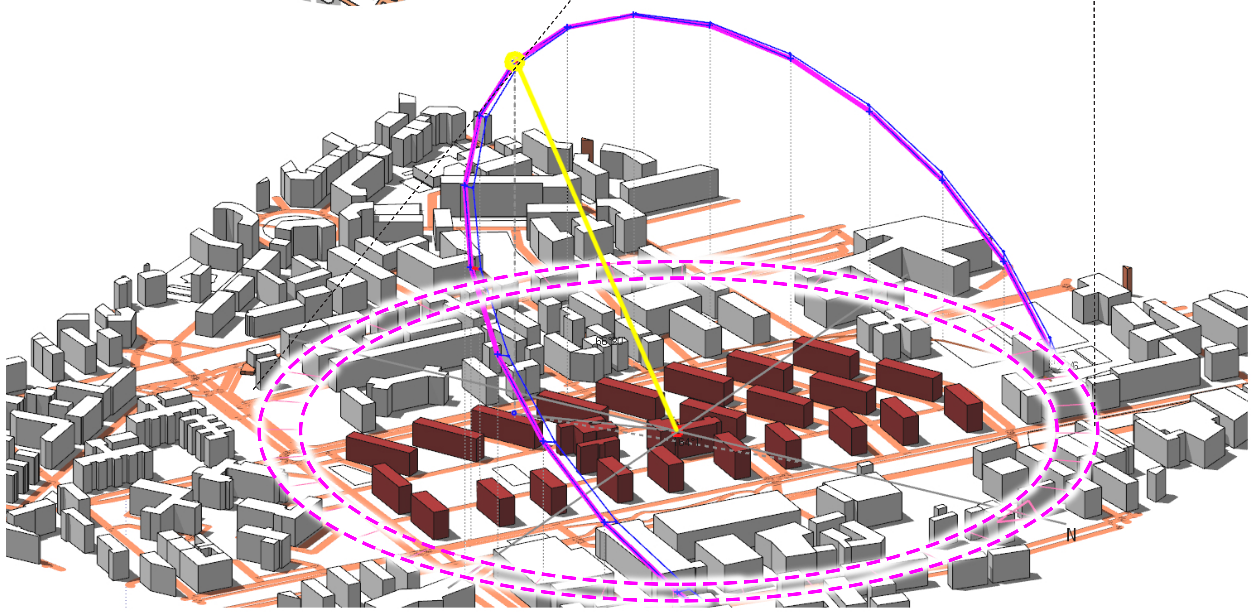

*Figure 120 Map Analysis of Corso Taranto*



*21 December 12am - Sun Path Analysis*

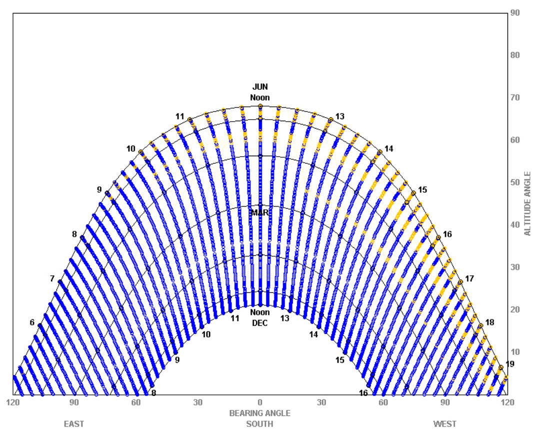




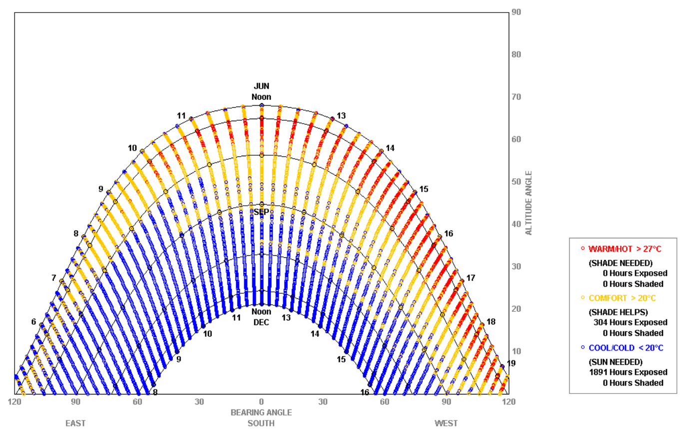


*21 June 12am - Sun Path Analysis*

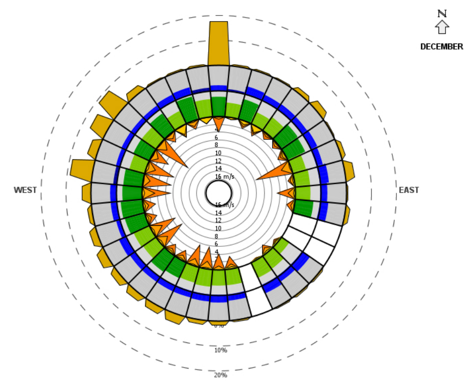
*Figure 121 Sun Path Analysis of Corso Taranto*



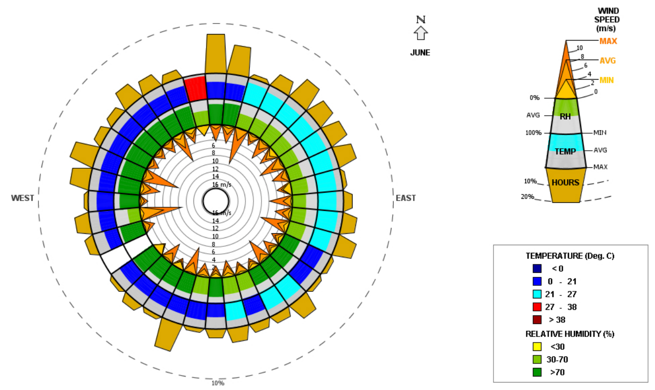
*21 June to 21 December - Sun Shading Chart*



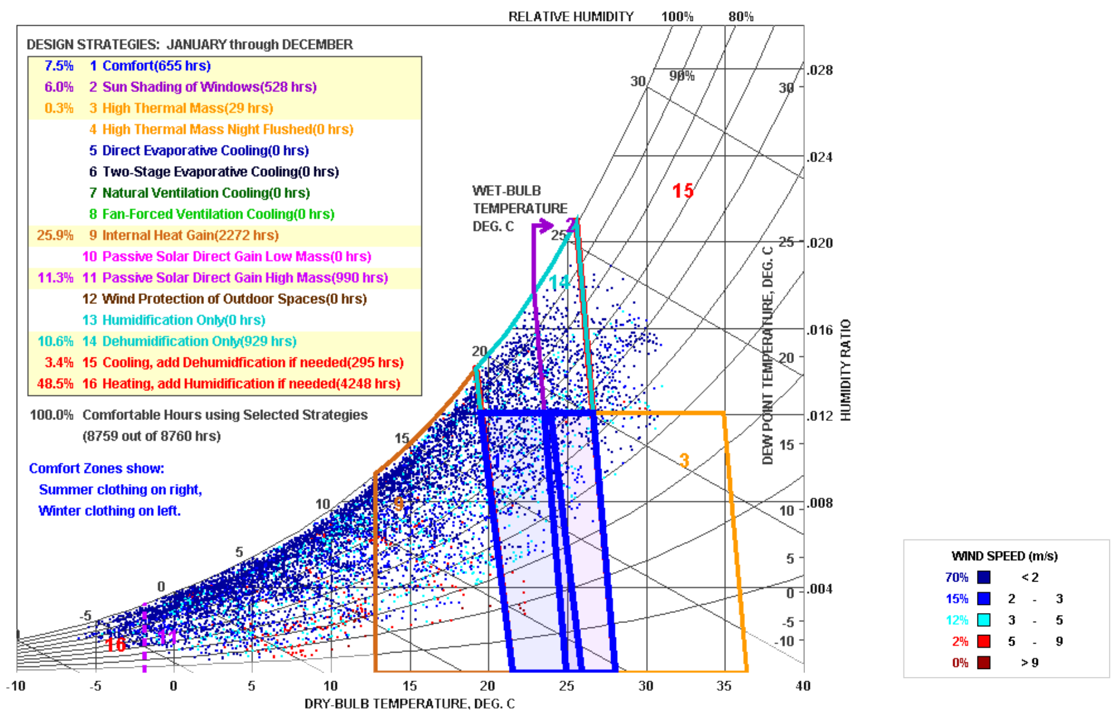
*21 December to 21 June - Sun Shading Chart*



*December - Wind Wheel*



*June - Wind Wheel*




*Psychrometric Chart - Wind Speed*

*Figure 122 Sun Shading Charts, Wind Wheel and Psychrometric Chart - Wind Speed Analysis of Corso Taranto*

### 6.5. General Plan With Indication of The Types of Buildings

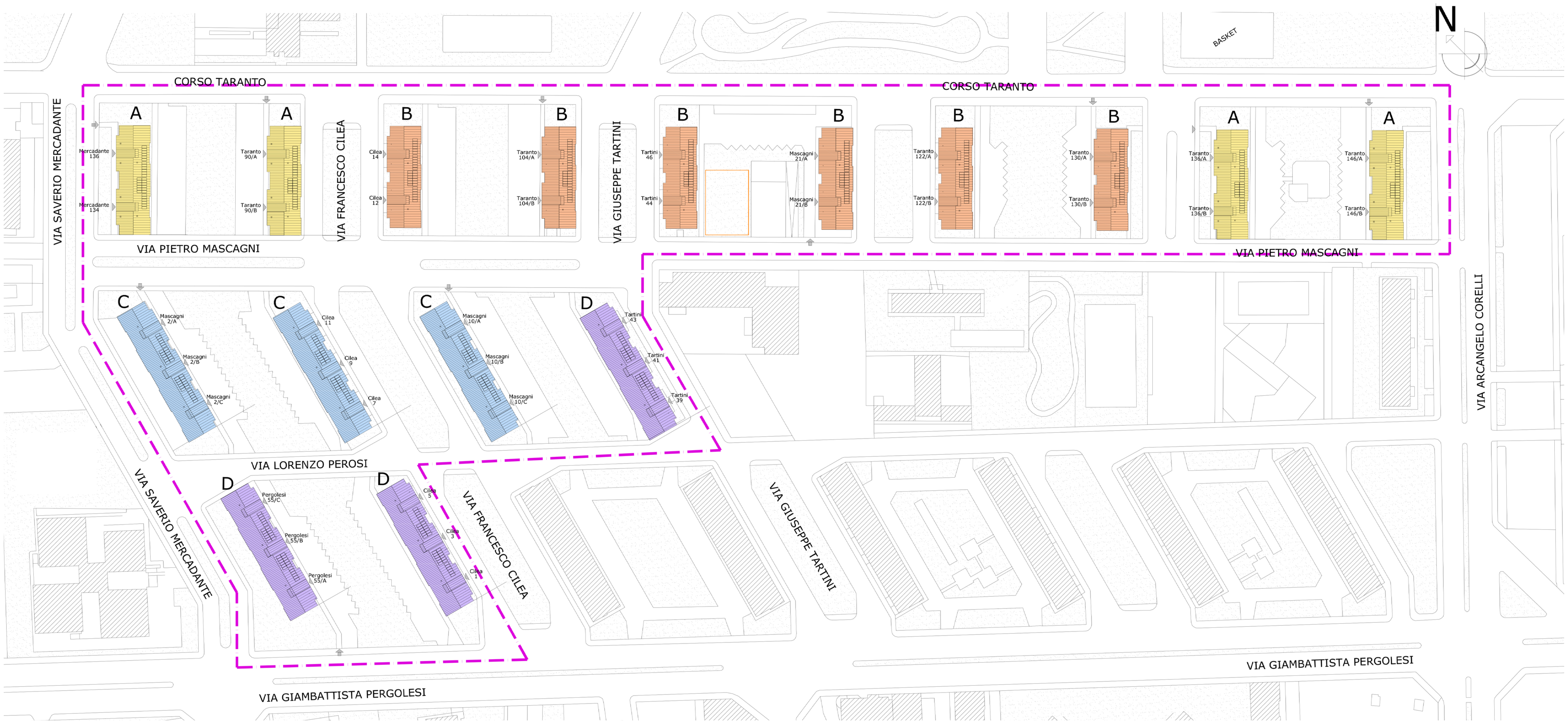



*Figure 123 General Plan with Indication of The Types of Buildings*

In the plot area which is defined by ATC Torino, there are four different types of buildings. The buildings are classified as A, B, C, and D types.

Both A and B types of buildings have 10 floors, 40 apartments, and 2 scales, while both C and D types of buildings have 7 floors, 42 apartments, and 3 scales.

For A and B types of buildings, their surface areas are approximately 500 and 460 square meters respectively. On the other hand, for C and D types of buildings, their surface areas are approximately 662 and 645 square meters respectively.

| Building Type | Number of Floor | Number of Apartment | Number of Scale | Surface Area ($m^2$) |
|---|---|---|---|---|
| A | 10 | 40 | 2 | 500 |
| B | 10 | 40 | 2 | 460 |
| C | 7 | 42 | 3 | 662 |
| D | 7 | 42 | 3 | 645 |

*Table 9 Summary of Building Types*

## 7. Design Proposal

### 7.1. Introduction

In the literature research, the importance of energy efficiency and energy saving in the building envelope were studied. In this chapter, to show the effect of building retrofitting energy technologies, energy estimations on a building will be done in the plot area.

During the estimation, as explained before in the methodology chapter, three different scenarios were identified. The idea is that scenario 0 will be the existing state in which there is no building envelope retrofitting development on the building.

Other scenarios are the new retrofitting proposals related to the building. The first design proposal will be scenario 1 which comprises light retrofitting technologies while the second design proposal will be scenario 2 and which comprises heavy retrofitting technologies.

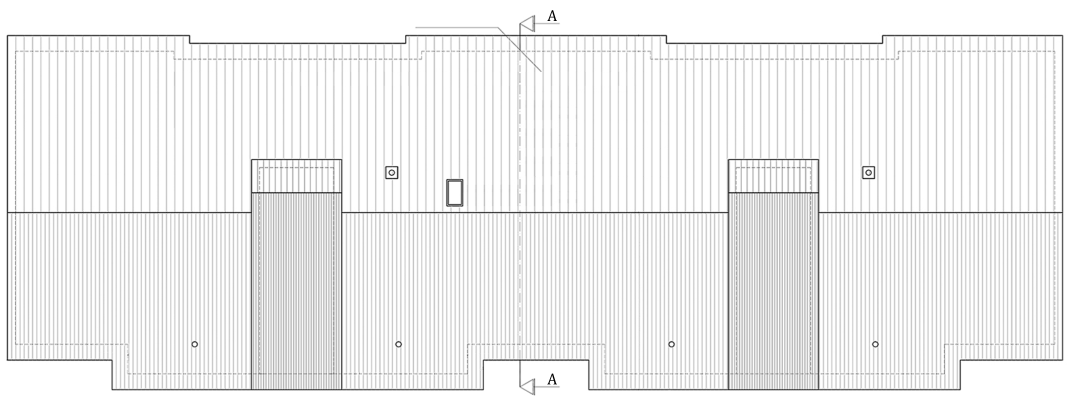


*Figure 107 Top View of Building Type B (Referance Building)*

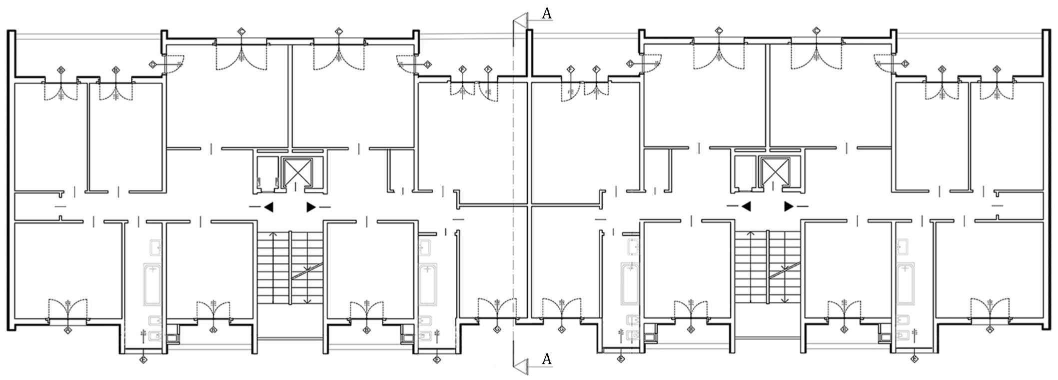


*Figure 124 Normal Floor Plan of Building Type B (Referance Building)*

In the plot area, there are four different types of buildings. The types of buildings are classified as A, B, C, and D typologies. As a building where energy estimations will be done, the type B building was chosen. The architectural drawings which are the normal floor plan, the section, and the front and top view of the type B building showed in the figures.

To start the energy estimations on TABULA, the volumetric information of the type B building was taken by using QGIS software. The volumetric information taken from QGIS is put on TABULA Calculator, and then the results are taken from the TABULA Calculator for all scenarios.

*Figure 125 Front View and Section A-A of Building Type B (Referance Building)*

## 7.2. Existing State - Senario 0

The existing state was considered Scenario 0 which is the building without retrofitting in the project.

The building and system databases related to Scenario 0 are shown in the following tables.

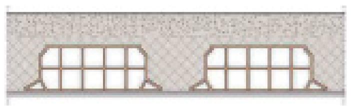
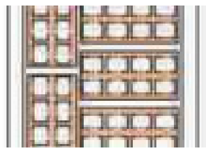
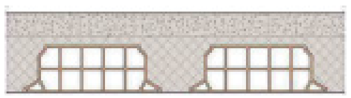
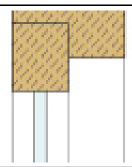
| | | Scenario 0 |
|---|---|---|
| Roof | surface area | 461.66 |
| | type of construction / refurbishment measure | Ceiling with reinforced brick-concrete slab |
| | picture |  |
| | U-value | 1.10 $W/(m^2K)$ |
| Wall | surface area | 3801.6 |
| | type of construction / refurbishment measure | Hollow brick masonry (40 cm) |
| | picture |  |
| | U-value | 0.91 $W/(m^2K)$ |
| Floor | surface area | 461.66 |
| | type of construction / refurbishment measure | Floor with reinforced brick-concrete slab |
| | picture |  |
| | U-value | 1.30 $W/(m^2K)$ |
| Window | surface area | 372.6 |
| | type of construction / refurbishment measure | Single glass, wood frame |
| | picture |  |
| | U-value | 4.90 $W/(m^2K)$ |

*Table 10 Building Data Information of Scenario 0 (Existing State)*

| | | Scenario 0 |
|---|---|---|
| general | **Supply system type** | gas central heating system: non-condensing boiler (forced draft burner) and central distribution, medium efficiency / individual dhw system (gas-fired instantaneous water heater) |
| space heating system | **Heat generator 1** | gas non-condensing boiler, forced draft burner, installed in thermal plant, after 1996 |
| | energy carrier | natural gas |
| | energy expenditure coefficient | 1.25 |
| | energy expenditure coefficientelectricity generation | 0.00 |
| | fraction of heat production | 100% |
| | **Heat generator 2** | |
| | energy expenditure coefficient | 0.00 |
| | energy expenditure coefficientelectricity generation | 0.00 |
| | fraction of heat production | 0% |
| | **Storage type** | |
| | floor-area related heat losses [$kWh/(m^2a)$] | |
| | **Distribution type** | central distribution, horizontal strings in unheated rooms (e.g. cellar or soil) / 1994-2005 |
| | specific heat losses [$kWh/(m^2a)$] | 9.9 |
| | **auxiliary electricity type** | pump for central heating - boiler with forced draft burner (auxiliary) |
| | floor-area related auxiliary electricity consumption [$kWh/(m^2a)$] | 2.62 |
| domestic hot water system | **Heat Generator 1** | gas-fired instantaneous water heater, non-condensing, sealed combustion chamber without standing pilot |
| | energy carrier | natural gas |
| | energy expenditure coefficient | 1.39 |
| | energy expenditure coefficientelectricity generation | 0.00 |
| | fraction of heat production | 100% |
| | **Heat Generator 2** | |
| | energy carrier | |
| | energy expenditure coefficient | 0 |
| | energy expenditure coefficientelectricity generation | 0 |
| | fraction of heat production | 0% |
| | **Storage type** | |
| | floor-area related heat losses [$kWh/(m^2a)$] | 0 |
| | **Distribution type** | separate DHW distribution per apartment without circulation - after 1975 |
| | specific heat losses losses [$kWh/(m^2a)$] | 1.3 |
| | **Auxiliary electricity type** | decentral DHW system |
| | floor-area related auxiliary electricity consumption [$kWh/(m^2a)$] | 0 |

*Table 11 System Data Information of Scenario 0 (Existing State)*

According to the existing state Scenario 0 building data and system data:

For building type B, the energy estimation results for scenario 0 are assumed to be using the building elements shown in the table above.

- The building roof which is 461.66 square meters has a ceiling with reinforced brick and concrete slab. The U value of the roof is 1.10 W/(m²K).
- The building wall area which is 3801.6 square meters in the surface area totally was constructed with hollow brick masonry (40 cm). The U value of the wall is 0.91 W/(m²K).
- The building floor which is 461.66 square meters has a material with reinforced brick and concrete slab. The U value of the roof is 1.30 W/(m2K).
- The building windows area which is 372.6 square meters in the surface area totally were constructed with a single glass and wood frame. The U value of the windows is 4.90 W/(m²K).
- The supply system type of the building is the gas central heating system which composes of a non-condensing boiler (forced draft burner), and central distribution, medium efficiency-individual DHW system (gas-fired instantaneous water heater).
- Natural gas is used as the energy carrier of the building for both heating and domestic hot water system. In the heating system of the building, there is also a pump for central heating as an auxiliary electricity type.

The energy estimations were done in TABULA calculator and energy performance results were obtained according to the Scenario 0 data, and the results are showed in the table below.

| | **Unit** | | **Existing state Scenario 0** |
|---|---|---|---|
| **Energy Need for Heating and DHW** | kWh/(m²a) | energy demand for heating | 102.53 |
| | | energy demand for DHW | 12.10 |
| **Energy Carriers** | kWh/(m²a) | fossil fuels | 173.90 |
| | | biomass | 0.00 |
| | | electricity | 2.11 |
| | | district heating | 0.00 |
| **Non-Renewable Primary Energy for Heating and DHW** | kWh/(m²a) | non-renewable primary energy demand | 168.34 |
| **Total Primary Energy(non-renewable+renewable)** | kWh/(m²a) | total primary energy demand for heating | 149.60 |
| | kWh/(m²a) | total primary energy demand for DHW | 19.10 |
| **Carbon Dioxide Emissions** | kg/(m²a) | carbon dioxide emissions | 44.43 |
| **Energy Costs** | Euro/(m²a) | energy costs | 12.96 |

*Table 12 Energy Estimation Results of Scenario 0 (Existing State)*

The gross annual energy need for heating which is 102.53 kWh/(m²a) is equal to the net annual energy need for heating. The reason for this, there is no recovered heat by any other system. On the other hand, the energy need for the DHW system is 12.10 kWh/(m²a). The building's annual energy need is becoming 114.63 kWh/(m²a) and the allocation of energy need for heating and DHW system is shown in the following figure.

The building is mainly using non-renewable primary energy sources and the usage of electricity is only by pump and very low. The main delivered energy need for energy carriers is coming from the fossil fuels category and it is around 98% of the total energy demand.

The total primary energy demand in the building is 168.70 kWh/(m²a) annually. While the heating primary energy demand is 149.60 kWh/(m2a), the primary energy demand for hot water is 19.10 kWh/(m²a). There is also renewable energy demand in the building which came from an electrical pump. But only 0.42 kWh/(m²a) is coming from renewable primary energy demand.

The usage of fossil fuels gives rise to CO2 emissions in buildings. After the estimations in TABULA calculater, we can see the CO2 emissions during the year is 44.43 kg/(m²a) in the building.

Another important point for the building is the cost of energy. Considering the existing system, the annual energy cost of the building is estimated at 12.96 Euro/(m²a).

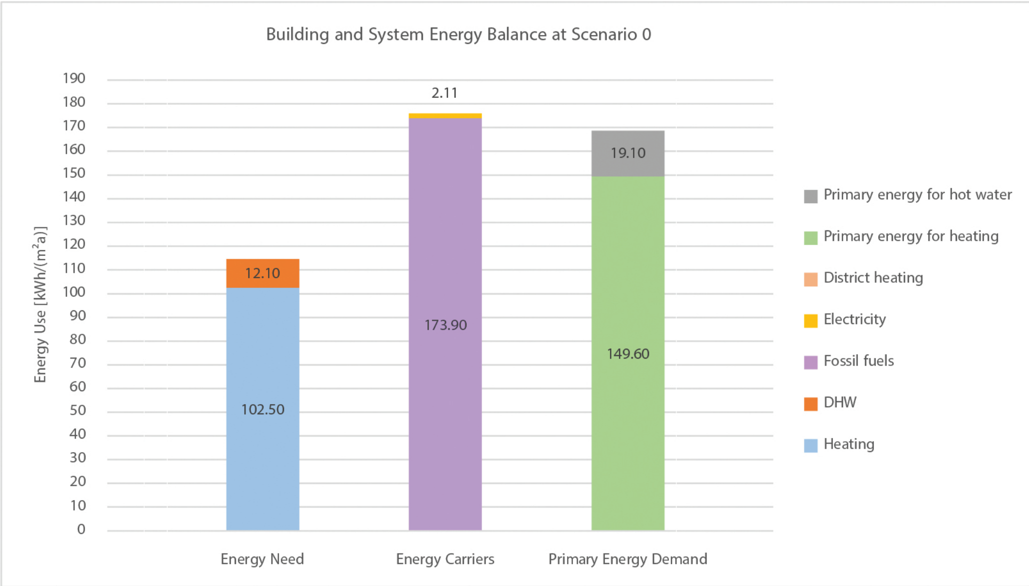



*Figure 126 Building and System Energy Balance at Scenario 0 (Existing State)*

Moreover, from TABULA calculator, the heat losses and heat gains is estimated for the building. Heat losses and heat gains can happen through any part of the building's envelope. Heat losses reflect the total transfer of heat through the fabric of the building from the inside out.

On the other hand, heat gains also referred to as solar gains are the opposite of heat losses. Heat gains is the term given to a temperature rise within a space due to heat from the sun (solar radiation), heat from surfaces, heat originating from other sources within the space, and so on. In the following table and figure, the results are shown related to heat losses and heat gains in the building.

| | Heat Losses | Heat Gains |
|---|---|---|
| **Transmission losses roof** | 6.45 | |
| **Transmission losses wall** | 44.00 | |
| **Transmission losses window** | 7.60 | |
| **Transmission losses floor** | 23.11 | |
| **Ventilation losses** | 37.55 | |
| **Usable solar heat load** | | 6.70 |
| **Usable internal heat load** | | 9.48 |
| **(Net) Energy need for heating** | | 102.53 |
| | | |
| **Sum check** | 118.71 | 118.71 |

*Table 13 Heat Losses and Gains Results of Scenario 0 (Existing State)*

According to the estimations, the biggest losses are due to transmission losses in the wall and transmission losses in the floor in the building envelope. Additionally, there is a big ventilation loss in the building due to the lack of a ventilation system. In conclusion, the total heat losses are 118.71 kWh/(m²a) annually in the building.

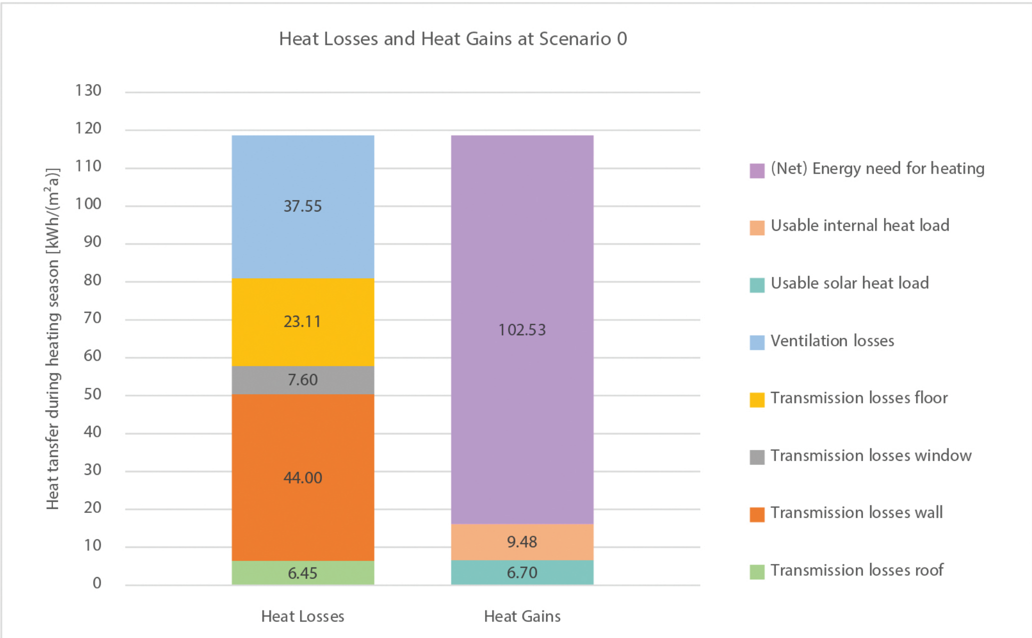



*Figure 127 Heat Losses and Gains at Scenario 0 (Existing State)*

To balance these heat losses, the building needs energy. The heating system of the building is supplied 85% of total heat gains approximately. The rest is coming from passive solar usable internal heat load in the building.

## 7.3. Usual Retrofitting - Senario 1

The first design proposal was considered Scenario 1 which implemented light building envelope retrofitting developments to the building in the project. In this design proposal, to obtain better energy performance, the energy estimations were done by some improvements and changes in the building data and system type of the building.

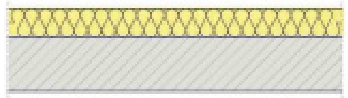
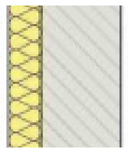
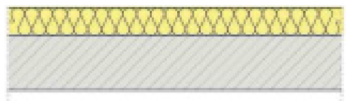
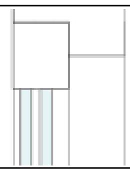
| | | Scenario 1 |
|---|---|---|
| Roof | surface area | 461.66 |
| | type of construction / refurbishment measure | add 11 cm of insulation |
| | picture |  |
| | U-value | 0.27 $W/(m^2K)$ |
| Wall | surface area | 3801.6 |
| | type of construction / refurbishment measure | add 9 cm of insulation |
| | picture |  |
| | U-value | 0.30 $W/(m^2K)$ |
| Floor | surface area | 461.66 |
| | type of construction / refurbishment measure | add 11 cm of insulation |
| | picture |  |
| | U-value | 0.28 $W/(m^2K)$ |
| Window | surface area | 372.6 |
| | type of construction / refurbishment measure | mount new windows, double glazed, argon filled, low E |
| | picture |  |
| | U-value | 2.00 $W/(m^2K)$ |

*Table 14 Building Data Propose Information for Scenario 1 (Usual Retrofitting)*



| | | Scenario 1 |
|---|---|---|
| general | **Supply system type** | district heating system / individual dhw system (gas-fired instantaneous water heater, condensing) |
| space heating system | **Heat generator 1** | district heating transfer station - high efficiency of the substation |
| | energy carrier | district heating |
| | energy expenditure coefficient | 1.09 |
| | energy expenditure coefficientelectricity generation | 0.00 |
| | fraction of heat production | 100% |
| | **Heat generator 2** | |
| | energy expenditure coefficient | 0.00 |
| | energy expenditure coefficientelectricity generation | 0.00 |
| | fraction of heat production | 0% |
| | **Storage type** | |
| | floor-area related heat losses [$kWh/(m^2a)$] | |
| | **Distribution type** | central distribution, horizontal strings in unheated rooms (e.g. cellar or soil) / after 2005 - high insulation level |
| | specific heat losses [$kWh/(m^2a)$] | 3.2 |
| | **auxiliary electricity type** | pump for central heating |
| | floor-area related auxiliary electricity consumption [$kWh/(m^2a)$] | 1.6 |
| domestic hot water system | **Heat Generator 1** | gas-fired instantaneous water heater, condensing |
| | energy carrier | natural gas |
| | energy expenditure coefficient | 1.24 |
| | energy expenditure coefficientelectricity generation | 0.00 |
| | fraction of heat production | 100% |
| | **Heat Generator 2** | |
| | energy carrier | |
| | energy expenditure coefficient | 0 |
| | energy expenditure coefficientelectricity generation | 0 |
| | fraction of heat production | 0% |
| | **Storage type** | |
| | floor-area related heat losses [$kWh/(m^2a)$] | 0 |
| | **Distribution type** | separate DHW distribution per apartment without circulation - after 1975 |
| | specific heat losses losses [$kWh/(m^2a)$] | 1.3 |
| | **Auxiliary electricity type** | decentral DHW system |
| | floor-area related auxiliary electricity consumption [$kWh/(m^2a)$] | 0 |

*Table 15 System Data Propose Information for Scenario 1 (Usual Retrofitting)*

According to Scenario 1 proposal, the building data and system data:

• The building roof construction had no insulation at Scenario 0. In this design proposal, 11 cm insulation was added to the roof of the building. Adding insulation to the building's envelope helps to save more energy by reducing the U value. By implementing insulation, the U value was decreased from 1.10 W/(m²K) to 0.27 W/(m²K) in the building roof.

• The building walls also had no insulation at Scenario 0. By adding 9 cm insulation to the building walls, the U value of the walls was decreased from 0.91 W/(m²K) to 0.30 W/(m²K).

• Another insulation material addition proposal was applied to the building floors to improve energy efficiency. For the building floors, 11 cm insulation material was added and the U value of the building floor became 0.28 W/(m²K).

• In Scenario 1, new types of windows are proposed. The building windows are changed from single glass and wooden frames to double-glazed, argon-filled, and low-E windows. The reason for using double glazed proposal is that the gap between two windows creates more effective insulation and helps to reduce U value. In the end, the U value of the windows decreased and became 2.00 W/(m2K). Between two window glasses, it must be a gas to fill in it. For this reason, argon gas was proposed, because argon gas helps to minimize heat transmission loss and increase the room insulation. On the other hand, finally, the low-E coating was proposed on the building windows. Because Low-E coating allows the sun's rays to pass in and prevents the energy from escaping by radiation. In this way, energy demand is reduced.

• In Scenario 1 system data, the main changes were done in the heating system of the building as a design proposal. The heating system of the building was changed from gas non-condensing to the district heating system and the energy carrier of the system was changed to district heating from natural gas. The reason for this proposal was that district heating is a system in which residentials buy useful energy from a district heating plant for space heating and hot water, and district heating provides more energy efficiency. Additionally in this system, the pump for central heating stayed as electrical auxiliary equipment. This proposal was made only for the space heating system of the building. In the end, the domestic hot water system partly stayed the same. The only proposal was using the condensing gas-fired instantaneous water heater instead of non-condensing.

The energy estimations were done in TABULA calculator and energy performance results were obtained according to the Scenario 1 data, and the results of the proposal are shown in the table below.

| | Unit | | Usual Retrofitting Scenario 1 |
|---|---|---|---|
| **Energy Need for Heating and DHW** | kWh/(m²a) | energy demand for heating | 52.27 |
| | | energy demand for DHW | 14.67 |
| **Energy Carriers** | kWh/(m²a) | fossil fuels | 39.44 |
| | | biomass | 0.00 |
| | | electricity | 1.57 |
| | | district heating | 59.72 |
| **Non-Renewable Primary Energy for Heating and DHW** | kWh/(m²a) | non-renewable primary energy demand | 101.94 |
| **Total Primary Energy(non-renewable+renewable)** | kWh/(m²a) | total primary energy demand for heating | 81.55 |
| | kWh/(m²a) | total primary energy demand for DHW | 20.71 |
| **Carbon Dioxide Emissions** | kg/(m²a) | carbon dioxide emissions | 31.51 |
| **Energy Costs** | Euro/(m²a) | energy costs | 7.93 |

*Table 16 Energy Estimation Results of Scenario 1 (Usual Retrofitting)*

The annual net energy need for heating was reduced to 52,57 kWh/(m²a) after applying the first design proposal. It shows that using insulation materials on building envelopes helps energy saving. Because the results demonstrate that the energy need for heating improved by approximately 50% according to the non-retrofitting building energy demand for heating results. On the other hand, there was no significant change in the energy need the domestic hot water system.

In scenario 1, the district heating system was used and the delivered energy demand of energy carriers was separated as shown in the figure below. By means of using district heating as an energy carrier helped to obtain more energy-friendly results. According to the results, annual delivered energy demand of energy carriers are 39,44 kWh/(m²a), 1,57 kWh/(m²a) and 59,72 kWh/(m²a) respectively for fossil fuels electricity and district heating. Additionally, another important point is that the use of fossil fuels has been reduced by 78%.

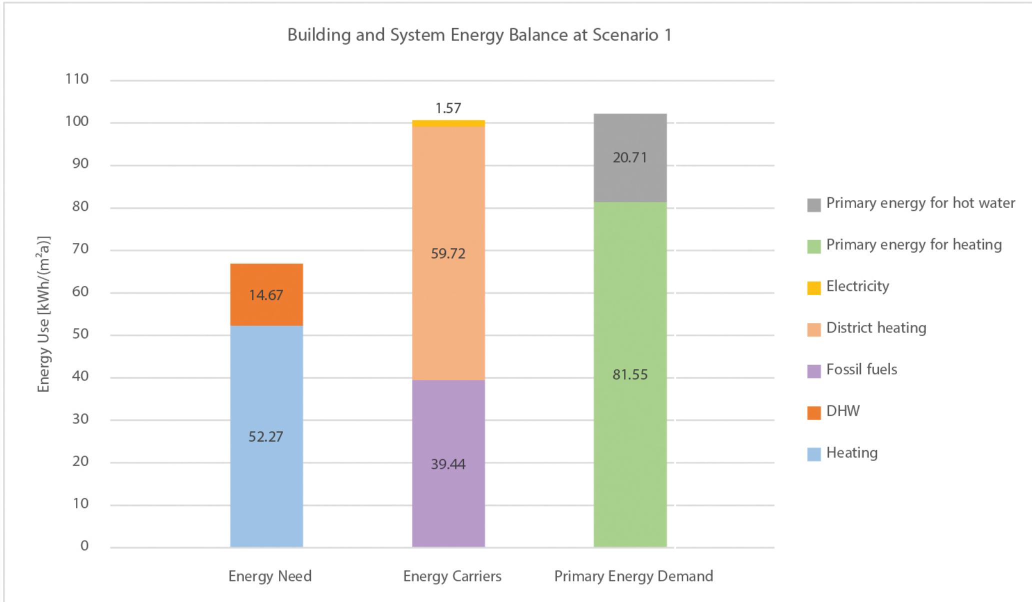



*Figure 128 Building and System Energy Balance at Scenario 1 (Usual Retrofitting)*

If we check the total primary energy demand results from the figure, the importance of adding insulation material and using district heating is clearly understood. The value decreased from 168.7 kWh/(m²a) to 102.3 kWh/(m²a), and this change was obtained from the reduction of heating demand by around 45%.

From the result table, we can see the reduction of the CO2 emissions by around 30%. The main reason for this is that fewer fossil fuels were used in this design proposal and less pollution was created thanks to the district heating system.

Implementing new retrofitting systems will have costs at the beginning as predicted. But we must need to think about the future always. With new building envelope retrofitting technologies in Scenario 1, the annual energy costs were reduced by around 60%.

When examined the Scenario 1 estimations related to heat losses and heat gains, we can see a significant reduction in total energy balance. Total energy balance was reduced by around 40%, and critical results were obtained in the parts of the building's envelope. It can be clearly understood the effect of the insulation materials on the building elements or the effect of changing the construction type ( like from single glass wooden frame windows to double glazed, argon filled, and low-E coating windows) as shown in the following table and figure. On the other hand, even though new retrofitting was applied to the building, the ventilation loss was estimated as the biggest heat loss source in the building.

| | **Heat Losses** | **Heat Gains** |
|---|---|---|
| **Transmission losses roof** | 2.37 | |
| **Transmission losses wall** | 21.31 | |
| **Transmission losses window** | 2.46 | |
| **Transmission losses floor** | 13.97 | |
| **Ventilation losses** | 30.29 | |
| **Usable solar heat load** | | 6.48 |
| **Usable internal heat load** | | 11.64 |
| **(Net) Energy need for heating** | | 52.27 |
| | | |
| **Sum check** | 70.39 | 70.39 |

*Table 17 Heat Losses and Gains Results of Scenario 1 (Usual Retrofitting)*

Additionally, most of the heat gains were obtained by heating to balance the energy against heat losses. The heat gains which come from passive solar and usable internal heat load were estimated at 6.48 and 11.64 kWh/(m$^2$a) respectively.

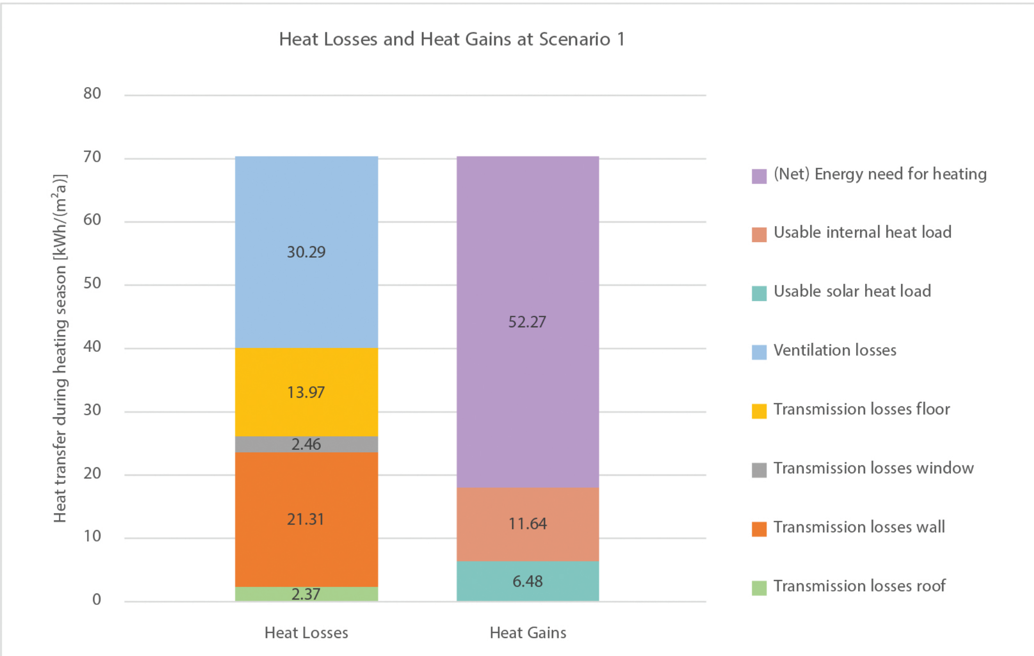



*Figure 129 Heat Losses and Gains at Scenario 1 (Usual Retrofitting)*

## 7.4. Advanced Retrofitting - Senario 2

The second design proposal was considered Scenario 2 which implemented heavy building envelope retrofitting developments to the building in the project. In this design proposal, the energy estimations were done by some improvements and changes in the building data and system type to obtain better energy performance.

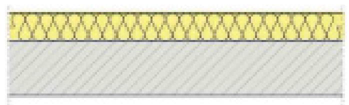
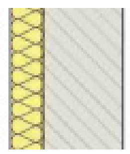
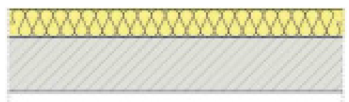
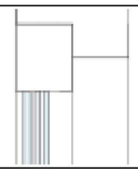
| | | Scenario 2 |
|---|---|---|
| Roof | **surface area** | 461.66 |
| | **type of construction / refurbishment measure** | add 15 cm of insulation |
| | **picture** |  |
| | **U-value** | 0.21 $W/(m^2K)$ |
| Wall | **surface area** | 3801.6 |
| | **type of construction / refurbishment measure** | add 13 cm of insulation |
| | **picture** |  |
| | **U-value** | 0.23 $W/(m^2K)$ |
| Floor | **surface area** | 461.66 |
| | **type of construction / refurbishment measure** | add 15 cm of insulation |
| | **picture** |  |
| | **U-value** | 0.22 $W/(m^2K)$ |
| Window | **surface area** | 372.6 |
| | **type of construction / refurbishment measure** | mount new windows, triple glazed, argon filled, low E |
| | **picture** |  |
| | **U-value** | 1.70 $W/(m^2K)$ |

*Table 18 Building Data Propose Information for Scenario 2 (Anvanced Retrofitting)*

| | | Scenario 2 |
|---|---|---|
| general | **Supply system type** | gas central heating system: thermal solar plant + condensing boiler, central distribution, high efficiency / central dhw system: thermal solar plant + condensing boiler, with circulation (portion of pipeline outside), high efficiency |
| space heating system | **Heat generator 1** | condensing boiler, installed in thermal plant |
| | energy carrier | natural gas |
| | energy expenditure coefficient | 1.14 |
| | energy expenditure coefficientelectricity generation | 0.00 |
| | fraction of heat production | 80% |
| | **Heat generator 2** | thermal solar plant |
| | energy expenditure coefficient | 0.00 |
| | energy expenditure coefficientelectricity generation | 0.00 |
| | fraction of heat production | 20% |
| | **Storage type** | hot water storage (tank) for central heating system - high insulation |
| | floor-area related heat losses [$kWh/(m^2a)$] | 0.8 |
| | **Distribution type** | central distribution, horizontal strings in unheated rooms (e.g. cellar or soil) / after 2005 - very high insulation level |
| | specific heat losses [$kWh/(m^2a)$] | 2.00 |
| | **auxiliary electricity type** | pump for central heating |
| | floor-area related auxiliary electricity consumption [$kWh/(m^2a)$] | 2.6 |
| domestic hot water system | **Heat Generator 1** | condensing boiler, installed in thermal plant |
| | energy carrier | natural gas |
| | energy expenditure coefficient | 1.12 |
| | energy expenditure coefficientelectricity generation | 0.00 |
| | fraction of heat production | 40% |
| | **Heat Generator 2** | thermal solar plant |
| | energy carrier | |
| | energy expenditure coefficient | 0 |
| | energy expenditure coefficientelectricity generation | 0 |
| | fraction of heat production | 60% |
| | **Storage type** | hot water storage (tank) for central DHW system, in unconditioned space - high insulation |
| | floor-area related heat losses [$kWh/(m^2a)$] | 2.1 |
| | **Distribution type** | central DHW distribution with circulation, fraction of pipeline outside of thermal envelope, after 1991 |
| | specific heat losses losses [$kWh/(m^2a)$] | 2.8 |
| | **Auxiliary electricity type** | central DHW system with thermal solar system, with circulation pump, in association with condensing boiler (auxiliary) |
| | floor-area related auxiliary electricity consumption [$kWh/(m^2a)$] | 2.5 |

*Table 19 System Data Propose Information for Scenario 2 (Advanced Retrofitting)*

According to Scenario 2 proposal, the building data and system data:

• We experienced in Scenario 1 that adding insulation material to a building's envelope helped to obtain more energy-efficient building performance. However, another important point is also the thickness of the insulation material on a building element. To show the effect of thicker insulation, the addition of 15 cm insulation on the building roof was proposed in Scenario 2, and by means of this, 4 cm additional insulation material was obtained by comparing Scenario 1. On the other hand, an excellent decrease of the U value was obtained and it became 0.21 W/(m2K).

• The same insulation method was done for both the building walls and the building floors. The insulation material thicknesses were made 13 cm and 15 cm respectively for the building walls and building floors. Their U values were 0.91W/($m^2$K) and 1.30 W/($m^2$K) respectively for the building walls and the building floors in Scenario 0, while new U values became 0.23 W/($m^2$K) and 0.22 W/($m^2$K).

• For the windows, triple-glazed, argon-filled, and low-E coating window type was proposed in Scenario 2. In the second design proposal, not just only the effect of the new construction window type but also understanding the difference between triple-glazed and double-glazed windows was aimed.

• In Scenario 2 system data, many changes were done by comparing with Scenario 0. For the heating system of the building, district heating was used in Scenario 1. In the second design proposal, the heating system and DHW system have stayed again gas central system, but additionally to them, the thermal solar system was added. The thermal solar system is one of the most efficient method to reduce energy demand in a building. The system can be used for both space heating and producing hot water in a building. But this system is supported by other systems during the whole year. Because during the year, the energy taken from the sun is not stable. According to the proposal, the thermal solar system is constituted 20% of the heating system while 60% is proposed for the domestic hot water system. For the rest of the heat generators, the condensing boiler was proposed for gas central heating and hot water.

• Another additional feature in the building is adding the storage type because of thermal solar plants. The hot water storage tank is proposed to use for the heating system and the DHW system.

The energy estimations were done in TABULA calculator and energy performance results were obtained according to the Scenario 2 data, and the results of the proposal are shown in the table below.

| | Unit | | Advanced Retrofitting Scenario 2 |
|---|---|---|---|
| **Energy Need for Heating and DHW** | kWh/($m^2$a) | energy demand for heating | 46.43 |
| | | energy demand for DHW | 15.30 |
| **Energy Carriers** | kWh/($m^2$a) | fossil fuels | 62.61 |
| | | biomass | 0.00 |
| | | electricity | 7.78 |
| | | district heating | 0.00 |
| **Non-Renewable Primary Energy for Heating and DHW** | kWh/($m^2$a) | non-renewable primary energy demand | 68.20 |
| **Total Primary Energy(non-renewable+renewable)** | kWh/($m^2$a) | total primary energy demand for heating | 53.30 |
| | kWh/($m^2$a) | total primary energy demand for DHW | 15.95 |
| **Carbon Dioxide Emissions** | kg/($m^2$a) | carbon dioxide emissions | 18.05 |
| **Energy Costs** | Euro/($m^2$a) | energy costs | 5.54 |

*Table 20 Energy Estimation Results of Scenario 2 (Advanced Retrofitting)*



As predicted from the first design proposal, adding more insulation material was affected the energy use for heating. As we can see from the results, the energy need for heating decreased by 55% approximately and it became 46.40 kWh/($m^2$a) annually. This reduction when together with the hot water system was estimated at approximately 45% overall. On the other hand, if the results of Scenario 1 and Scenario 2 are compared, the effect of thicker insulation material was shown with the estimation results of TABULA calculator.

In Scenario 2, there is a significant reduction in energy demand of energy carriers because of using the thermal solar system. Fossil fuel demand is reduced by almost % 60. Even though this ratio is higher according to Scenario 1, the total delivered energy demand of energy carriers is lower overall. Because the heating system and domestic hot water system were used a natural gas-based central system. If we point out all results, the total energy demand by energy carriers was reduced from 176.01 kWh/($m^2$a) to 70.4 kWh/($m^2$a) annually. Additionally, the electricity demand was estimated at 7.80 kWh/($m^2$a) annually. This value is higher than both Scenario 0 and Scenario 1. The reason is that the thermal solar system helps to generate electricity for the DHW system as an Auxilary electricity type.

In conclusion, the use of the thermal solar system for space heating and domestic hot water together with more insulated building elements helped to reduce the total primary energy demand annually in the building. The results can not be underestimated, because the total energy demand was 168.76 kWh/($m^2$a) while it reduced to 69.28 kWh/($m^2$a) annually as shown in the figure.

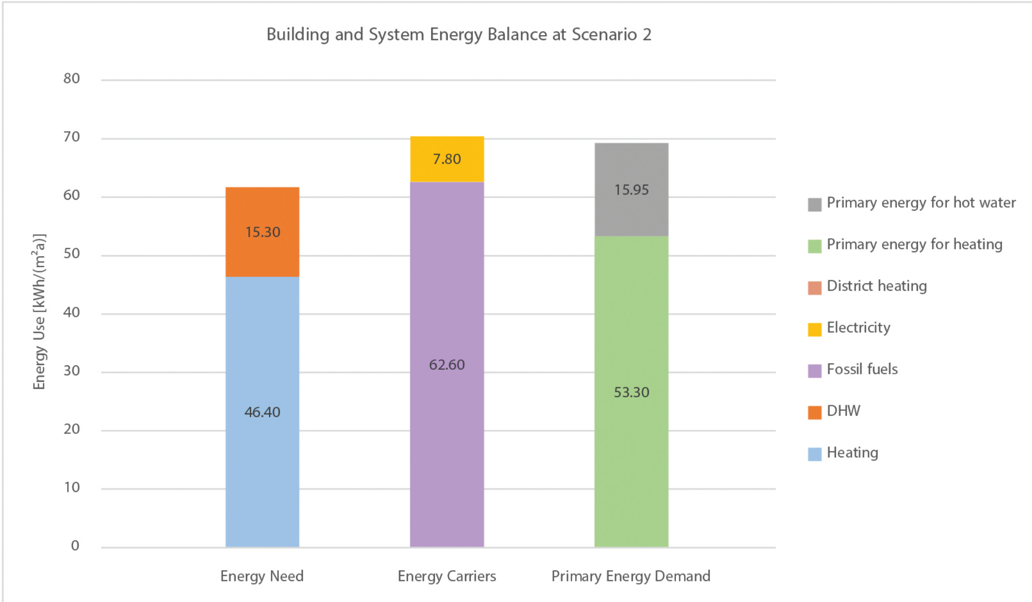



*Figure 130 Building and System Energy Balance at Scenario 2 (Advanced Retrofitting)*

The usage of a thermal solar system brings more green energy to buildings, and in the end, the CO2 emissions can be reduced. This improvement can be seen clearly from the estimation results. We can see that the building is more environmentally friendly by using a thermal solar system. The CO2 emissions are reduced by around 60% together with the second design proposal.

If we exclude the cost of the thermal solar system on the building, in Scenario 2, a more cost-effective system was brought. The cost decreased by more than half in a year. We know that this is one of the important cases for not only people but also for governments.

When examined the Scenario 2 estimations related to heat losses and heat gains, significant improvements can be seen in total energy balance. Total energy balance was reduced by around 45%, and critical results were obtained in the parts of the building's envelope. With these results, using more thicker insulation on the building's envelope helped to obtain fewer heat losses. On the other side, the difference between triple-glazed by comparing with double-glazed can be understood according to the results as shown in the following table and figure.

| | Heat Losses | Heat Gains |
|---|---|---|
| **Transmission losses roof** | 1.83 | |
| **Transmission losses wall** | 16.18 | |
| **Transmission losses window** | 1.89 | |
| **Transmission losses floor** | 11.71 | |
| **Ventilation losses** | 32.19 | |
| **Usable solar heat load** | | 5.10 |
| **Usable internal heat load** | | 12.27 |
| **(Net) Energy need for heating** | | 46.43 |
| | | |
| **Sum check** | 63.80 | 63.80 |

*Table 21 Heat Losses and Gains Results of Scenario 2 (Advanced Retrofitting)*

Once again, the ventilation loss was estimated as the biggest heat loss in the building due to the lack of a ventilation system.

Additionally, most of the heat gains were obtained by heating to balance the energy against heat losses as happened in other scenarios. The heat gains which come from passive solar and usable internal heat load were estimated at 5.10 and 12.27 kWh/(m²a) respectively.

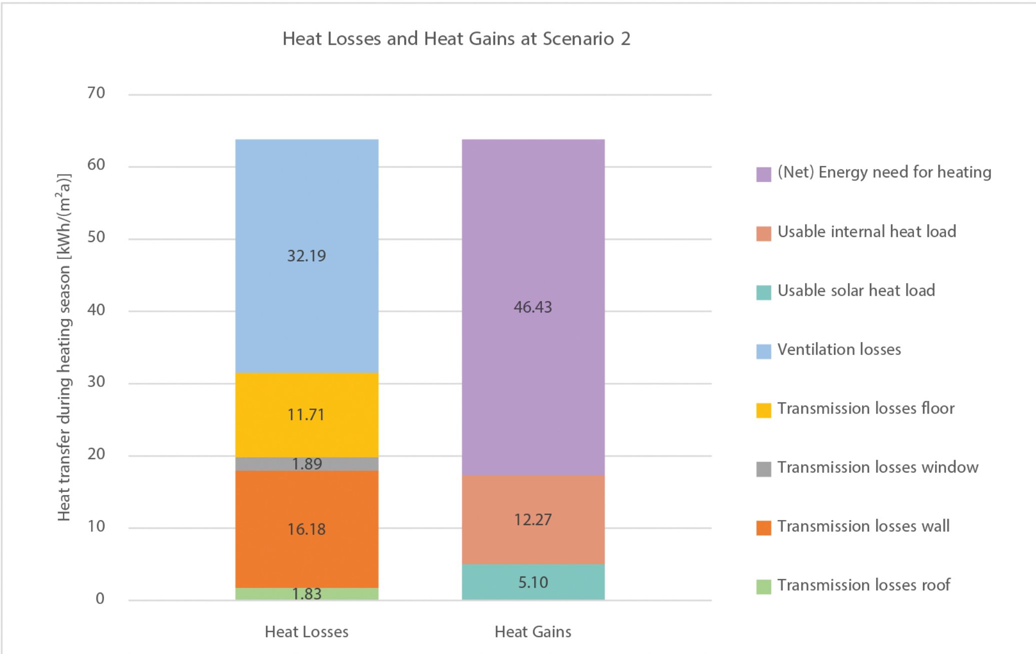



*Figure 131 Heat Losses and Gains at Scenario 2 (Advanced Retrofitting)*

## 7.5. Results

### 7.5.1. Results for Building Type B

The energy estimations of the plot area were done for Scenarios 0, 1, and 2 by using TABULA calculator. In this section, the results were evaluated by comparing retrofitting scenarios together.

As energy prices increase, and there is greater awareness of sustainability, performance measures such as U-values have become more important, and building standards (such as the Building Regulations) have required that lower and lower U-values are achieved. This has required changes in the design of buildings, both in the use of materials (such as insulation), the make-up of the building elements (such as cavity walls and double glazing), and the overall makeup of a building's fabric.

The lower the U-value of an element of a building's fabric, the more slowly heat is able to transmit through it, and so the better it performs as an insulator. At the same time, a lower U value will help to maintain comfortable conditions inside the building.

In the table below, the thickness of insulation materials, and the U values of each scenario are summarized.

| | Scenario 0 | | Scenario 1 | | Scenario 2 | |
|---|---|---|---|---|---|---|
| | Insulation thickness (cm) | U value (W/(m²K)) | Insulation thickness (cm) | U value (W/(m²K)) | Insulation thickness (cm) | U value (W/(m²K)) |
| **Roof** | 0 | 1.10 | 11 | 0.27 | 15 | 0.21 |
| **Wall** | 0 | 0.91 | 9 | 0.30 | 13 | 0.23 |
| **Floor** | 0 | 1.30 | 11 | 0.28 | 15 | 0.22 |
| **Window** | Single glass | 4.90 | Double Glazed, argon filled, low E | 2.00 | Triple Glazed, argon filled, low E | 1.70 |

*Table 22 Insulation Tickness and U Values of the Building Elements for All Scenarios*

Thanks to the thermal insulation applied in the building, the required energy can be used more efficiently and effectively without limiting the comfort of human life. Therefore, it minimizes wasted energy, and energy resources are used more efficiently. In the figure below, we can see the delivered energy demand by energy carriers in the building. If the energy demand of energy carriers' results are checked for each scenario, it is seen that the energy demand decreases proportionally to the insulation material.

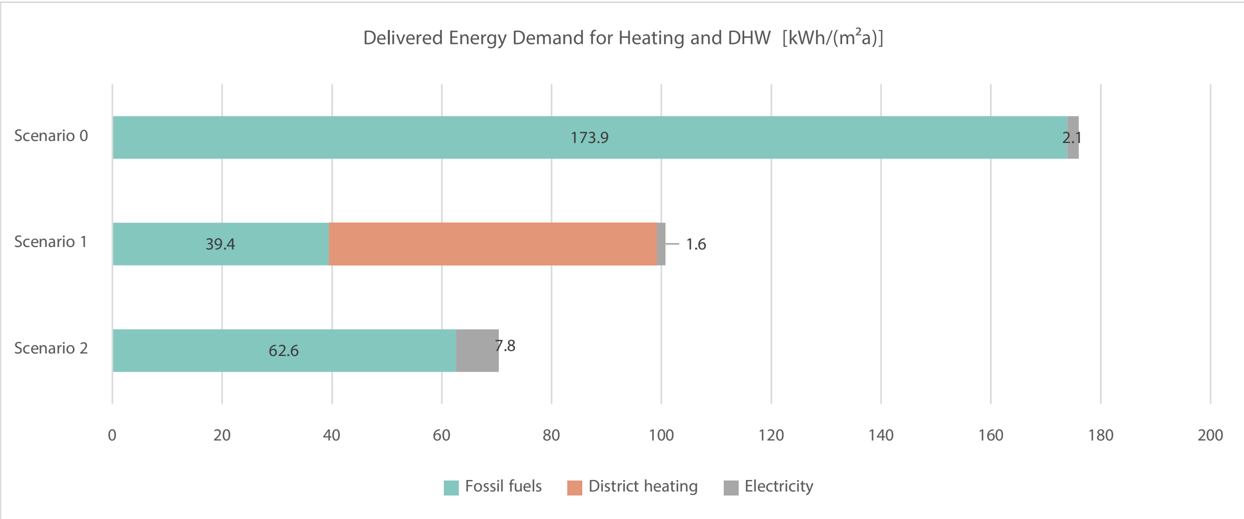



*Figure 132 Comparison of Delivered Energy Demand of Energy Carriers for Heating and DHW*

Of course, adding insulation material is not the only solution to decrease energy demand. As we can see in the figure above, we can say that different types of energy carrier usage can affect energy demand. In the design proposals, using district heating as an energy carrier was proposed to see the effect on the building. District heating can be described as a system in which heat is produced centrally by one or more energy sources and then transported through a network of pipes to the final user. District heating networks can connect the buildings of a neighborhood, town center, or entire city. The district heating system in a building is more efficient and requires less maintenance than a gas center condensing/ non-condensing boiler system. In the light of this information and when we compare the results of Scenario 0 and Scenario 1, the energy estimations were done in TABULA calculator support why district heating is more useful in our building.

On the other hand, although used natural gas as an energy carrier both in Scenario 0 and Scenario 2, there is a huge reduction in the delivered energy to the building annually. We know that the first reason is using a thermal solar system additionally to the improvements on the building envelope by adding insulation. On the other side, there is also another factor which helps to reduce energy demand in our building. Gas central heating and hot water system were used for both Scenario 0 and Scenario 2. The difference is here that condensing boiler was proposed in Scenario 2, while a non-condensing boiler was used in the existing scenario. Condensing and non-condensing boilers both burn fuel, such as natural gas, but the main difference is that the energy efficiency of condensing boilers is up to 99% efficient while non-condensing boilers are only up to 78% efficient. The main advantages of the condensing boiler are increased energy efficiency and lower carbon footprint.

The energy need for space heating and DHW in the building is calculated not just only by building specifications but also by environmental conditions of the plot area in the TABULA calculator. In our project, the external factors related to the plot area are accepted the same for all scenarios. Basically, the factors done by different retrofitting in the building affected the energy estimation results. The insulation thickness, the U value, the type of system used in the building, and the type of building element were considered as main factors.

When we compare the results between Scenario 0 and Scenario 1, the important development in energy need for our building can be seen clearly. The main reasons for this improvement came from adding insulation to the building elements, and changing the system type of the building from a gas center system to a district system as predicted. As shown in the figure below, the annual net energy need for heating and DHW was reduced by around 40%.

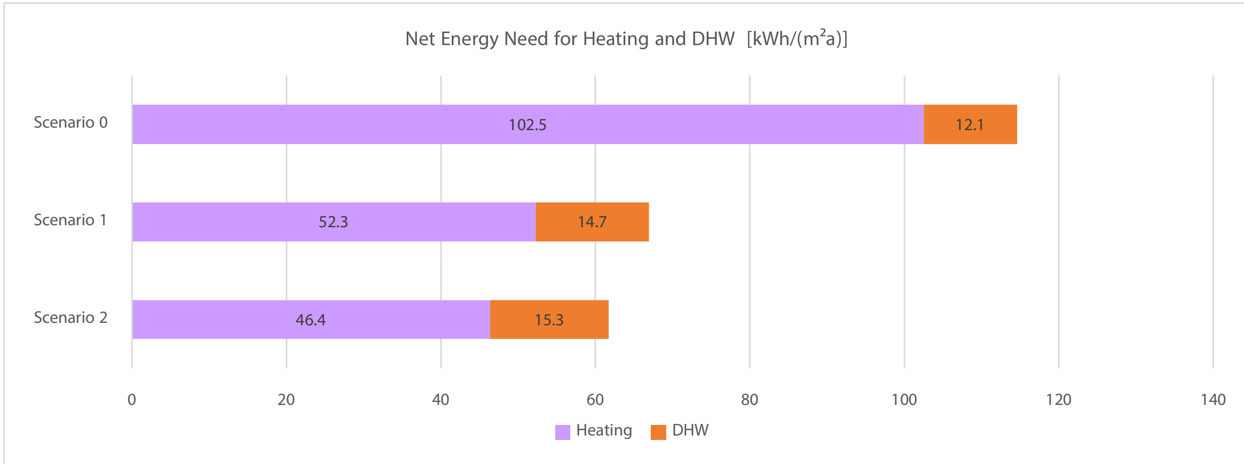



*Figure 133 Comparison of Net Energy Need for Heating and DHW*

On the other hand, there is a very important proposal which affects Scenario 2 energy need for our building. Except for support of insulation and improvement of building elements, the thermal solar system is proposed for Scenario 2. Thermal energy obtained from the sun with a solar thermal system can be used for domestic water heating, and heating or even cooling of buildings. The system gives very important advantages to the building. The system means an actually endless amount of energy for the buildings. In this case, it brings a great effect on energy saving in the buildings. Another important point is that thermal solar panel has no CO2 emissions during operation. Because the use of fossil fuels reduces. We can see this effect also the figure related to energy carriers above. Finally, the energy need was reduced by approximately 45% for space heating and DHW. But the critical reduction happened on space heating. The energy need for space heating was decreased from 102.53 kWh/($m^2$a) to 46.43 kWh/($m^2$a) annually.

Implementing different retrofitting strategies affects also the primary energy demand in the building. The primary energy demand in the building comes from renewable and non-renewable energy primary energy demands. The building has very less renewable energy demand for all scenarios. This fewer amount came from electrical pump usage as an auxiliary system in the building. Only for Scenario 2, the renewable primary energy demand is slightly higher than in Scenario 0 and Scenario 1. Because of the DHW system of Scenario 2, the thermal solar panel was proposed together with a circular pump for hot water. In the figure below, it is clearly understood that the proposed retrofitting strategies helped to reduce the total primary energy demand in the building. Especially for space heating of the building, the total primary energy demand decreased approximately by 45% and  65% respectively for Scenario 1 and Scenario 2.

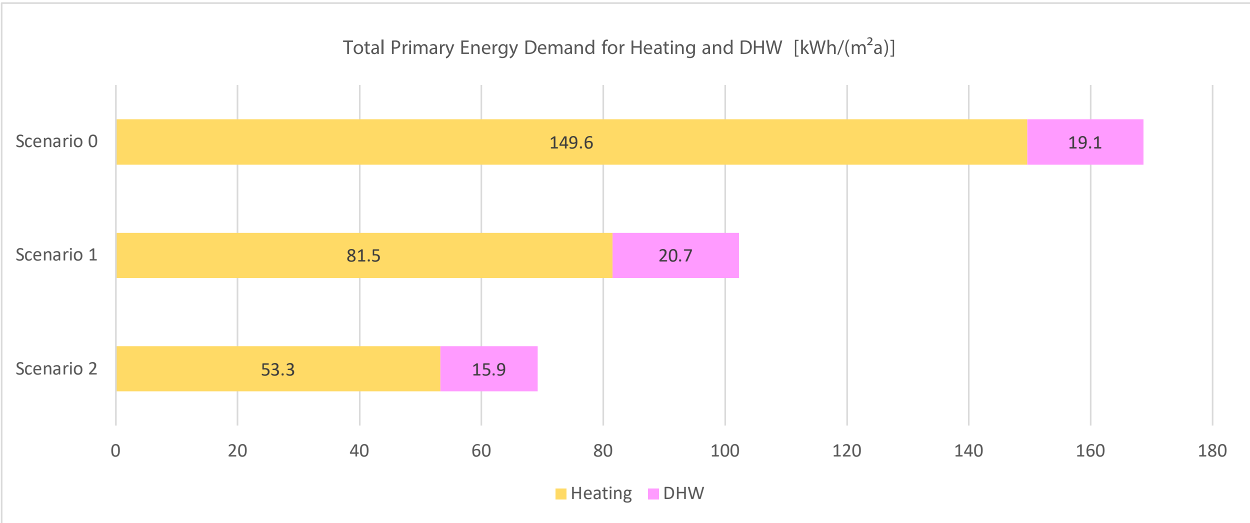



*Figure 134 Comparison of Total Primary Energy Demand for Heating and DHW*

Another important factor that affected the building energy performance was proposed as changing of window type of the building. The building windows were changed from wooden frame single glass to double-glazed and triple-glazed argon-filled, Low-E coating window types respectively for Scenario 1 and Scenario 2.

The glazing windows are more energy-efficient compared with single glass in the building. The reason for this, conduction occurs easily with single glazing, as there is only one layer of glass between the inside air and outside air, allowing energy to escape more readily. On the other hand, double glazing in scenario 1 is the installation of two sheets of glass, with spacer bars fixed around the edge to keep the panes apart. Between the two glass sheets is a layer of insulated air; this air space is filled with argon gas. For Scenario 2, triple glazing is the installation of three sheets of glass, with spacer bars positioned around the edge. Again, between each sheet is a layer of insulative air. But triple glazing has a lower U-value and therefore better energy efficiency. In addition to this, triple glazing can also improve summer comfort by reducing overheating. The solar heat gain (g-value) for a well-specified triple-glazed window is less than double-glazing. A triple-glazed unit can result in a bigger reduction in heat loss compared to double-glazing.

For both scenarios, argon gas and Low-E coating were proposed. The main reason for proposing argon gas was that it helps to minimize heat transmission loss and increase the room insulation. On the other hand, finally, the low-E coating was proposed on the building windows. Because Low-E coating lets sunlight through while preventing energy loss through radiation. Energy use is decreased in this way.

The rough and ready method of comparing the energy performance of windows is to use the U value measurement, just as we do with walls, floors, and roof. The higher the U-value, the more heat a window loses. In the scenarios, the U-values are;

- Single glazing: 4.9 W/($m^2$K)
- Double glazing: 2 W/($m^2$K)
- Triple glazing: 1.7 W/($m^2$K)

Another purpose of this study was to reduce CO2 emissions for heating and DHW in the building. According to the retrofitting proposals in the scenarios, adding insulation material, using a condensing boiler instead of a non-condensing boiler, changing the energy carrier from natural gas to district heating, using a thermal solar system instead of a gas center system, and changing the construction type of building elements were contributed to reducing CO2 emissions. According to the figure below, CO2 emissions in the building were strictly reduced for both Scenario 1 and Scenario 2. The annual CO2 emissions were decreased to 31.5 kg/($m^2$a) and 18 kg/($m^2$a) respectively in the building.

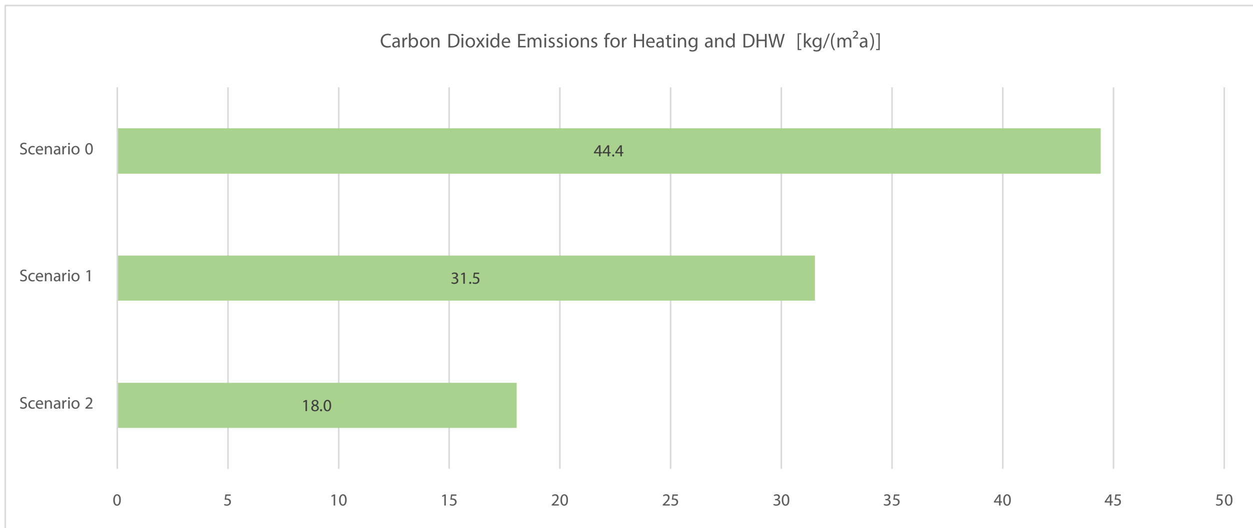



*Figure 135 Comparison of Carbon Dioxide Emissions for Heating and DHW*

Thermal insulation applications, using different energy carriers in the energy supply system, and adding a thermal solar system that provides energy efficiency can be considered as an additional cost for the initial investments of the projects. However, significant economic gains are obtained when the rate of return is calculated.

In addition, by providing energy savings in the old buildings that are actively used, positive contributions can be made to the household and national economy.

When we examined the annual energy cost in the building according to Scenarios 0,1 and 2, we can see critical cost savings thanks to the new retrofitting implementation on the building envelope. Annual energy cost was estimated at 12.95 Euro/($m^2$a) in the TABULA calculator for Scenario 0. This cost was reduced by approximately 40% and 60% respectively for Scenario 1 and Scenario 2 in the building as shown in the figure below.

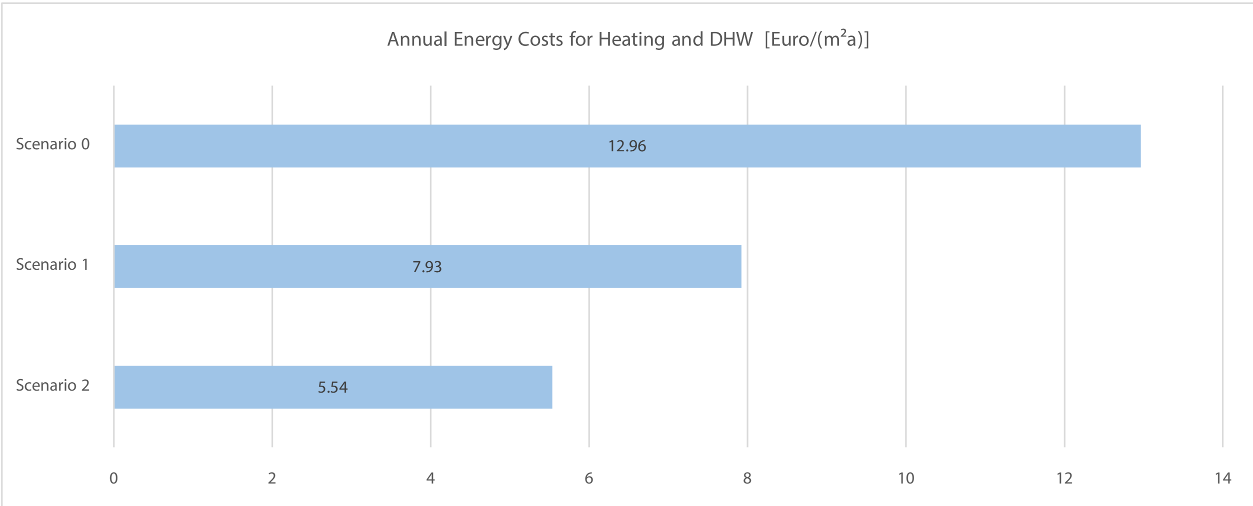



*Figure 136 Comparison of Annual Energy Costs for Heating and DHW*

To show the retrofitting effects, heat loss and heat gain play a critical role in building energy performance. The entire amount of heat that has been transferred from within to outside of the building is represented by heat loss. Heat gain, often known as solar gain, is the opposite of heat loss. Heat gain happens when warmth enters the room from radiant heat from the sun shining through the glass. Additionally, it indicates a low U value rating. After our design proposal, lower heat gains were obtained. The annual heat loss estimations related to all scenarios are shown in the figure below. We can understand that very huge energy achievements were obtained on the building elements.



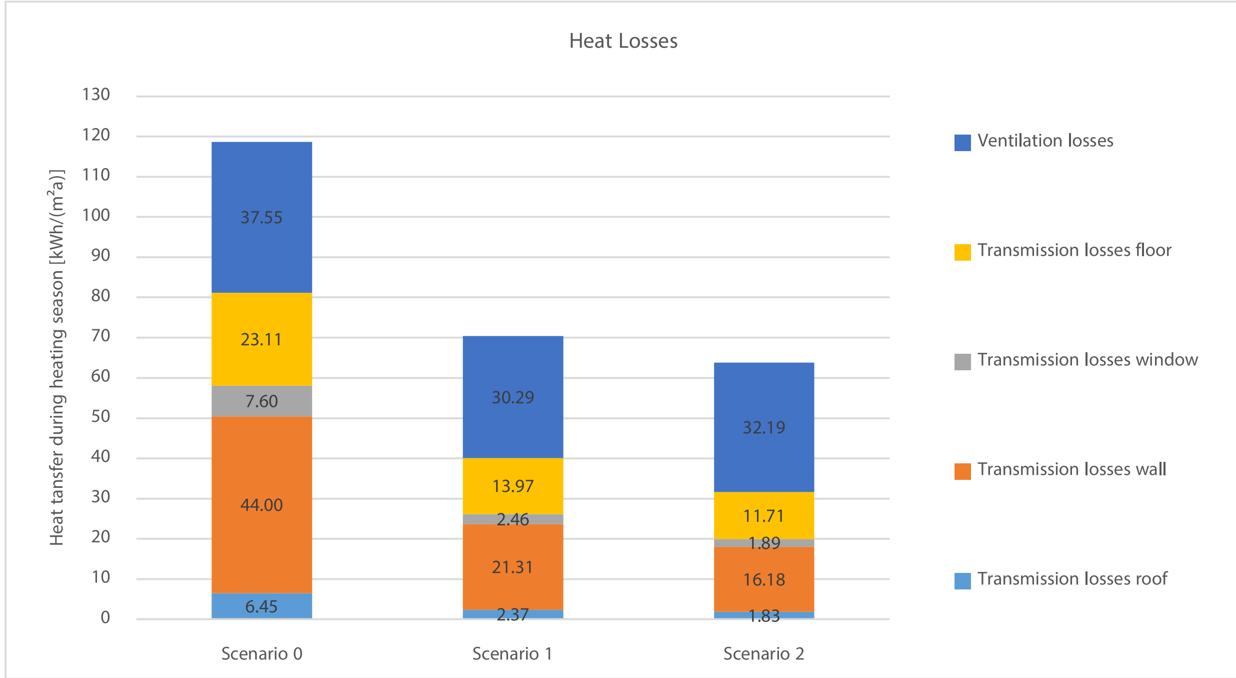



*Figure 137 Comparison of Heat Losses*

In conclusion, different types of retrofitting strategies were implemented in our building in the TABULA calculator. The results are telling us that the old buildings are required to have many improvements to save more energy. Because saving energy means also saving costs and saving our nature. The summary of the TABULA estimations is shown in the table below.

| | Unit | | Existing state Scenario 0 | Usual Retrofitting Scenario 1 | Advanced Retrofitting Scenario 2 |
|---|---|---|---|---|---|
| **Energy Need for Heating and DHW** | kWh/($m^2$a) | energy demand for heating | 102.53 | 52.27 | 46.43 |
| | | energy demand for DHW | 12.10 | 14.67 | 15.30 |
| **Energy Carriers** | kWh/($m^2$a) | fossil fuels | 173.90 | 39.44 | 62.61 |
| | | biomass | 0.00 | 0.00 | 0.00 |
| | | electricity | 2.11 | 1.57 | 7.78 |
| | | district heating | 0.00 | 59.72 | 0.00 |
| **Non-Renewable Primary Energy for Heating and DHW** | kWh/($m^2$a) | non-renewable primary energy demand | 168.34 | 101.94 | 68.20 |
| **Total Primary Energy(non-renewable+renewable)** | kWh/($m^2$a) | total primary energy demand for heating | 149.60 | 81.55 | 53.30 |
| | kWh/($m^2$a) | total primary energy demand for DHW | 19.10 | 20.71 | 15.95 |
| **Carbon Dioxide Emissions** | kg/($m^2$a) | carbon dioxide emissions | 44.43 | 31.51 | 18.05 |
| **Energy Costs** | Euro/($m^2$a) | energy costs | 12.96 | 7.93 | 5.54 |

*Table 23 Energy Estimation Results for All Scenarios*

### 7.5.2. Results for Neighborhood Scale

| Building Type | Number of Building | Number of Floor | Number of Apartment | Surface Area (m$^2$) |
|---|---|---|---|---|
| A | 4 | 10 | 40 | 500 |
| B | 6 | 10 | 40 | 460 |
| C | 3 | 7 | 42 | 662 |
| D | 3 | 7 | 42 | 645 |

*Table 24 Building Informations in the Neighborhood*

When estimating the energy needs of the buildings determined by ATC Torino at the neighborhood scale, the building types and the number of apartments, as well as the number of floors and square meters of each building using QGIS software are shown in the table above.

| | Unit | | Existing state Scenario 0 | Usual Retrofitting Scenario 1 | Advanced Retrofitting Scenario 2 |
|---|---|---|---|---|---|
| **Energy Need for Heating and DHW** | kWh/(m$^2$a) | energy demand for heating | 1672.77 | 852.82 | 757.50 |
| | | energy demand for DHW | 197.41 | 239.38 | 249.61 |
| **Energy Carriers** | kWh/(m$^2$a) | fossil fuels | 2837.11 | 643.53 | 1021.41 |
| | | biomass | 0.00 | 0.00 | 0.00 |
| | | electricity | 34.42 | 25.53 | 126.98 |
| | | district heating | 0.00 | 974.28 | 0.00 |
| **Non-Renewable Primary Energy for Heating and DHW** | kWh/(m$^2$a) | non-renewable primary energy demand | 2746.35 | 1663.14 | 1112.72 |
| **Total Primary Energy(non-renewable+renewable)** | kWh/(m$^2$a) | total primary energy demand for heating | 2440.66 | 1330.40 | 869.64 |
| | | total primary energy demand for DHW | 311.61 | 337.85 | 260.14 |
| **Carbon Dioxide Emissions** | kg/(m$^2$a) | carbon dioxide emissions | 724.86 | 514.08 | 294.42 |
| **Energy Costs** | Euro/(m$^2$a) | energy costs | 211.47 | 129.30 | 90.30 |

*Table 25 Energy Estimation Results for All Scenarios in Neighborhood Scale*

The total energy needs of all buildings in the project area have been determined by making the direct proportion of the estimates made for Type B Building. Additionally, all features of the buildings in the neighborhood were assumed same as the reference building. The values found as a result of these estimations are shown in the table above.

When the results are analyzed at the neighborhood scale, similar results are seen again. Looking at the figure showing the delivered energy demands of the energy carriers above, a reduction of 43% and 61%, respectively, was achieved with the retrofitting studies. On the other hand, with these results, the annual energy needs of the buildings in the neighborhood have been significantly reduced as shown in the figure above, resulting in a much more energy-efficient environment. Considering the energy needs of the buildings, especially for heating in the neighborhood, the annual energy needs for heating is 2440.66 kWh/(m2a), while it is estimated as 1330.4 kWh/(m2a) for Scenario 1 and 869.64 kWh/(m2a) for Scenario 2.



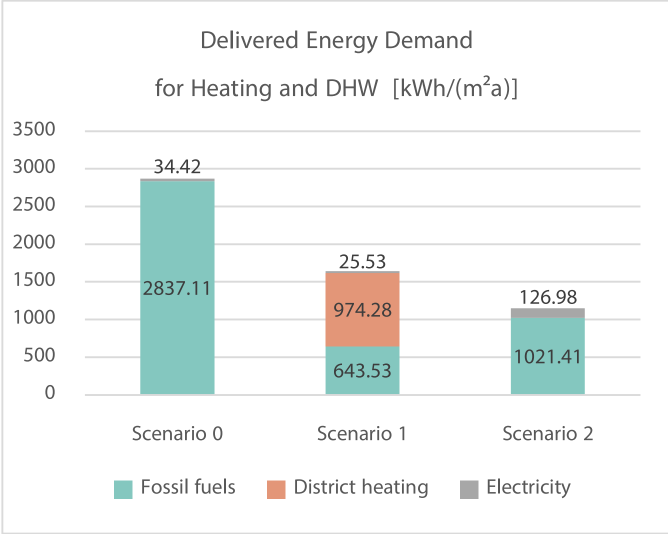



*Figure 138 Delivered Energy Demand of Energy Carriers for Heating and DHW in Neighborhood Scale*

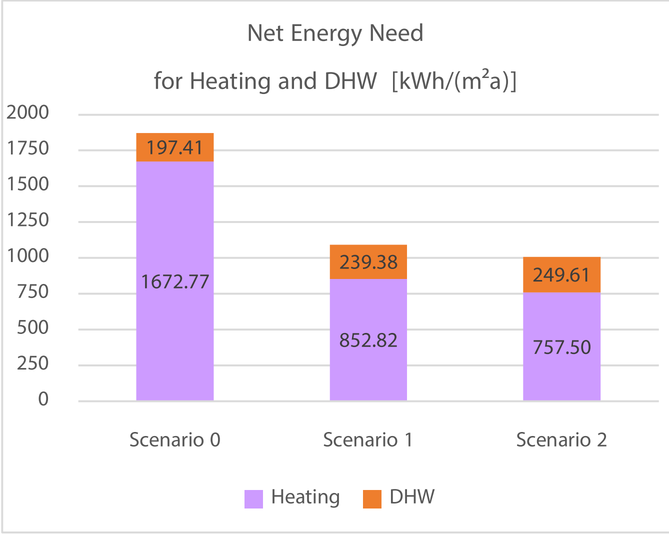



*Figure 139 Net Energy Need for Heating and DHW in Neighborhood Scale*

In addition, when the total primary energy demands (almost all non-renewable) are analyzed, as seen in the figure below, it decreased by 40% in scenario 1 compared to scenario 0 and by 59% in scenario 2 compared to scenario 0. Another important result is the reduction of CO2 emissions. With the change in energy carriers used and the large decrease in energy demands in the neighborhood, CO2 emissions were estimated to be 30% and 60% less for Scenario 1 and Scenario 2, respectively.

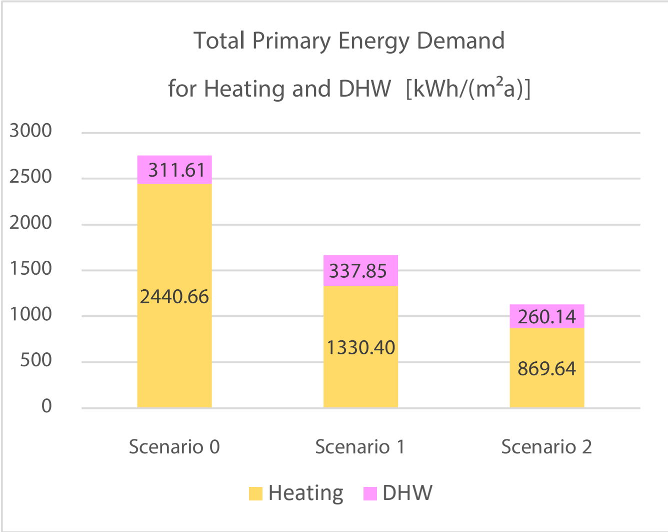



*Figure 140 Total Primary Energy Demand for Heating and DHW in Neighborhood Scale*

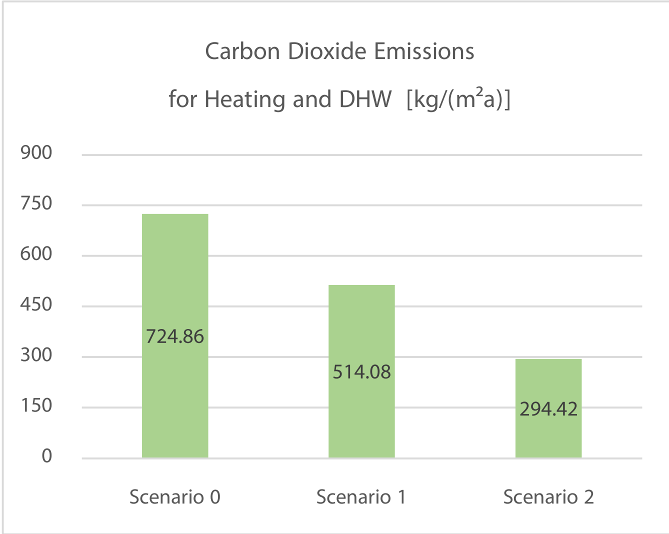



*Figure 141 Carbon Dioxide Emissions for Heating and DHW in Neighborhood Scale*

# 8. CONCLUSION

## 8. Conclusion

Unprecedented global and regional climate change, overpopulation, intense urbanization, overuse of resources and the resulting increased greenhouse gas emissions and increased energy consumption in the residential sector cause architectural concerns. In addition to all these concerns, we know that another problem in our world is the shortage of energy resources. Energy, regardless of its source, is a crucial component of development. It is necessary for transportation, business, and industrial operations, construction and infrastructure, the supply of water, and food production. Energy resources vary with many parameters in countries and cities. These factors affect how much energy each country needs. It is therefore important to have a good understanding of the architecture and the country's environment. In order to address this issue, nations have begun to embrace renewable energy sources. In particular, more laws have been set up in Europe to create more habitable and sustainable communities. To understand the energy requirements from an architectural perspective, a thorough investigation of the rural area is crucial. The demography of cities, the climate, and other factors can be used to understand energy demand and consumption. In the thesis, answers to these problems and the questions that arise as a result of these problems are sought. Thus, based on a real case study determined by the regional agency of ATC in the city of Turin in the Piedmont region of Italy, solutions are presented to increase the energy efficiency of an existing residence by retrofitting proposals. In order to present these design proposals, first of all, the demographic, climate and geographical location of the city of Turin were understood and the energy infrastructure of the city was examined. Turin is the metropolitan center of the Piedmont region (northwest Italy). Since the 1950s, Torino has served as a hub for important manufacturing businesses, which has had an impact on the city's urban planning. And Turin's geographic location is surrounded on all sides by the Alps, with a steep hill on the eastern front that naturally continues the Monferrato hills. In addition, climatic condition is Turin features a mid-latitude, four seasons humid subtropical climate. Summers are mild in the hills and rather hot on the plains, with winters being relatively chilly and dry. Most rain falls in the spring and fall; otherwise, rainfall are less frequent but stronger during the hottest months (thunderstorms are frequent). The city's location near the Alps helps with weaker winds and keeping the temperature in a narrower range between day and night. In the end, energy consumption is kept lower. On the other hand, while examining the city's energy sources, it was determined that the most popular energy sources were natural gas, followed by fossil fuels and electricity. Research has shown that the majority of the city's energy, especially in individual homes and businesses, still comes from non-renewable sources. However, it is known that when the city's energy needs increase, air pollution and thermal comfort of people will also be affected. In other words, the necessity of renewable energy sources becomes clearer. However, the technology for renewable energy supply is still insufficient.

The balance of energy demand and supply are examined at different scales: building scale, block of buildings, neighborhood scale, or urban scale. In this study, the building energy modeling was examined both on the building scale and neighborhood scale. There are different energy efficiency strategies for both scales. The application of these strategies are always determined by the local environment. In the neighborhood scale, people want to live in a sustainable area that provides benefits in terms of socially, economically, healthy, and safety. For proper design, the neighborhood should provide the required energy demand, have adequate space for streets and an efficient street network, give priority to walking, cycling, and transit, promote efficient use of energy sources, and should be socially cohesive and diverse. Minimizing the energy demand is one of the purposes of energy efficiency strategies. For this purpose, while designing at the neighborhood scale, the climatic conditions of the region where the neighborhood is located play a critical role to obtain better thermal comfort for people. The buildings' design, dimensions, shapes, locations, and materials must be chosen by considering the climatic conditions of the regions. In this way, the building will be heated, cooled by natural ventilation, and illuminated by a passive solar system. Another energy efficiency strategy is designing the neighborhood which allows air movements to obtain required natural ventilation in the streets. In conclusion, in a neighborhood where air movements are sufficient and correct, the energy efficiency and thermal comfort of people will increase. On the other hand, other energy efficiency strategies on the neighborhood scale are creating vegetation effect by green areas, organizing good transportation lines, using energy conversion technologies, and using renewable energy sources. For example, creating green areas in the streets, parks, and on buildings (green walls and green roofs) will help increase thermal properties, obtain a more comfortable environment, minimize the impact of the urban heat island, and obtain heat and noise insulation. Additively, the designing easy accessible and well-organized transportation will help reduce energy demand and reduce Greenhouse Gas Emissions in the neigborhood. In case of using energy conversion technologies and renewable energy sources at the neighborhood, the energy needs will reduce significantly and these strategies also will help to reduce energy consumption. Additionally, this will help reduce $CO_2$ emissions and obtain more clear environment. As an example of using renewable energy sources, solar energy is used for thermal solar panels and photovoltaic panel systems. As in the project part of the thesis, thermal solar systems are used for heating and domestic hot water system, significantly reducing the building and neighborhood energy needs. Also, energy efficiency can be increased at the neighborhood scale by using photovoltaic panels in electrical power generation. On the other side, there are energy efficiency strategies at the building scale to reduce energy demand. All design features must be adjusted to create an energy-efficient building. In this case, the building should be designed according to energy-saving standards to reduce economic costs over the life of the building. During the life cycle of the building, less $CO_2$ should be released into the atmosphere. At the building scale, great emphasis is placed on building shape and geometry in order to achieve an energy-efficient building. If we give an example to explain the reason for this situation, the shape of the building affects the solar system panel efficiency a lot. A mistake in building design can increase energy requirements by up to 25%. Design considerations examined at the building scale take into account not only the construction features but also the location of the building. Since topography, solar path, humidity, and wind direction affect building design building size, climate type and region should be considered when deciding where to locate. On the other hand, passive cooling and passive heating techniques are considered very important energy-efficient strategies. Passive cooling techniques are examined in five different categories: natural ventilation, radiant cooling, evaporative cooling, ground-air cooling, and open spaces. For example, a building designed based on the ideology of natural ventilation helps to increase people's thermal comfort and reduce energy demand. On the other hand, the strategies of the passive heating of the building provide energy savings as a result of the gains obtained thanks to the building elements (wall, roof, window). The most common passive heating strategies in the buildings are using Trombe walls, solar chimney applications on the roof, and using argon-filled glazing windows with low-E coating. If we give an example from windows, switching from single glazing to a double glazing unit improves thermal performance, while improving the frame material not only improves its thermal performance but also reduces infiltration. And it will increase thermal comfort for building occupants. Considering additional treatments such as Low-E glass, thermal conductivity improvement can exceed 50%.

In addition, understanding new technologies for energy saving in buildings plays an important role in improving the energy performance of the building. Technology advances that combine ambient intelligence with home automation are being driven by worries about global warming, and climate change to make buildings safer and more comfortable to live in. Every technology in a structure has an energy requirement as a result. Not only should architects, engineers, and designers create comfortable, safe, and better-optimized buildings, but they also need to work with energy-saving technologies to produce those structures. In order to save energy in buildings, the latest technologies must be applied according to a specific building type. Building envelope technologies are the most important and fundamental strategy among other saving technologies. In order to increase the sustainability of the building and to better understand the relationship between building envelope technologies, are explained the important technologies in the field of energy-saving in the thesis. It is known that the functions of the building envelope are to provide thermal comfort, solar control, indoor air quality, and humidity control, access to daylight, fire resistance, external appearance, acoustic control, and aesthetic value. Meeting these needs is significantly influenced by factors such as building type, climate, geographic location, building materials and construction method, and energy performance over the lifetime of a building. As discussed in the design proposal part of the thesis, retrofitting strategies are applied in existing buildings to increase the energy performance level. The main design solution proposed for retrofitting external walls and roofs is adding a thermal insulation layer on the inner or outer surface of the structure. Compared to the external insulation option, in most cases, the internal insulation would be a better selection as it requires less effort and cost for implementation. For interior partitions and floors, retrofit is only required when separating two different units that are heated/cooled by different energy sources. Also, retrofitting windows is considered the biggest contributor to heat loss and heat gain in buildings as explained before. Depending on the building envelope retrofit method, several materials can be employed in various building envelope components. When choosing thermal insulation materials, it is important to consider their thermal properties, cost, ease of installation, building code requirements, durability, acoustic performance, air tightness, and environmental impact. On the other hand, Light Pipe, Reflecting Roof, Cogeneration, and HVAC Systems technologies in addition to building envelope technologies increase energy-saving and reduce energy demand in buildings and improve the health conditions of building occupants and increase thermal comfort. These efforts not only reduce potential energy demand but also improve the quality of life inside buildings where users spend most of their time. It also provides an opportunity to extend the life of the building, and conserve the energy embedded in the buildings.

In the light of literature research conducted throughout the thesis, architectural retrofit scenarios were proposed using TABULA webtool and QGIS software to show the effects of correct retrofitting strategies by selecting a reference building from residential buildings in Corso Taranto, Turin, Italy, determined by ATC Torino Territorial Agency. It has been seen that the data obtained from the QGIS software throughout the study is sufficient to make the necessary energy estimations and to use it in the TABULA web tool. In addition, there are many parameters in the TABULA web tool to make the most accurate energy calculations for the building. In this way, the energy performance of the building has been estimated as close to reality. However, diversifying the materials of the structural members of the selected buildings and adapting the building retrofitting systems to newer technologies will result in much better energy estimates.

After all the energy estimates were made, important results were obtained in the building determined in the project. First of all, the decreasing U values as a result of insulation highlighted the building elements. It has been observed that as the U value decreases, the heat losses in the building decrease and it helps to reduce the amount of energy required for the building. In addition to the insulations, changing the building windows to glazing (double and triple) also reduced the U-values in the windows. In addition to these, significant changes have been made in the energy system used in the building, and the building's energy demands and CO2 emissions have been significantly reduced. In the energy supply system between Scenario 0 and Scenario 1, a district heating system is used for building heating. By using this system, the use of natural gas in the building has been reduced. Thanks to the District system, energy was used more efficiently, and the building's energy needs and primary energy demand were significantly reduced. In the hot water system in the building, the non-condensing boiler system was switched to the condensing boiler system. With this change, energy efficiency in the hot water system has been increased. In addition to the positive effects of these systems, there are also some negative effects that are not reflected in the results. Although the systems that reduce the cost are the systems at the beginning of these effects, they are the systems that need a certain investment in the first place. In addition, the condensing boilers used for the hot water system are known as systems that require more maintenance than the non-condensing ones. More effective changes were made in the energy system between Scenario 0 and Scenario 2. A solar panel has been added to the building's heating and hot water system, and it is aimed to meet most of the energy need through this system. Considering the climate and environmental conditions of the building, it has been suggested that the entire energy need of the building cannot be met with the solar thermal system, and the remaining energy need will be met with a gas-centered system. When the results are compared, it is observed that the effect of the thermal solar system greatly reduces the building energy requirement and primary energy demand. On the other hand, it has been understood by the results that the proposed second design proposal is much more efficient than the first one. Another important effect of the proposed design scenarios was the reduction of greenhouse gases. With the building retrofit, annual CO2 emissions were reduced by 30% for Scenario 1 and 60% for Scenario 2. With the decrease in the annual energy need of the building, the costs spent for energy have decreased proportionally. The only downside to costs is that the proposed design work requires an investment to be implemented in the building. In addition to the results found, the effects of the retrofitting studies at the neighborhood scale are similar to the reference building. The annual energy needs of the buildings in the neighborhood have been reduced together with the design proposals, and energy efficiency and energy savings have been increased.

According to the results of the thesis, it has been proven how important the place of energy in our lives is. All efforts to improve the energy performance of buildings affect not only home comfort, but also our world. It is understood that every work done is a new step for a more livable environment and future.

# 9. ANNEX

## Annex 1 - Thermal Envelope Area Estimations for Scenario 0, 1, 2

### Thermal Envelope Area Estimation — Parameters

Thermal envelope area estimation according to TABULA method

building: IT.MidClim.AB.05.Gen.ReEx.001.001

reference area $A_{C,ref}$: 3924.1 m²

area estimation parameter set: -

**Input Data**

| | | | |
|---|---|---|---|
| reference area (conditioned floor area) | $A_{C,ref}$ | 3924.1 | m² |
| number of full storeys (not incl. cellar and attic) | $n_{storey}$ | 10 | |
| clear ceiling height (averaged over full storeys)** | $h_{ceiling}$ | 2.15 | |

for determination of

*) optional input quantity, if not available standard values are used

**) input only necessary if actual value is < 2.3m or > 2.7m, otherwise the standard value 2,5m is used

ceiling height correction factor: $h_{ceiling}$** (m) 2.15 / 2,5 m = $f_{corr\ ceiling\ height}$ 0.86

**Conditioned Reference Area per Storey**

number of effective storeys, conditioned by the heating system:

$f_{cellar\ cond}$ 0.0 + $n_{storey}$ 10.0 + 0.7 · $f_{attic\ cond}$ 0.0 = $n_{eff\ storey}$ 10.0

conditioned reference area per storey:

$A_{C,ref}$ (m²) 3924.1 / $n_{eff\ storey}$ 10.0 = $A_{C/storey}$ (m²) 392.4

**Parameters**

**Basic Parameters**

| envelope area section | depending on variable | category (TABULA Code) | specification | $f_{attic\ cond}$ | roof p (m²/m²) | roof q (m²) | upper ceiling p (m²/m²) | upper ceiling q (m²) |
|---|---|---|---|---|---|---|---|---|
| roof / upper ceiling | $A_{C/storey}$ | - | flat roof (no attic) | 0 | 1.2 | 5 | | |
| | | N | attic not conditioned | 0 | | | 1.2 | 5 |
| | | P | attic partly conditioned | 0.5 | 0.8 | 7 | 0.6 | 3 |
| | | C | attic completely conditioned | 1 | 1.6 | 15 | | |
| | | NI | attic not cond., insulated* | 0 | 1.6 | 15 | | |
| | | PI | attic partly cond., insulated* | 0.5 | 1.6 | 15 | | |
| | | **N** | **current value** | **0** | **0.0** | **0** | **1.2** | **5** |

| envelope area section | depending on variable | category (TABULA Code) | specification | p (m²/m²) | q (m²) |
|---|---|---|---|---|---|
| **window** | $A_{C,ref}$ | | | **0.18** | |
| **door** | $A_{C,ref}$ | | | **0.01** | **1.5** |
| **gross wall (walls + windows)** | $A_{C,ref}$ | B_Alone | 0 neighbours | | 50 |
| | | B_N1 | 1 neighbours | | 25 |
| | | B_N2 | 2 neighbours | | 5 |
| | | **B_Alone** | **current value** | **0.7** | **50** |
| **ground floor** | $A_{C/storey}$ | | | **1.2** | **5** |

*) attic not or partly conditioned, thermal envelope in the plain of the roof area

**Consideration of Complexity**

| envelope area section | category (TABULA Code) | specification | $f_{complex}$ |
|---|---|---|---|
| roof | Simple | simple roof shape | 0.9 |
| | Standard | usual roof shape (or: information not available) | 1.0 |
| | Complex | roof with several dormers or other complex shape | 1.3 |
| | **Standard** | | **1.0** |
| gross wall (walls + windows) | Simple | simple square-type footprint shape | 0.9 |
| | Standard | usual footprint shape (or: information not available) | 1.0 |
| | Complex | building footprint is very complex or significantly stretched | 1.2 |
| | **Standard** | | **1.0** |

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### Thermal Envelope Area Estimation — Calculation

Thermal envelope area estimation according to TABULA method

building: IT.MidClim.AB.05.Gen.ReEx.001.001

reference area $A_{C,ref}$: 3924.1 m²

area estimation parameter set: IT.MidClim.AB.05.Gen.ReEx.001.001

**Estimation of Thermal Envelope Areas**

**roof area**: $f_{roof\ complex}$ 1.0 · ( $A_{C/storey}$ 392 m² · $p_{roof}$ 0.00 m²/m² + $q_{roof}$ 0.0 m² ) = $A_{roof,estim}$ **0.0** m²

**upper ceiling area**: $A_{C/storey}$ 392 m² · $p_{upper\ ceiling}$ 1.20 m²/m² + $q_{upper\ ceiling}$ 5.0 m² = $A_{estim,ceiling}$ **475.9** m²

**gross wall area per storey**: $f_{corr\ ceiling\ height}$ 0.9 · $f_{footprint\ complex}$ 1.0 · ( $A_{C/storey}$ 392 m² · $p_{gross\ wall}$ 0.70 m²/m² + $q_{gross\ wall}$ 50.0 m² ) = $A_{estim,grosswall/storey}$ 279.2 m²

**door area**: $A_{C,ref}$ 3,924 m² · $p_{upper\ ceiling}$ 0.01 m²/m² + $q_{upper\ ceiling}$ 1.5 m² = $A_{estim,door}$ **40.7** m²

**window area**: $A_{C,ref}$ 3,924 m² · $p_{window}$ 0.18 m²/m² − $A_{estim,door}$ 40.7 m² = $A_{estim,window}$ **665.6** m²

**wall area bordering at soil**: 0.50 · $f_{cellar\ cond}$ 0.0 · $A_{estim,grosswall/storey}$ 279 m² = $A_{estim,wall,soil}$ **0.0** m²

**wall area** (bordering at external air): $n_{eff\ storey}$ 10.0 · $A_{estim,\ gross\ wall\ /\ storey}$ 279.2 m² − $A_{estim,\ wall,\ soil}$ 0.0 m² − $A_{estim,\ window}$ 665.6 m² − $A_{estim,\ door}$ 40.7 m² = $A_{estim,wall}$ **2,086.0** m²

**ground floor area**: $A_{C/storey}$ 392 m² · $p_{floor}$ 1.20 + $q_{floor}$ 5.0 = $A_{estim,floor}$ **476** m²

**conditioned gross building volume**: 3.50 m²/m² · $f_{corr\ ceiling\ height}$ 0.86 · $A_{C,ref}$ 3,924 m² = $V_c$ **11,812** m²

**Plausibility Check of Envelope Area Input Values**

| | | Roof 1 | Roof 2 | Wall 1 | Wall 2 | Wall 3 | Window 1 | Window 2 | Door 1 | Floor 1 | Floor 2 | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| input values | $A_{env,i}$ | 0 | 462 | 0 | 3802 | 0 | 373 | 0 | 0 | 462 | 0 | 5098 | m² |
| estimated values | $A_{estim,env,i}$ | 0 | 476 | 2086 | 0 | 0 | 666 | 0 | 41 | 476 | 0 | 3744 | m² |
| ratio imput to estimated values | | 97% | | 182% | | | 53% | | | 97% | | | |
| gross wall area | | | | 149% | | | | | | | | | |
| total envelope | | 136% | | | | | | | | | | | |

used for further calculation

| | Roof 1 | Roof 2 | Wall 1 | Wall 2 | Wall 3 | Window 1 | Window 2 | Door 1 | Floor 1 | Floor 2 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| input values | 0 | 462 | 0 | 3802 | 0 | 373 | 0 | 0 | 462 | 0 | m² |

determined by status indicator in the dataset

| | Horiz. | East | South | West | North | |
|---|---|---|---|---|---|---|
| distribution of window areas | 0 | 186 | 0 | 186 | 0 | m² |

## TABULA Energy Balance Calculation — Building Performance

Standard Reference Calculation - based on: EN ISO 13790 / seasonal method

| | | | |
|---|---|---|---|
| building | IT.MidClim.AB.05.Gen.ReEx.001.001 (1961 ... 1975) | reference area $A_{C,ref}$ | 3924.1 m² |
| climate | IT.MidClim (Climatic Middle Zone (Italian Climatic Zone E)) | (conditioned floor area) | |

| construction element | original U-value $U_{original,i}$ W/(m²K) | measure type | nominal insulation thickness $d_{insulation,i}$ mm | effective thermal conductivity $\lambda_{insulation,i}$ W/(m·K) | area fraction $f_{measure,i}$ | actual U-value $U_{actual,i}$ W/(m²K) | | area (basis: external dimensions) $A_{env,i}$ m² | | adjustment factor soil $b_{tr,i}$ | | $H_{tr,i}$ W/K | annual heat flow related to $A_{C,Ref}$ kWh/(m²a) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Roof 1 | | | | | | | x | | x | | = | | |
| Roof 2 | 1.65 | | | | 100% | 1.10 | x | 461.7 | x | 1.00 | = | 509.5 | 7.4 |
| Wall 2 | 1.26 | | | | 100% | 0.91 | x | 3801.6 | x | 1.00 | = | 3476.1 | 50.6 |
| Floor 1 | 1.30 | | | | | 1.30 | x | 461.7 | x | 1.00 | = | 600.2 | 8.7 |
| Window 1 | 4.90 | | | | 100% | 4.90 | x | 372.6 | x | 1.00 | = | 1825.7 | 26.6 |
| thermal bridging: surcharge on the U-values | | | | | | $\Delta U_{tb}$ 0.10 | x | $\Sigma A_{env,i}$ 5097.5 | x | 1.00 | = | $H_{tr,tb}$ 509.8 | 7.4 |
| | | | | | related to: | | | envelope area 1.36 | | reference area 1.76 | | | |
| **Heat transfer coefficient by transmission $H_{tr}$** | | | | | | | | | | | sum | **6921** | **100.8** |

**Heat transfer coefficient by ventilation $H_{ve}$**

volume-specific heat capacity air $c_{p,air}$ Wh/(m³K); air change rate by use $n_{air,use}$ 1/h; by infiltration $n_{air,infiltration}$ 1/h; $A_{C,ref}$ m²; room height (standard value) $h_{room}$ m; W/K

$0.34 \times (0.40 + 0.40) \times 3924.1 \times 3.00 = \mathbf{3202}$ — 46.6

accumulated differences between internal and external temperature

internal temp. $\vartheta_i$ °C; external temp. $\vartheta_e$ °C; heating days $d_{hs}$ d/a; Kd/a

$(20.0 - 5.2) \times 174 = 2575$

**Total heat transfer $Q_{ht}$**

$H_{tr}$ W/K; $H_{ve}$ W/K; temperature reduction factor $F_{red}$ ($h_c$= W/(m²K)); x 0,024 kKh/a; kWh/a

$(6921 + 3202) \times 0.92 \times 61.8 = \mathbf{578457}$ — 147.4

| | window orientation | external shading $F_{sh}$ | | reduction factors: (1 - frame area fraction $F_F$) | | non-perpendicular $F_W$ | | solar energy transmittance $g_{gl,n}$ | | window area $A_{window,i}$ m² | | solar global radiation $I_{sol,i}$ kWh/(m²a) | | kWh/a | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Horizontal | 0.80 | × | (1 - 0.30 | ) × | 0.90 | × | 0.85 | × | | × | 378 | = | | 0.0 |
| 2. | East | 0.60 | × | (1 - 0.30 | ) × | 0.90 | × | 0.85 | × | 186.3 | × | 290 | = | 17359 | 4.4 |
| 3. | South | 0.60 | × | (1 - 0.30 | ) × | 0.90 | × | 0.85 | × | | × | 496 | = | | 0.0 |
| 4. | West | 0.60 | × | (1 - 0.30 | ) × | 0.90 | × | 0.85 | × | 186.3 | × | 290 | = | 17359 | 4.4 |
| 5. | North | 0.60 | × | (1 - 0.30 | ) × | 0.90 | × | 0.85 | × | | × | 122 | = | | 0.0 |
| | **Solar heat load during heating season $Q_{sol}$** | | | | | | | | | | | | sum | **34718** | **8.8** |

**Internal heat sources $Q_{int}$**

kh/d; internal heat sources $\varphi_i$ W/m²; heating days $d_{hs}$ d/a; $A_{C,ref}$ m²; kWh/a

$0.024 \times 3.00 \times 174 \times 3924.1 = \mathbf{49161}$ — 12.5

| | | | |
|---|---|---|---|
| internal heat capacity per m² $A_{C,ref}$ | $c_m$ = 45 Wh/(m²K) | heat balance ratio for the heating mode | $\gamma_{h,gn} = \frac{Q_{sol}+Q_{int}}{Q_{ht}}$ = 0.145 |
| time constant of the building | $\tau = \frac{c_m \cdot A_{C,ref}}{H_{tr}+H_{ve}}$ = 17 h | | |
| parameter | $a_H = a_{H,0} + \frac{\tau}{\tau_{H,0}}$ = 1.38 | **gain utilisation factor for heating** | $\eta_{h,gn} = \frac{1-\gamma^{a_H}}{1-\gamma^{a_H+1}}$ = 0.94 |

**Energy need for heating $Q_{H,nd}$**

$Q_{ht} - \eta_{h,gn} \times (Q_{sol} + Q_{int}) = \mathbf{499607}$ kWh/a — 127.3

## TABULA Energy Balance Calculation — System Performance

Standard Reference Calculation - based on: EN ISO 15316 / level B (tabled values)

| | code | | |
|---|---|---|---|
| building | IT.MidClim.AB.05.Gen.ReEx.001.001 | conditioned floor area $A_{C,ref}$ | 3924.1 m² |
| system | IT.<Gas.B_NC.MUH.14>.<Gas.G_IWH_NC.MUH.02>.<-.Gen.01>.<-> | | |

### Domestic Hot Water System

system — code: IT.Gas.G_IWH_NC.MUH.02

| | code | | value | thereof recoverable for space heating | |
|---|---|---|---|---|---|
| energy need hot water | | $q_{nd,w}$ | 15.0 | | |
| + losses distrib. | IT.NoCirc_A.MUH.02 | $q_{d,w}$ | 1.3 | $q_{d,w,h}$ | 0.6 |
| + losses storage | | $q_{s,w}$ | 0.0 | $q_{s,w,h}$ | 0.0 |
| $q_{g,w,out} = q_{nd,w} + q_{d,w} + q_{s,w}$ | | | 16.3 kWh/(m²a) | $q_{w,h} = q_{d,w,h} + q_{s,w,h}$ | 0.6 kWh/(m²a) |

| | energyware for domestic hot water (code) | heat generator (code) | $\alpha_{nd,w,i}$ | | heat generator output $q_{g,w,out}$ | | expenditure factor $e_{g,w,i}$ | | delivered energy $q_{del,w,i}$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Gas | IT.G_IWH_NC.Gen.03 | 100% | x | 16.3 kWh/(m²a) | x | 1.39 (related to gross calorific value) | = | 22.6 kWh/(m²a) |
| aux | auxiliary energy: El | IT.D.Gen.01 | | | | | | | $q_{del,w,aux}$ 0.0 kWh/(m²a) |

### Heating System

system — code: IT.Gas.B_NC.MUH.14

| | code | | value | | |
|---|---|---|---|---|---|
| energy need space heating | | $q_{nd,h}$ | 127.3 kWh/(m²a) | | |
| − usable contribution of hot water system | | $\eta_{h,gn} \cdot q_{w,h}$ | 0.6 kWh/(m²a) | $\eta_{h,gn}$ 1.00 x $q_{w,h}$ | |
| − usable contrib. of vent. heat recovery | | $\eta_{h,gn} \cdot q_{ve,h,rec}$ | 0.0 kWh/(m²a) | x $q_{ve,h,rec}$ | |
| + losses distribution and heat emission | IT.C_Ext.MUH.04 | $q_{d,h}$ | 9.9 kWh/(m²a) | | |
| + losses storage | | $q_{s,h}$ | 0.0 kWh/(m²a) | | |
| $q_{g,h,out} = q_{nd,h} - q_{w,h} - q_{ve,h,rec} + q_{d,h} + q_{s,h}$ | | | 136.6 kWh/(m²a) | | |

gain utilisation factor (heating contributions from DHW and vent. system): $\eta_{h,gn} = \frac{1-\gamma^{a_H}}{1-\gamma^{a_H+1}}$ = 1.00

building parameter $a_H$ = 1.38

gain/loss ratio $\gamma_{h,gn} = \frac{q_{w,h}+q_{ve,h,rec}}{q_{nd,h}}$ = 0.00

ventilation heat recovery: $\eta_{ve,rec}$ 0% x $q_{ht,ve}$ 46.6 kWh/(m²a)

for information: net energy need for heating $q_{nd,h,net} = q_{nd,h} - \eta_{h,gn} \cdot q_{ve,h,rec}$ = 127.3 kWh/(m²a)

| | energyware for space heating (code) | heat generator (code) | $\alpha_{nd,h,i}$ | | heat generator output $q_{g,h,out}$ | | expenditure factor $e_{g,h,i}$ | | delivered energy $q_{del,h,i}$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Gas | IT.B_NC.Gen.02 | 100% | x | 136.6 kWh/(m²a) | x | 1.25 (related to gross calorific value) | = | 170.7 kWh/(m²a) |
| aux | auxiliary energy — heating system: El | IT.C.MUH.02 | | | | | | | $q_{del,h,aux}$ 2.6 kWh/(m²a) |

## Energy Balance Calculation — Energy Carriers

| | code | | $A_{C,ref}$ | |
|---|---|---|---|---|
| building | IT.MidClim.AB.05.Gen.ReEx.001.001 | conditioned floor area | 3924.1 | m² |
| system | IT.<Gas.B_NC.MUH.14>.<Gas.G_IWH_NC.MUH.02>.<-.Gen.01>.<-> | | | |

### Assessment of Energywares

version of energy carrier specification — code: EU.001

#### Assessment by Energy Carrier (Standard Calculation)

| | | delivered energy $q_{del,i}$ | total primary energy $f_{p,total,i}$ | $q_{p,total,i} = q_{del,i} \cdot f_{p,total,i}$ | non-renewable primary energy $f_{p,nonren,i}$ | $q_{p,nonren,i} = q_{del,i} \cdot f_{p,nonren,i}$ | carbon dioxide emissions $f_{CO2,i}$ | $m_{CO2,i} = q_{del,i} \cdot f_{CO2,i}$ | energy costs $p_i$ (energyware price) | $c_i = q_{del,i} \cdot p_i$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **Heating (+ Ventilation) System** | | | | | | | | | | |
| Gas | | 170.7 | 1.05 | 179.3 | 1.05 | 179.3 | 277 | 47.3 | 8.0 | 13.66 |
| auxiliary electricity | El | 2.6 | 2.50 | 6.6 | 2.30 | 6.0 | 617 | 1.6 | 24.0 | 0.63 |
| **Domestic Hot Water System** | | | | | | | | | | |
| Gas | | 22.6 | 1.05 | 23.7 | 1.05 | 23.7 | 277 | 6.3 | 8.0 | 1.81 |
| auxiliary electricity | El | 0.0 | 2.50 | 0.0 | 2.30 | 0.0 | 617 | 0.0 | 24.0 | 0.00 |
| | | kWh/(m²a) | | kWh/(m²a) | | kWh/(m²a) | g/kWh | kg/(m²a) | Cent/kWh | Euro/(m²a) |

#### Summary and Expenditure Factors

| | $q_{nd}$ heat need | $\Sigma q_{del}$ | $e_{p,total} = \frac{q_{p,total}}{q_{nd}}$ | $q_{p,total} = \Sigma q_{p,total}$ | $e_{p,nonren} = \frac{q_{p,nonren}}{q_{nd}}$ | $q_{p,nonren} = \Sigma q_{p,nonren,i}$ | $f_{CO2,heat} = \frac{m_{CO2}}{q_{nd}}$ | $m_{CO2,i} = \Sigma m_{CO2,i}$ | $p_{heat} = \frac{c}{q_{nd}}$ | $c = \Sigma c_i$ |
|---|---|---|---|---|---|---|---|---|---|---|
| heating (+ ventilation) system | 127.3 | 173.4 | 1.46 | 185.8 | 1.46 | 185.3 | 384 | 48.9 | 11.2 | 14.29 |
| domestic hot water system | 15.0 | 22.6 | 1.58 | 23.7 | 1.58 | 23.7 | 417 | 6.3 | 12.1 | 1.81 |
| **total** | 142.3 | 196.0 | 1.47 | **209.6** | 1.47 | **209.0** | 388 | **55.2** | 11.3 | **16.10** |
| | kWh/(m²a) | kWh/(m²a) | | kWh/(m²a) | | kWh/(m²a) | g/kWh | kg/(m²a) | Cent/kWh | Euro/(m²a) |

### Typical Values of the Measured Consumption - Empirical Calibration

| | |
|---|---|
| code | EU.M.01 |
| application field | average adaptation |
| determination method | average values from countries where information is available |
| accuracy level | C = estimated (e.g. on the basis of few example buildings) |

| | empirical relation | | | | | | current value |
|---|---|---|---|---|---|---|---|
| | 0 | 100 | 200 | 300 | 400 | 500 | 193.3 |
| adaptation factor | 1.10 | 0.95 | 0.80 | 0.65 | 0.55 | 0.48 | 2 0.81 |

| Summary (including subcategories) | | | Standard Calculation heating | dhw | sum | Typical Measured Consumption heating | dhw | sum |
|---|---|---|---|---|---|---|---|---|
| Gas | related to | $q_{del,\Sigma gas}$ | 170.7 | 22.6 | **193.3** | 137.5 | 18.2 | **155.7** |
| Auxiliary Electricity | | $q_{del,\Sigma aux}$ | 2.6 | 0.0 | **2.6** | 2.1 | 0.0 | **2.1** |





## Energy Balance Calculation — Building Performance

Standard Reference Calculation - based on: EN ISO 13790 / seasonal method

| | | | | |
|---|---|---|---|---|
| building | IT.MidClim.AB.05.Gen.ReEx.001.002 (1961 ... 1975) | reference area $A_{C,ref}$ | 3924.1 | m² |
| climate | IT.MidClim (Climatic Middle Zone (Italian Climatic Zone E)) | (conditioned floor area) | | |

| construction element | original U-value $U_{original,i}$ W/(m²K) | measure type | nominal insulation thickness $d_{insulation,i}$ mm | effective thermal conductivity $\lambda_{insulation,i}$ W/(m·K) | area fraction $f_{measure,i}$ | actual U-value $U_{actual,i}$ W/(m²K) | | area (basis: external dimensions) $A_{env,i}$ m² | | adjustment factor soil $b_{tr,i}$ | | $H_{tr,i}$ W/K | annual heat flow related to $A_{C,Ref}$ kWh/(m²a) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Roof 2 | 1.65 | Add | 110 | 0.040 | 100% | 0.27 | x | 461.7 | x | 1.00 | = | 126.3 | 2.0 |
| Wall 2 | 1.26 | Add | 90 | 0.040 | 100% | 0.30 | x | 3801.6 | x | 1.00 | = | 1137.0 | 17.6 |
| Floor 1 | 1.30 | Add | 110 | 0.040 | 100% | 0.28 | x | 461.7 | x | 1.00 | = | 131.2 | 2.0 |
| Window 1 | 4.90 | Replace | | | 100% | 2.00 | x | 372.6 | x | 1.00 | = | 745.2 | 11.5 |
| thermal bridging: surcharge on the U-values | | | | | | $\Delta U_{tb}$ 0.10 | × | $\Sigma A_{env,i}$ 5097.5 | × | 1.00 | = | $H_{tr,tb}$ 509.8 | 7.9 |
| related to: | | | | | | | | envelope area 0.52 | | reference area 0.68 | | | |
| **Heat transfer coefficient by transmission $H_{tr}$** | | | | | | | | | | | sum | **2649** | **41.0** |

**Heat transfer coefficient by ventilation $H_{ve}$**

| volume-specific heat capacity air $c_{p,air}$ Wh/(m³K) | | air change rate by use $n_{air,use}$ 1/h | | by infiltration $n_{air,infiltration}$ 1/h | | $A_{C,ref}$ m² | | room height (standard value) $h_{room}$ m | | W/K | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.34 | x ( | 0.40 | + | 0.10 | ) × | 3924.1 | × | 3.00 | = | **2001** | **31.0** |

accumulated differences between internal and external temperature: ( internal temp. $\vartheta_i$ 20.0 °C − external temp. $\vartheta_e$ 5.2 °C ) × heating days $d_{hs}$ 174 d/a = 2575 Kd/a

temperature reduction factor $F_{red}$ ($h_{tr}$= W/(m²K)); x 0,024

**Total heat transfer $Q_{ht}$**: ( $H_{tr}$ 2649 W/K + $H_{ve}$ 2001 W/K ) × 0.98 × 61.8 kKh/a = **282399** kWh/a — **72.0**

| | window orientation | reduction factors: external shading $F_{sh}$ | | frame area fraction $F_F$ | | non-perpendicular $F_W$ | | solar energy transmittance $g_{gl,n}$ | | window area $A_{window,i}$ m² | | solar global radiation $I_{sol,i}$ kWh/(m²a) | | kWh/a | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Horizontal | 0.80 | × (1 - | 0.30 | ) × | 0.90 | × | 0.67 | × | | × | 378 | = | | 0.0 |
| 2. | East | 0.60 | × (1 - | 0.30 | ) × | 0.90 | × | 0.67 | × | 186.3 | × | 290 | = | 13683 | 3.5 |
| 3. | South | 0.60 | × (1 - | 0.30 | ) × | 0.90 | × | 0.67 | × | | × | 496 | = | | 0.0 |
| 4. | West | 0.60 | × (1 - | 0.30 | ) × | 0.90 | × | 0.67 | × | 186.3 | × | 290 | = | 13683 | 3.5 |
| 5. | North | 0.60 | × (1 - | 0.30 | ) × | 0.90 | × | 0.67 | × | | × | 122 | = | | 0.0 |

**Solar heat load during heating season $Q_{sol}$** — sum **27366** — **7.0**

**Internal heat sources $Q_{int}$**: 0.024 kh/d × internal heat sources $\varphi_i$ 3.00 W/m² × heating days $d_{hs}$ 174 d/a × $A_{C,ref}$ 3924.1 m² = **49161** kWh/a — **12.5**

| | | | | | |
|---|---|---|---|---|---|
| internal heat capacity per m² $A_{C,ref}$ | $c_m$ | 45 Wh/(m²K) | heat balance ratio for the heating mode | $\gamma_{h,gn} = \frac{Q_{sol}+Q_{int}}{Q_{ht}}$ = | 0.271 |
| time constant of the building | $\tau = \frac{c_m \cdot A_{C,ref}}{H_{tr} + H_{ve}}$ = | 38 h | | | |
| parameter | $a_H = a_{H,0} + \frac{\tau}{\tau_{H,0}}$ = | 2.07 | **gain utilisation factor for heating** | $\eta_{h,gn} = \frac{1-\gamma^{aH}}{1-\gamma^{aH+1}}$ = | 0.95 |

**Energy need for heating $Q_{H,nd}$**: $Q_{ht} - \eta_{h,gn} \times (Q_{sol} + Q_{int})$ = **209702** kWh/a — **53.4**

[tabula-calculator - thesis_20.06.22_scenario1]Calc.Demo.Building 6/21/2022 8:08 PM

## Energy Balance Calculation — System Performance

Standard Reference Calculation - based on: EN ISO 15316 / level B (tabled values)

| | code | | $A_{C,ref}$ | |
|---|---|---|---|---|
| building | IT.MidClim.AB.05.Gen.ReEx.001.002 | conditioned floor area | 3924.1 | m² |
| system | IT.<DH.TS.MUH.01>.<Gas.G_IWH_C.MUH.01>.<-.Gen.01>.<-> | | | |

### Domestic Hot Water System

| | code |
|---|---|
| system | IT.Gas.G_IWH_C.MUH.01 |

| | code | | value | | thereof recoverable for space heating: | |
|---|---|---|---|---|---|---|
| energy need hot water | | $q_{nd,w}$ | 15.0 | | | |
| + losses distrib. | IT.NoCirc_A.MUH.02 | $q_{d,w}$ | 1.3 | → | $q_{d,w,h}$ | 0.6 |
| + losses storage | | $q_{s,w}$ | 0.0 | → | $q_{s,w,h}$ | 0.0 |
| | | $q_{g,w,out} = q_{nd,w} + q_{d,w} + q_{s,w}$ | 16.3 | | $q_{w,h} = q_{d,w,h} + q_{s,w,h}$ | 0.6 |
| | | | kWh/(m²a) | | | kWh/(m²a) |

| | energyware for domestic hot water | heat generator | | heat generator output | | expenditure factor | | delivered energy |
|---|---|---|---|---|---|---|---|---|
| | code | code | $\alpha_{nd,w,i}$ | $q_{g,w,out}$ | | $e_{g,w,i}$ | | $q_{del,w,i}$ |
| 1 | Gas | IT.G_IWH_C.Gen.01 | 100% | 16.3 | x | 1.24 | = | 20.2 |
| | | | | | | *related to gross calorific* | | |
| | **auxiliary** | code | | | | | | $q_{del,w,aux}$ |
| aux | El | IT.D.Gen.01 | | | | | | 0.0 |
| | | | | | | | | kWh/(m²a) |

### Heating System

| | code |
|---|---|
| system | IT.DH.TS.MUH.01 |

| | code | | value | unit |
|---|---|---|---|---|
| energy need space heating | | $q_{nd,h}$ | 53.4 | kWh/(m²a) |
| − usable contribution of hot water system | | $\eta_{h,gn} \cdot q_{w,h}$ | 0.6 | kWh/(m²a) |
| − usable contrib. of vent. heat recovery | | $\eta_{h,gn} \cdot q_{ve,h,rec}$ | 0.0 | kWh/(m²a) |
| + losses distribution and heat emission | IT.C_Ext.MUH.05 | $q_{d,h}$ | 3.2 | kWh/(m²a) |
| + losses storage | | $q_{s,h}$ | 0.0 | kWh/(m²a) |
| | | $q_{g,h,out} = q_{nd,h} - q_{w,h} - q_{ve,h,rec} + q_{d,h} + q_{s,h}$ | 56.0 | kWh/(m²a) |

building parameter $a_H$ = 2.07

gain/loss ratio $\gamma_{h,gn} = \frac{q_{w,h}+q_{ve,h,rec}}{q_{nd,h}}$ = 0.01

gain utilisation factor (heating contributions from DHW and vent. system) $\eta_{h,gn} = \frac{1-\gamma^{aH}}{1-\gamma^{aH+1}}$ = 1.00

ventilation heat recovery: $q_{ve,h,rec}$ = $\eta_{ve,rec}$ 0% x $q_{ht,ve}$ 31.0 kWh/(m²a)

for information: net energy need for heating $q_{nd,h,net} = q_{nd,h} - \eta_{h,gn} \cdot q_{ve,h,rec}$ = 53.4 kWh/(m²a)

| | energyware for space heating | heat generator | | heat generator output | | expenditure factor | | delivered energy |
|---|---|---|---|---|---|---|---|---|
| | code | code | $\alpha_{nd,h,i}$ | $q_{g,h,out}$ | | $e_{g,h,i}$ | | $q_{del,h,i}$ |
| 1 | DH | IT.TS.MUH.01 | 100% | 56.0 | x | 1.09 | = | 61.1 |
| | | | | kWh/(m²a) | | *related to gross calorific value* | | kWh/(m²a) |
| | **auxiliary energy** | | | | | | | |
| | heating system | code | | | | | | $q_{del,h,aux}$ |
| aux | El | IT.C.MUH.04 | | | | | | 1.6 |
| | | | | | | | | kWh/(m²a) |



## Energy Balance Calculation — Energy Carriers

| | code | | $A_{C,ref}$ | |
|---|---|---|---|---|
| building | IT.MidClim.AB.05.Gen.ReEx.001.002 | conditioned floor area | 3924.1 | m² |
| system | IT.<DH.TS.MUH.01>.<Gas.G_IWH_C.MUH.01>.<-.Gen.01>.<-> | | | |

### Assessment of Energywares

version of energy carrier specification — code: EU.001

#### Assessment by Energy Carrier (Standard Calculation)

| | | delivered energy | total primary energy | | non-renewable primary energy | | carbon dioxide emissions | | energy costs | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $q_{del,i}$ | $f_{p,total,i}$ | $q_{p,total,i} = q_{del,i} \cdot f_{p,total,i}$ | $f_{p,nonren,i}$ | $q_{p,nonren} = q_{del,i} \cdot$ | $f_{CO2,i}$ | $m_{CO2,i} = q_{del,i} \cdot f_{CO2,i}$ | $p_i$ (energyware price) | $c_i = q_{del,i} \cdot p_i$ |
| **Heating (+ Ventilation) System** | | | | | | | | | | |
| DH | | 61.1 | 1.30 | 79.4 | 1.30 | 79.4 | 420 | 25.6 | 10.0 | 6.11 |
| auxiliary electricity | El | 1.6 | 2.50 | 4.0 | 2.30 | 3.7 | 617 | 1.0 | 24.0 | 0.38 |
| **Domestic Hot Water System** | | | | | | | | | | |
| Gas | | 20.2 | 1.05 | 21.2 | 1.05 | 21.2 | 277 | 5.6 | 8.0 | 1.61 |
| auxiliary electricity | El | 0.0 | 2.50 | 0.0 | 2.30 | 0.0 | 617 | 0.0 | 24.0 | 0.00 |
| | | kWh/(m²a) | | kWh/(m²a) | | kWh/(m²a) | g/kWh | kg/(m²a) | Cent/kWh | Euro/(m²a) |

#### Summary and Expenditure Factors

| | $q_{nd}$ heat need | $\Sigma q_{del}$ | $e_{p,total} = \frac{q_{p,total}}{q_{nd}}$ | $q_{p,total} = \Sigma q_{p,total}$ | $e_{p,nonren} = \frac{q_{p,nonren}}{q_{nd}}$ | $q_{p,nonren}$ = | $f_{CO2,heat} = \frac{m_{CO2}}{q_{nd}}$ | $m_{CO2,i} = \Sigma m_{CO2,i}$ | $p_{heat} = \frac{c}{q_{nd}}$ | $c = \Sigma c_i$ |
|---|---|---|---|---|---|---|---|---|---|---|
| heating (+ ventilation) system | 53.4 | 62.7 | 1.56 | 83.4 | 1.55 | 83.0 | 498 | 26.6 | 12.1 | 6.49 |
| domestic hot water system | 15.0 | 20.2 | 1.41 | 21.2 | 1.41 | 21.2 | 372 | 5.6 | 10.8 | 1.61 |
| **total** | 68.4 | 82.8 | 1.53 | **104.5** | 1.52 | **104.2** | 471 | **32.2** | 11.8 | **8.10** |
| | kWh/(m²a) | kWh/(m²a) | | kWh/(m²a) | | kWh/(m²a) | g/kWh | kg/(m²a) | Cent/kWh | Euro/(m²a) |

### Typical Values of the Measured Consumption - Empirical Calibration

| | |
|---|---|
| code | EU.M.01 |
| application field | average adaptation |
| determination method | average values from countries where information is available |
| accuracy level | C = estimated (e.g. on the basis of few example buildings) |

| | empirical relation | | | | | | | current value |
|---|---|---|---|---|---|---|---|---|
| | 0 | 100 | 200 | 300 | 400 | 500 | | 81.2 |
| adaptation factor | 1.10 | 0.95 | 0.80 | 0.65 | 0.55 | 0.48 | 1 | 0.98 |

| Summary (including subcategories) | | | Standard Calculation | | | Typical Measured Consumption | | |
|---|---|---|---|---|---|---|---|---|
| | | | heating | dhw | sum | heating | dhw | sum |
| Gas | *related to* | $q_{del,\Sigma gas}$ | 0.0 | 20.2 | **20.2** | 0.0 | 19.7 | **19.7** |
| Auxiliary Electricity | | $q_{del,\Sigma aux}$ | 1.6 | 0.0 | **1.6** | 1.6 | 0.0 | **1.6** |

## TABULA Energy Balance Calculation — Building Performance

Standard Reference Calculation - based on: EN ISO 13790 / seasonal method

| | | | | |
|---|---|---|---|---|
| building | IT.MidClim.AB.05.Gen.ReEx.001.003 (1961 ... 1975) | reference area (conditioned floor area) | $A_{C,ref}$ | 3924.1 m² |
| climate | IT.MidClim (Climatic Middle Zone (Italian Climatic Zone E)) | | | |

| construction element | original U-value $U_{original,i}$ W/(m²K) | measure type | nominal insulation thickness $d_{insulation,i}$ mm | effective thermal conductivity $\lambda_{insulation,i}$ W/(m·K) | area fraction $f_{measure,i}$ | actual U-value $U_{actual,i}$ W/(m²K) | | area (basis: external dimensions) $A_{env,i}$ m² | | adjustment factor soil $b_{tr,i}$ | | $H_{tr,i}$ W/K | annual heat flow related to $A_{C,Ref}$ kWh/(m²a) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Roof 2 | 1.65 | Add | 150 | 0.040 | 100% | 0.21 | x | 461.7 | x | 1.00 | = | 99.2 | 1.6 |
| Wall 2 | 1.26 | Add | 130 | 0.040 | 100% | 0.23 | x | 3801.6 | x | 1.00 | = | 875.2 | 13.8 |
| Floor 1 | 1.30 | Add | 150 | 0.040 | 100% | 0.22 | x | 461.7 | x | 1.00 | = | 102.2 | 1.6 |
| Window 1 | 4.90 | Replace | | | 100% | 1.70 | x | 372.6 | x | 1.00 | = | 633.4 | 10.0 |
| thermal bridging: surcharge on the U-values | | | | | | $\Delta U_{tb}$ 0.05 | x | $\Sigma A_{env,i}$ 5097.5 | x | 1.00 | = | $H_{tr,tb}$ 254.9 | 4.0 |
| related to: | | | | | | | | envelope area 0.39 | | reference area 0.50 | | | |
| **Heat transfer coefficient by transmission $H_{tr}$** | | | | | | | | | | | sum | **1965** | **30.9** |

**Heat transfer coefficient by ventilation $H_{ve}$**

| volume-specific heat capacity air $c_{p,air}$ Wh/(m³K) | | air change rate by use $n_{air,use}$ 1/h | | by infiltration $n_{air,infiltration}$ 1/h | | $A_{C,ref}$ m² | | room height (standard value) $h_{room}$ m | | W/K | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.34 | x ( | 0.40 | + | 0.10 | ) x | 3924.1 | x | 3.00 | = | **2001** | **31.5** |

accumulated differences between internal and external temperature

| internal temp. $\vartheta_i$ °C | | external temp. $\vartheta_e$ °C | | heating days $d_{hs}$ d/a | | Kd/a |
|---|---|---|---|---|---|---|
| ( 20.0 | − | 5.2 | ) x | 174 | = | 2575 |

**Total heat transfer $Q_{ht}$**

| $H_{tr}$ W/K | | $H_{ve}$ W/K | | temperature reduction factor $F_{red}$ ($h_{tr}$ = W/(m²K)) | | x 0,024 kKh/a | | kWh/a | |
|---|---|---|---|---|---|---|---|---|---|
| ( 1965 | + | 2001 | ) x | 1.00 | x | 61.8 | = | **245107** | **62.5** |

| | window orientation | reduction factors: external shading $F_{sh}$ | | frame area fraction $F_F$ | | non-perpendicular $F_W$ | | solar energy transmittance $g_{gl,n}$ | | window area $A_{window,i}$ m² | | solar global radiation $I_{sol,i}$ kWh/(m²a) | | kWh/a | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Horizontal | 0.80 | x (1 - | 0.30 | ) x | 0.90 | x | 0.50 | x | | x | 378 | = | | 0.0 |
| 2. | East | 0.60 | x (1 - | 0.30 | ) x | 0.90 | x | 0.50 | x | 186.3 | x | 290 | = | 10211 | 2.6 |
| 3. | South | 0.60 | x (1 - | 0.30 | ) x | 0.90 | x | 0.50 | x | | x | 496 | = | | 0.0 |
| 4. | West | 0.60 | x (1 - | 0.30 | ) x | 0.90 | x | 0.50 | x | 186.3 | x | 290 | = | 10211 | 2.6 |
| 5. | North | 0.60 | x (1 - | 0.30 | ) x | 0.90 | x | 0.50 | x | | x | 122 | = | | 0.0 |
| **Solar heat load during heating season $Q_{sol}$** | | | | | | | | | | | | | sum | **20422** | **5.2** |

**Internal heat sources $Q_{int}$**

| kh/d | | internal heat sources $\varphi_i$ W/m² | | heating days $d_{hs}$ d/a | | $A_{C,ref}$ m² | | kWh/a | |
|---|---|---|---|---|---|---|---|---|---|
| 0.024 | x | 3.00 | x | 174 | x | 3924.1 | = | **49161** | **12.5** |

| | | | | | |
|---|---|---|---|---|---|
| internal heat capacity per m² $A_{C,ref}$ | $c_m$ | 45 Wh/(m²K) | heat balance ratio for the heating mode | $\gamma_{h,gn} = \frac{Q_{sol}+Q_{int}}{Q_{ht}}$ = | 0.284 |
| time constant of the building | $\tau = \frac{c_m \cdot A_{C,ref}}{H_{tr}+H_{ve}}$ = | 45 h | | | |
| parameter | $a_H = a_{H,0} + \frac{\tau}{\tau_{H,0}}$ = | 2.28 | **gain utilisation factor for heating** | $\eta_{h,gn} = \frac{1-\gamma^{aH}}{1-\gamma^{aH+1}}$ = | 0.96 |

**Energy need for heating $Q_{H,nd}$** $Q_{ht} - \eta_{h,gn} \times (Q_{sol} + Q_{int})$ = **178378** kWh/a **45.5**



## TABULA Energy Balance Calculation — System Performance

Standard Reference Calculation - based on: EN ISO 15316 / level B (tabled values)

| | code | | $A_{C,ref}$ |
|---|---|---|---|
| building | IT.MidClim.AB.05.Gen.ReEx.001.003 | conditioned floor area | 3924.1 m² |
| system | IT.<Gas.B_C+Solar.MUH.01>.<Gas.B_C+Solar.MUH.01>.<-.Gen.01>.<-> | | |

### Domestic Hot Water System

system (code): IT.Gas.B_C+Solar.MUH.01

| | code | | kWh/(m²a) | thereof recoverable for space heating: | kWh/(m²a) |
|---|---|---|---|---|---|
| energy need hot water | | $q_{nd,w}$ | 15.0 | | |
| + losses distrib. | IT.C_Circ_Ext.MUH.03 | $q_{d,w}$ | 2.8 | $q_{d,w,h}$ | 0.6 |
| + losses storage | IT.S_C_Ext.MUH.03 | $q_{s,w}$ | 2.1 | $q_{s,w,h}$ | 0.0 |
| $q_{g,w,out} = q_{nd,w} + q_{d,w} + q_{s,w}$ | | | 19.9 | $q_{w,h} = q_{d,w,h} + q_{s,w,h}$ | 0.6 |

**energyware for domestic hot water**

| | energyware code | heat generator code | $\alpha_{nd,w,i}$ | | heat generator output $q_{g,w,out}$ kWh/(m²a) | | expenditure factor $e_{g,w,i}$ (related to gross calorific value) | | delivered energy $q_{del,w,i}$ kWh/(m²a) | combined heat and power: expenditure factor electricity generation $e_{g,el,w,i}$ | | electricity production $q_{prod,el,w,i}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Gas | IT.B_C.Gen.01 | 40% | x | 19.9 | x | 1.12 | = | 8.9 | : 0.00 | = | 0.0 |
| 2 | | IT.Solar.Gen.01 | 60% | x | | x | 0.00 | = | 0.0 | : 0.00 | = | 0.0 |

**auxiliary energy**

| | | code | $q_{del,w,aux}$ kWh/(m²a) |
|---|---|---|---|
| aux | El | IT.C_Circ_Sol.MUH.02 | 2.5 |

### Heating System

system (code): IT.Gas.B_C+Solar.MUH.01

building parameter $a_H$ = 2.28; gain/loss ratio $\gamma_{h,gn} = \frac{q_{w,h}+q_{ve,h,rec}}{q_{nd,h}}$ = 0.01

gain utilisation factor (heating contributions from DHW and vent. system) $\eta_{h,gn} = \frac{1-\gamma^{aH}}{1-\gamma^{aH+1}}$ = 1.00

| | code | | kWh/(m²a) |
|---|---|---|---|
| energy need space heating | | $q_{nd,h}$ | 45.5 |
| − usable contribution of hot water system | | $\eta_{h,gn} \cdot q_{w,h}$ | 0.6 |
| − usable contrib. of vent. heat recovery | | $\eta_{h,gn} \cdot q_{ve,h,rec}$ | 0.0 |
| + losses distribution and heat emission | IT.C_Ext.MUH.06 | $q_{d,h}$ | 2.0 |
| + losses storage | IT.BS.MUH.03 | $q_{s,h}$ | 0.8 |
| $q_{g,h,out} = q_{nd,h} - q_{w,h} - q_{ve,h,rec} + q_{d,h} + q_{s,h}$ | | | 47.7 |

ventilation heat recovery: $q_{ve,h,rec}$ = $\eta_{ve,rec}$ 0% x $q_{ht,ve}$ 31.5 kWh/(m²a)

for information: net energy need for heating $q_{nd,h,net} = q_{nd,h} - \eta_{h,gn} \cdot q_{ve,h,rec}$ = 45.5 kWh/(m²a)

**energyware for space heating**

| | energyware code | heat generator code | $\alpha_{nd,h,i}$ | | heat generator output $q_{g,h,out}$ kWh/(m²a) | | expenditure factor $e_{g,h,i}$ (related to gross calorific value) | | delivered energy $q_{del,h,i}$ kWh/(m²a) | combined heat and power: expenditure factor electricity generation $e_{g,el,h,i}$ | | electricity production $q_{prod,el,h,i}$ kWh/(m²a) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Gas | IT.B_C.Gen.01 | 80% | x | 47.7 | x | 1.14 | = | 43.5 | : 0.00 | = | 0.0 |
| 2 | | IT.Solar.Gen.01 | 20% | x | | x | 0.00 | = | 0.0 | : 0.00 | = | 0.0 |

**auxiliary energy**

| | heating system | code | $q_{del,h,aux}$ kWh/(m²a) |
|---|---|---|---|
| aux | El | IT.C.MUH.03 | 2.6 |

# Energy Balance Calculation — Energy Carriers

| | code | | $A_{C,ref}$ | |
|---|---|---|---|---|
| building | IT.MidClim.AB.05.Gen.ReEx.001.003 | conditioned floor area | 3924.1 | m² |
| system | IT.<Gas.B_C+Solar.MUH.01>.<Gas.B_C+Solar.MUH.01>.<-.Gen.01>.<-> | | | |

## Assessment of Energywares

version of energy carrier specification — code: EU.001

### Assessment by Energy Carrier (Standard Calculation)

| | delivered energy | total primary energy | | non-renewable primary energy | | carbon dioxide emissions | | energy costs | |
|---|---|---|---|---|---|---|---|---|---|
| | $q_{del,i}$ | $f_{p,total,i}$ | $q_{p,total,i} = q_{del,i} \cdot f_{p,total,i}$ | $f_{p,nonren,i}$ | $q_{p,nonren,i} = q_{del,i} \cdot f_{p,nonren,i}$ | $f_{CO2,i}$ | $m_{CO2,i} = q_{del,i} \cdot f_{CO2,i}$ | $p_i$ (energyware price) | $c_i = q_{del,i} \cdot p_i$ |
| **Heating (+ Ventilation) System** | | | | | | | | | |
| Gas | 43.5 | 1.05 | 45.6 | 1.05 | 45.6 | 277 | 12.0 | 8.0 | 3.48 |
| auxiliary electricity (El) | 2.6 | 2.50 | 6.6 | 2.30 | 6.0 | 617 | 1.6 | 24.0 | 0.63 |
| **Domestic Hot Water System** | | | | | | | | | |
| Gas | 8.9 | 1.05 | 9.4 | 1.05 | 9.4 | 277 | 2.5 | 8.0 | 0.71 |
| auxiliary electricity (El) | 2.5 | 2.50 | 6.3 | 2.30 | 5.8 | 617 | 1.5 | 24.0 | 0.60 |
| | kWh/(m²a) | | kWh/(m²a) | | kWh/(m²a) | g/kWh | kg/(m²a) | Cent/kWh | Euro/(m²a) |

### Summary and Expenditure Factors

| | $q_{nd}$ heat need | $\Sigma q_{del}$ | $e_{p,total} = \frac{q_{p,total}}{q_{nd}}$ | $q_{p,total} = \Sigma q_{p,total}$ | $e_{p,nonren} = \frac{q_{p,nonren}}{q_{nd}}$ | $q_{p,nonren} = \Sigma q_{p,nonren,i}$ | $f_{CO2,heat} = \frac{m_{CO2}}{q_{nd}}$ | $m_{CO2,i} = \Sigma m_{CO2,i}$ | $p_{heat} = \frac{c}{q_{nd}}$ | $c = \Sigma c_i$ |
|---|---|---|---|---|---|---|---|---|---|---|
| heating (+ ventilation) system | 45.5 | 46.1 | 1.15 | 52.2 | 1.14 | 51.7 | 300 | 13.7 | 9.0 | 4.11 |
| domestic hot water system | 15.0 | 11.4 | 1.04 | 15.6 | 1.01 | 15.1 | 267 | 4.0 | 8.8 | 1.31 |
| **total** | 60.5 | 57.5 | 1.12 | **67.8** | 1.10 | **66.8** | 292 | **17.7** | 9.0 | **5.42** |
| PV electricity bonus | | 0.0 | | 0.0 | | 0.0 | | 0.0 | | 0.00 |
| **total, considering PV bonus** | | 57.5 | | **67.8** | | **66.8** | | **17.7** | | **5.42** |
| | kWh/(m²a) | kWh/(m²a) | | kWh/(m²a) | | kWh/(m²a) | g/kWh | kg/(m²a) | Cent/kWh | Euro/(m²a) |

### Typical Values of the Measured Consumption - Empirical Calibration

| | |
|---|---|
| code | EU.M.01 |
| application field | average adaptation |
| determination method | average values from countries where information is available |
| accuracy level | C = estimated (e.g. on the basis of few example buildings) |

| | empirical relation | | | | | | | current value |
|---|---|---|---|---|---|---|---|---|
| | 0 | 100 | 200 | 300 | 400 | 500 | | 52.4 |
| adaptation factor | 1.10 | 0.95 | 0.80 | 0.65 | 0.55 | 0.48 | 1 | 1.02 |

| Summary (including subcategories) | related to | Standard Calculation heating | dhw | sum | Typical Measured Consumption heating | dhw | sum |
|---|---|---|---|---|---|---|---|
| Gas | $q_{del,\Sigma gas}$ | 43.5 | 8.9 | **52.4** | 44.4 | 9.1 | **53.5** |
| Auxiliary Electricity | $q_{del,\Sigma aux}$ | 2.6 | 2.5 | **5.1** | 2.7 | 2.6 | **5.2** |

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