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Towards a Healthy Living

A Net Zero Carbon Student Community Design in Milan Città Studi

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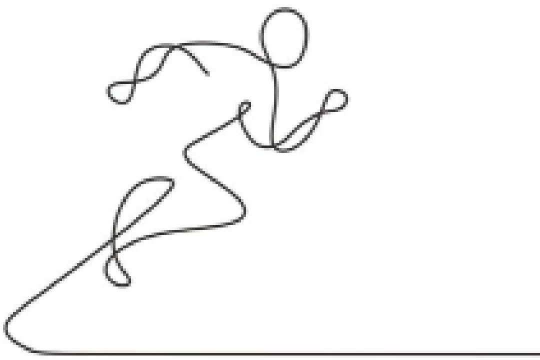


ABSTRACT

The residential space is main function in traditional students' community layout. Lacking of public space leads college students to unhealthy lifestyle. Sports is a competition, it's also a kind of social method. The values of sport are many: physical health, psychological wellbeing, education, respect, collaboration, tolerance, and equality. Today many young adults suffer from social anxiety in relation to performing physical activity in public spaces and private gyms, bringing them to give up sports by being scared of judgment and fearing failure.

The project site is in Citta Studi in Milan, we want to add a sports center in our project to help students find a balance between socializing and studying. So itt will include students housing, co-working space, sharing kitchen, sports center, commercial space, etc.

The building sector accounts for 38% of carbon emissions, the principal cause of climate change. To meet the targets set by the Paris Agreement, including zero net emissions by 2050, it is necessary that governments develop a culture of sustainability. The project hopes to explore the relationship between green space and Architecture, import sports space and renew the public space in students' community to help students recreate a healthy living.This project recognizes that energy efficiency and passive/low-energy design are the fundamental components of buildings that aim for high performance. We will obtain some existing ways to reduce building carbon emissions through case studies, summarize and apply in the practice of student community design, this includes the selection of building materials, simulation of energy consumption, application of sustainable energy, etc. Finally, determine whether it has reached energy balance through quantitative calculation of carbon emissions, propose a design method for student community that meets NZCB trend.

Keywords: Community, Sports, Net-Zero Carbon, Computer Aided Design

CONTENT

1. INTRODUCTION

1.1 Research Background

1.1.1 The necessity of reducing greenhouse gas emissions in world and Italy

During the current century, global warming and climate change have emerged as the most significant threats to humanity. Since the 1950s, numerous observed changes have occurred at an unprecedented rate, surpassing the variations witnessed over periods spanning decades to millennia. These changes encompass the warming of the atmosphere and oceans, the decline in snow and ice coverage, and the rising sea levels. Recently, IPCC sixth Assessment Report on global warming IPCC report (IPCC, 2022) points to a range of daunting climate challenge we face:

"Human-induced global warming of 1.1 °C has spurred changes to the Earth's climate that are unprecedented in recent human history"; "Climate impacts on people and ecosystems are more widespread and severe than expected, and future risks will escalate rapidly with every fraction of a degree of warming"...

Hence, the urgency of reducing greenhouse gas emissions is paramount, especially for the most industrialized nations. The extent to which both present and future generations will encounter a hotter and altered world hinges on the choices we make today and in the near future (figure 1).

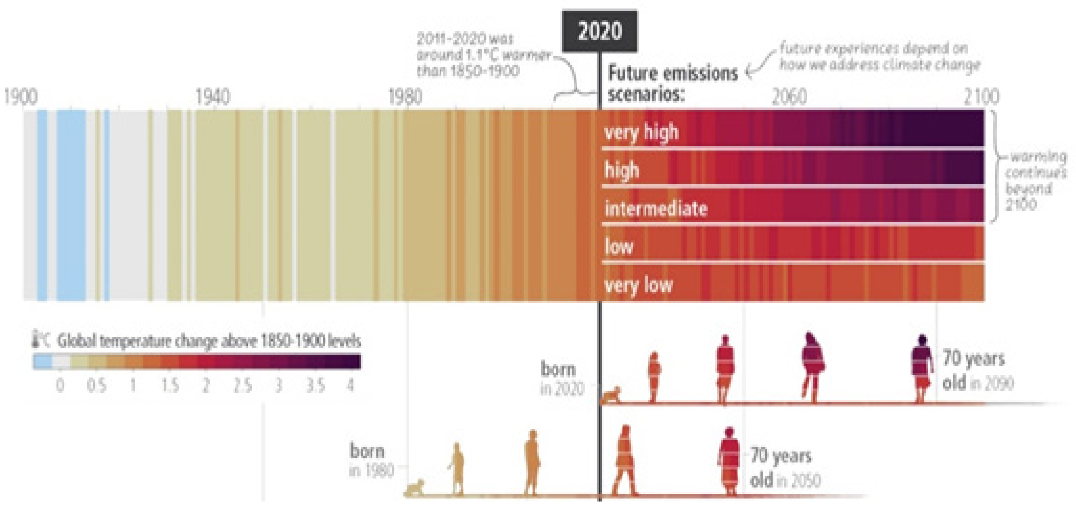


Figure 1: Observed (1900–2020) and projected (2021–2100) changes in global surface temperature (relative to 1850–1900)
Source: IPCC Report, 2022

Italy, as one of the long-established industrialized countries, has experienced a significant increase in its average annual temperature over the past century. The rate of warming has reached 1°C during this period, with the pace of temperature increase accelerating notably in the last 50 years. In fact, over the past two decades, Italy's temperature has been rising slightly more rapidly compared to the global average. The warming trend has been particularly pronounced during the summer and spring seasons, as well as at higher altitudes. It is expected that Italy's average annual temperature will continue to rise, leading to an increase in the number of summer days and tropical nights (figure 2).

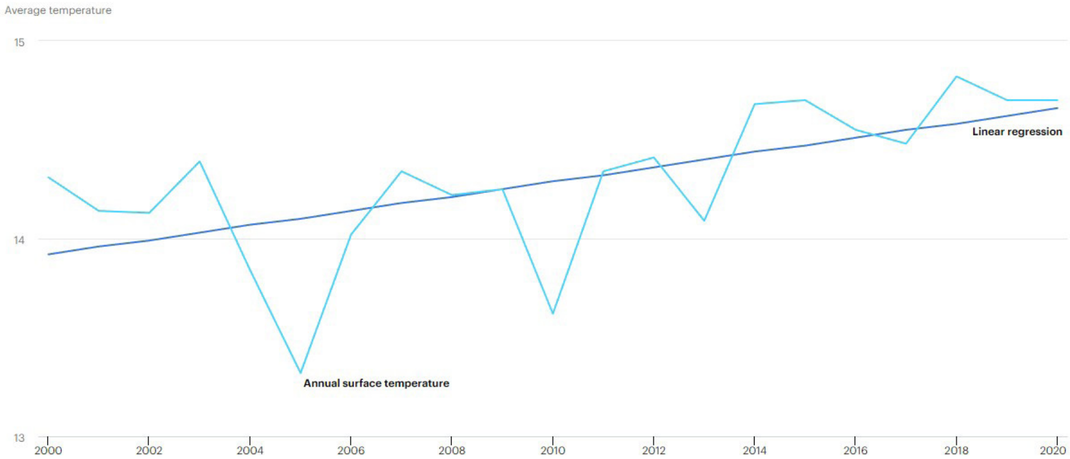


Figure 2: Temperature in Italy, 2000-2020
Source: IEA, 2022

In addition, there has been a slight decrease in average annual rainfall in Italy. From 1800 to 2011, the northern regions of Italy experienced a 19% reduction in summer precipitation and a 25% reduction in autumn precipitation. In the southern regions, the most significant declines were observed in spring (22%) and winter (12%). While there has been a decrease in the frequency of low and medium precipitation events, there has been an increase in the number of heavy rainfall episodes across the country. This increase in heavy precipitation events poses a potential threat to the operation of electricity networks and power plants, which may face challenges in managing and accommodating the higher volumes of water associated with such events (IEA, 2023).

1.1.2 History and current situation of carbon dioxide emissions

Carbon dioxide (CO_2) emissions resulting from human activities have reached levels that surpass any point in our history. Numerous factors have contributed to this unprecedented and precarious situation. Population growth, economic development, increasing energy consumption, and various other influences have collectively contributed to the rise in CO_2 emissions.

In the early stages from 1850 to 1960, industrializing countries were the primary contributors to global emissions. During this period, the world witnessed a steady and continuous growth in emissions, primarily driven by industrialization and population growth. However, this upward trajectory was occasionally interrupted by significant historical events such as the Great Depression in the 1930s and the conclusion of World War II in 1945. These events temporarily impacted emissions trends due to economic slowdowns and shifts in industrial production. Nonetheless, the overall pattern during this period remained one of consistent emission growth.

During 1960-2011, global emissions are still rising overall while new top emitters Emerge. In the second half of the 20th century, the per capita emissions of most industrialized countries reached a stabilization point. After 2005, China surpassed the United States to become the world's largest emitter of carbon dioxide (CO_2). By 2007, CO_2 emissions from developing nations exceeded those of industrialized nations. Additionally, in 2015, Asian countries also experienced an increase in emissions.

According to 2020 statistics (figure 3), China is the world's largest carbon dioxide emitter, with 11,680 metric tons (11.680GT) of carbon dioxide emissions in 2020, accounting for more than 32% of the total global emissions in 2020. The United States ranks second in terms of carbon emissions at 4.535GT, accounting for about 12.6% of the global total. The next major carbon emitting countries are India (2411.73GT), Russia (1674.23GT), and Japan (1061.77GT).

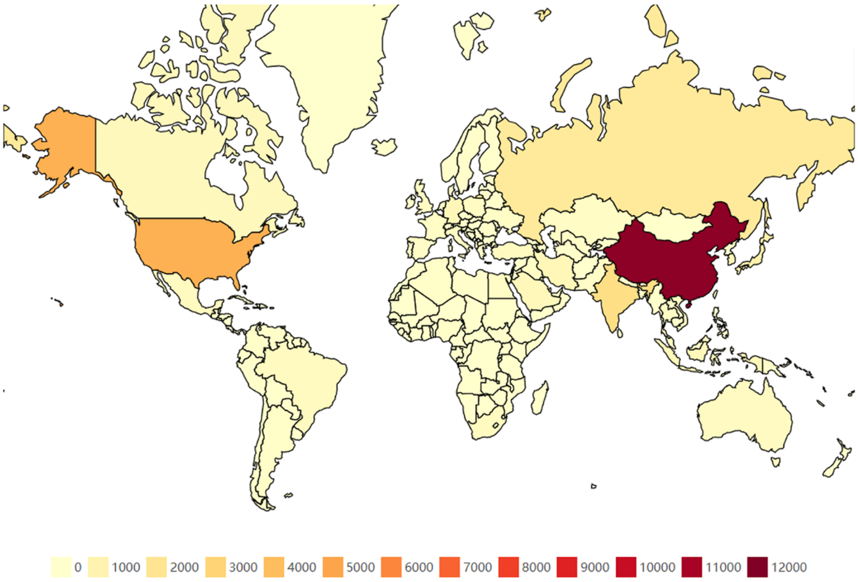


Figure 3: 2020 CO_2 Emissions (Mt)
Source: World Population Review, 2023

Total emissions, however, fall short of telling the full story. For example, the top three emitters are also three of the most populous countries on Earth, so it stands to reason that their emissions would be higher than that of countries with a fraction as many residents. For a more accurate measure of whether a country's policies are succeeding or failing to reduce CO_2 emissions, it is often helpful to examine not only total emissions, but also CO_2 emissions per capita, By this measure, the U.S. has the thirteenth-highest per capita emissions at 13.68 tons, while Russia is 20th (11.64), Japan is 26th (8.39), China is 28th (8.20), and India is 110th with a mere 1.74 tons per capita. Meanwhile, a number of developing nations occupy the top spots, largely due to less-regulated energy, industry, and transportation industries.

In terms of of Italy, carbon dioxide emissions underwent a substantial growth period between 1970 and 2005, witnessing a nearly 50 percent increase to reach a peak of 470.2 million metric tons ($MtCO_2$).

As of 2021, Italy's carbon dioxide emissions stood at 311.2 million metric tons ($MtCO_2$). This positioned Italy as the second-largest carbon polluter within the European Union (EU) for that year, following Germany and surpassing Poland. Italy's emissions accounted for approximately 11 percent of the total CO_2 emissions produced within the EU (Figure 4). The data underscores the ongoing efforts and challenges faced by Italy in reducing carbon emissions and transitioning towards a more sustainable and low-carbon economy.

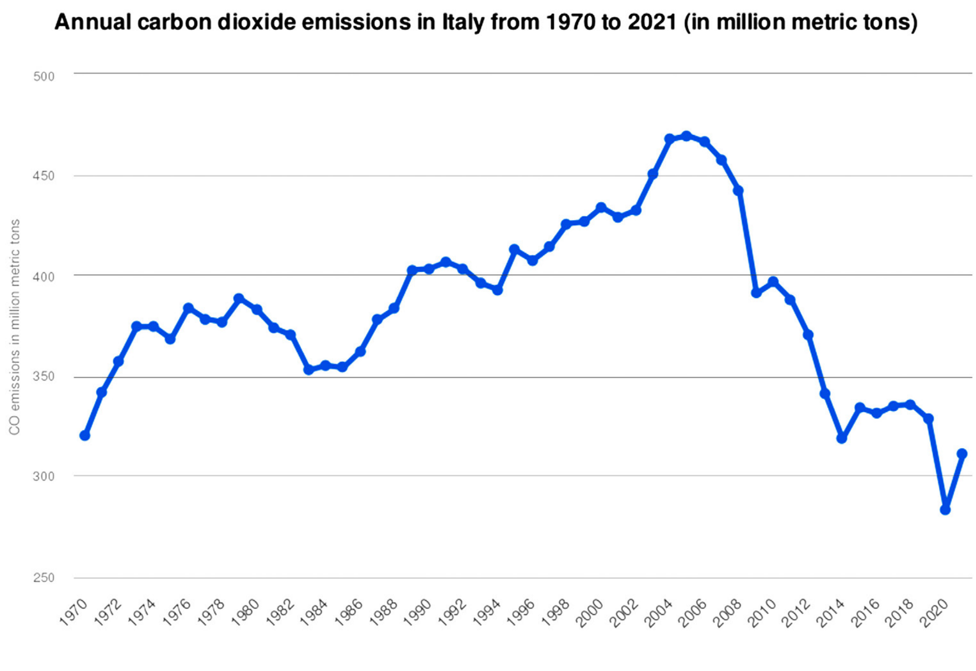


Figure 4: Annual carbon dioxide emissions in Italy from 1970 to 2021 (in million metric tons)
Source: Statista, 2023

According to preliminary forecasts from environmental agency ISPRA, greenhouse gas emissions in Italy were around 418 million tons of CO_2 equivalent in 2022, virtually the same as 2021, despite a big fall in energy consumption due to the COVID lockdowns (ISPRA, 2023).

As Italy suffered from a severe drought, renewables accounted for only 35% of the country's total energy production, carbon use increased significantly, and hydropower production fell by 38% and returned to 1950s levels. Solar and wind grew by 3 GW, but remained the European laggard for these sources.

1.1.3 The policies of reducing greenhouse gas emissions

Since the nineteen-seventies, the first effects of climate change began to be recorded, The discussion on theme of environmental protection and the reduction of anthropogenic impact has been growing, At the United Nations Conference held in Stockholm in 1972, the issue of safeguarding against risks to the environment was addressed, exploiting technological innovation, scientific research and education (UN: Stockholm, Sweden, 1972), Subsequently, in 1987, the concept of sustainable global development was defined with the Brundtland report, then resumed with the Rio conference in 1992 (Agenda 21), the United Nations Millennium Summit in 2000 (Millennium Development Goals, MDGs), the World Summit on Sustainable Development (WSSD, Rio + 10) in 2002 and the United Nations Conference on Sustainable Development (UNCSD, Rio + 20) in 2012 (Chou, 2021), noting every time the urgency to pay attention to the problem of pressure of man on the natural system, of its vulnerability and resilience.

The signing of the Paris Agreement in December 2015 by 197 countries was rightly hailed as a truly historic moment in the fight against climate change. It marked the start of the most important race in our existence – the race to curb global greenhouse gas (GHG) emissions. The deal established the pursuance of a carbon-neutral strategy to maintain the global average rise in temperature closer to 1.5 ◦C by 2050 and below 2 ◦C.

Countries around the world have introduced corresponding policies to reduce carbon emissions. This thesis will take China, the United States, and Italy as examples to introduce the measures to reduce carbon emissions in different countries:

China – Carbon Neutrality

As the world's largest carbon emitter, is continually increasing its efforts to reduce carbon emissions due to dual pressure domestically and internationally. Specifically, China has committed to achieving peak carbon emissions no later than 2030. Some scholars predict that strict low-carbon measures, greater production efficiency, use of renewable energies and natural gas, nationwide emissions-trading schemes can help China achieve this target, and reduce national CO_2 emissions by 30 Gt by 2035 (figure 5).

In order to achieve the peak of carbon emissions in 2030, in China's important future development planning document - "14th Five-Year Plan", addressing climate change is listed as the main goal, It also planned that during "14th Five-Year Plan" period (2020-2025), China's Energy consumption per unit of GDP is reduced by 13.5%, and non-fossil energy accounts for about 20% of total energy consumption. In addition, China announced in 2020 that it will achieve carbon neutrality by 2060.

Since then, China has been committed to environmental improvement, deeply promoting the low-carbon and clean transformation of energy, industry, construction, transportation and other fields, strictly controlling the consumption of fossil energy, especially coal, and vigorously developing non-fossil energy.

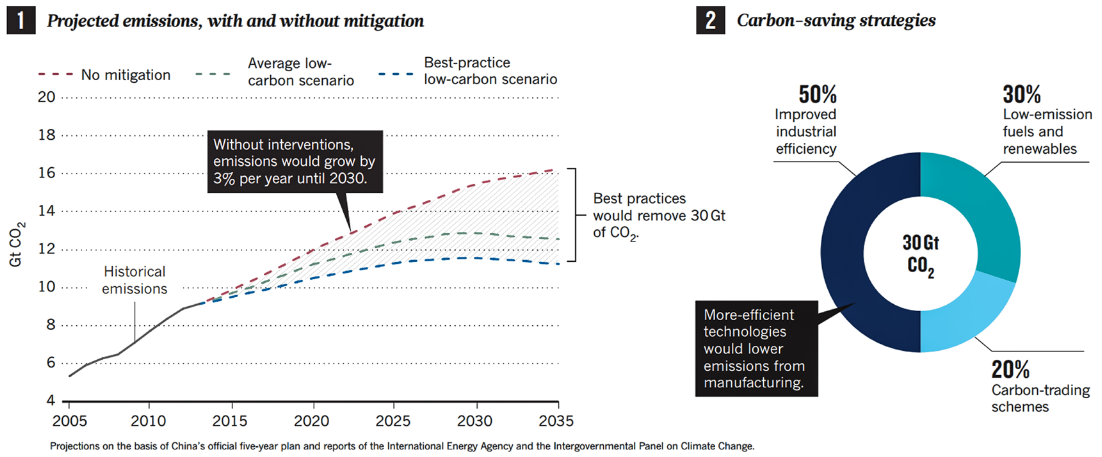


Figure 5: Carbon crunch of China
source: Liu Z, 2015

The United States - building a clean energy economy

President Biden campaigned on a bold vision: Tackling the climate crisis with the urgency that science demands, by building a clean energy economy that benefits all Americans (with lower costs for families, good-paying jobs for workers, and healthier air and cleaner water for communities). After rejoining the Paris Agreement, President Biden created the first-ever

National Climate Task Force, with more than 25 Cabinet-level leaders from across agencies working together on groundbreaking goals:

Reducing U.S. greenhouse gas emissions 50-52% below 2005 levels in 2030, Reaching 100% carbon pollution-free electricity by 2035, Achieving a net-zero emissions economy by 2050, Delivering 40% of the benefits from federal investments in climate and clean energy to disadvantaged communities…

President Biden and Vice President Harris also made tackling climate change, advancing environmental justice, and creating jobs centerpieces of the Inflation Reduction Act and Bipartisan Infrastructure Law. also made climate action and environmental justice a centerpiece of the Bipartisan Infrastructure Law.

Reducing emissions and accelerating clean energy, advancing environmental justice and empowering workers, strengthening climate resilience, leveraging domestic ambition to rally global peers will all become strategies for the United States to achieve its goal of reducing carbon emissions (The White House, 2023).

Italy - Vigorously develop renewable energy

The United Nations Framework Convention on Climate Change (FCCC) was ratified by Italy in the year 1994 through law no.65 of 15/01/1994. The Kyoto Protocol, adopted in December 1997, has established emission reduction objectives for Annex B Parties (i.e., industrialized countries and countries with economy in transition):

in particular, the European Union as a whole was committed to an 8% reduction within the period 2008-2012, in comparison with base year levels. For Italy, the EU burden sharing agreement, set out in Annex II to Decision 2002/358/EC and in accordance with Article 4 of the Kyoto Protocol, had established a reduction objective of 6.5% in the commitment period, in comparison with 1990 levels.

on 1st June 2002, Italy ratified the Kyoto Protocol through law no.120 of 01/06/2002. The ratification law also prescribed the preparation of a National Action Plan to reduce greenhouse gas emissions, The Kyoto Protocol entered into force in February 2005. The first commitment period ended in 2012, with an extension, for fulfilling commitments, to 18th November 2015, the so called true-up period.

As a Party to the Convention and the Paris Agreement, Italy is committed to develop, publish and regularly update national emission inventories of greenhouse gases (GHGs) as well as formulate and implement programs to reduce these emissions. According to statistics from the IEA (International Energy Agency), as of 2020, Italy's Total CO_2 emissions have decreased by 29.58% compared to 1990, while energy production has increased by 28.98%, total primary energy supply has decreased by 6.19%, and Electricity final consumption increased by 25.64% (International Energy Agency, 2022) (figure 6).

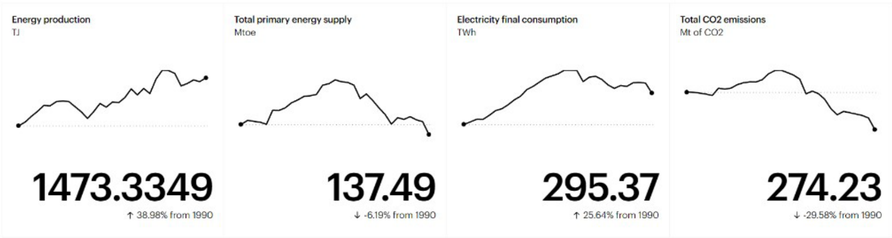


Figure 6: Key energy statistics in Italy, 2020
Source: International Energy Agency, 2022

Italy expects to triple its production of solar energy and double its production of energy from wind by 2030. The phasing out of coal in electricity production will be a main driver behind this development, with projections of 55 % of final electricity consumption to come from RES by 2030.

Recommendations from the IPCC Report, 2023

To deal with the climate problem and reduce carbon emissions, countries around the world have made a lot of efforts, however, there is still a long way to go to reduce greenhouse gas emissions. According to the IPCC publication, simulations indicate that the goal of Paris Agreement might not be respected since the increase in temperatures may vary between an additional 1.6 ◦C and 4.4 ◦C during the 21st century in the most severe simulation, leading to an increase in extreme events, including fires, floods, heat waves and monsoons.

To meet the targets set by the Paris Agreement, zero net emissions in 2050, it is therefore necessary that governments work together through an intense development of clean technologies and the production of energy from wind and photovoltaic plants, hydroelectric system and nuclear fission. At the same time, it is necessary to raise awareness and develop a culture of sustainability in the population in order to change choices and habits, In the 2023 IPCC Report also mentioned several key solutions needed to mitigate climate change: retire coal plants, invest in clean energy and efficiency, retrofit and decarbonize building and so on (figure 7) (IEA: Paris, France, 2021).

Figure 7: 10 key solutions needed to mitigate climate change
Source: IPCC Report, 2022

1.1.4 The role of construction sector in reducing greenhouse gas emissions

While the signatories of the Paris Agreement are countries, the breadth of its ambition will require action from every major sector of the global economy, including and especially buildings and construction. The construction sector is currently one of the main emitters of carbon dioxide, whose contribution is estimated at around 38% of total emissions in 2019. Of this percentage, 28% is attributable to buildings, while 10% is due to industries that produce materials and building components: a total of about 10 billion tons of CO_2e, a figure higher than that of transport and the rest of industrial production (UNEP, 2020). Buildings are also one of the main consumers of electricity, accounting for 33% of the entire production in 2020 (figure 8).

The percentage destined to rise by 2050 to 72% (Compass Lexacon, 2020) at the European level. In Italy, over 57% of electricity production still takes place from the combustion of fossil fuels, primarily natural gas, contributing significantly to emissions (figure 9).

Taking action on buildings is one of the most cost-effective means of reducing global emissions. Furthermore, low carbon, green buildings offer significant opportunities in terms of energy reduction, cost savings, job creation and building a more resilient economy.

For this reason, the World Green Building Council (WorldGBC) is calling for the dual goals of:

1. All new buildings must operate at net zero carbon from 2030
Net zero carbon buildings must become standard business practice as soon as possible, so we build right from the start; avoid the need for future major retrofits; and prevent the lock-in of carbon emitting systems for decades to come.

2. 100% of buildings must operate at net zero carbon by 2050

Existing buildings require not only an acceleration of current renovation rates, but these renovations must be completed to a net zero carbon standard so that all buildings are net zero carbon in operation by 2050.

In the faster transition scenario proposed by the International Energy Agency (IEA), near-zero-energy construction and deep-energy resoliciting will cut energy needs by 30% by 2050. Heating and cooling systems are expected to grow their energy efficiency (IEA: Paris, France, 2021).

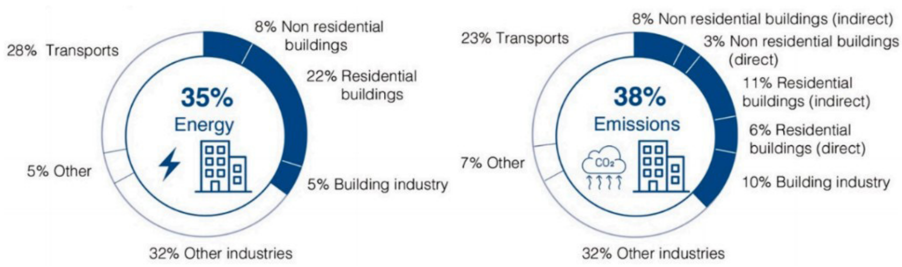


Figure 8: Proportion of energy use and CO_2 emissions in the construction sector in 2020
Source: Besana D, Tirelli D. 2022

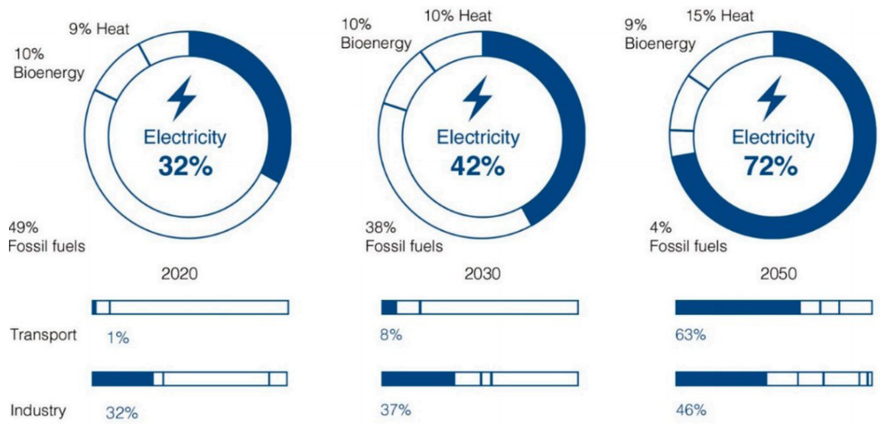


Figure 9: Electricity consumption percentage in the building and other sectors in the next decades, 2021
Source: Besana D, Tirelli D. 2022

1.1.5 Current buildings situation and major decarbonization initiatives in the EU

Collectively, construction sectors in the EU are responsible for a substantial 40% of our total energy consumption and contribute to a significant 36% of greenhouse gas emissions. These emissions predominantly arise during construction, ongoing usage, renovation, and eventual demolition phases. Presently, around 75% of the EU's building inventory suffers from energy inefficiency, leading to the wasteful utilization of a considerable portion of our energy resources (figure 10).

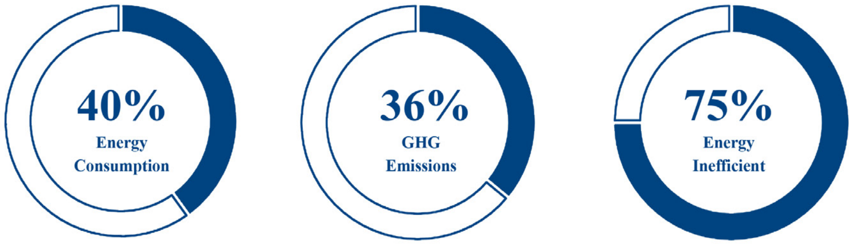


Figure 10: Current buildings energy consumption situation in the EU
Source: Adapted by European Commission, 2020

Moreover, a significant 35% of the EU building stock is over 50 years old, and Up to 97% of buildings need partial or deep renovation to comply with the long-term strategy ambition (figure 11).

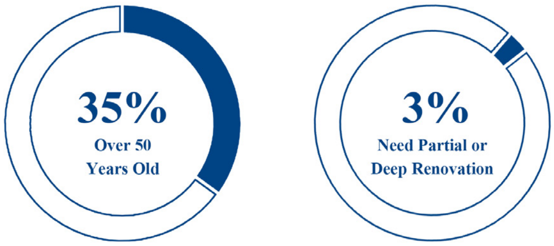


Figure 11: Current buildings situation in the EU
Source: Adapted by Epo.org, 2022

In response to the current situation, the EU has launched the following major decarbonization initiatives:

Energy Performance of Buildings (EPBD) Directive

EPBD (2002), EPBD recast (2010), EPBD recast (2018) and EPBD recast (2023-under review).

The Energy Performance of Buildings Directive (EPBD) is a crucial European Union policy aimed at improving building energy efficiency to meet EU energy and climate targets. It includes guidelines for insulation, heating, cooling, lighting improvements, mandatory Energy Performance Certificates, regular HVAC system inspections, and the promotion of Nearly Zero-Energy Buildings (nZEBs).

Energy Roadmap 2050 (2012)

The Energy Roadmap 2050, a pivotal document issued by the European Commission in 2012, lays out the European Union's overarching goal: to establish a sustainable, low-carbon, secure, and competitive energy system by the year 2050. At its core, this roadmap places paramount emphasis on reducing greenhouse gas emissions to mitigate climate change, improving energy efficiency to make the most of available resources, and accelerating the adoption of renewable energy sources to ensure both environmental sustainability and energy security. These key objectives reflect a comprehensive and forward-thinking strategy to address the pressing challenges of our time.

European Green Deal and Rennovation Wave (2020)

The European Green Deal, initiated in 2020, is the European Union's comprehensive strategy to achieve climate neutrality by 2050. Its key objectives include a transition to a greener economy, increased utilization of renewable energy, and a just transition for affected industries and regions.

As for the Renovation Wave, also launched in 2020, its primary goals are to renovate buildings throughout the EU to enhance energy efficiency, generate employment opportunities, and make housing more affordable and sustainable.

REPowerEU (2022)

The European Commission has unveiled the REPowerEU Plan in response to the challenges and disruptions in the global energy market caused by Russia's invasion of Ukraine. There is a pressing need for a dual transformation in Europe's energy system: firstly, to break free from the EU's reliance on Russian fossil fuels, which are wielded as both an economic and political tool, imposing an annual cost of nearly €100 billion on European taxpayers, and secondly, to confront the urgent climate crisis. By acting in unity as a Union, Europe can expedite the process of reducing its dependence on Russian fossil fuels. The measures outlined in the REPowerEU Plan are geared towards realizing this goal, focusing on energy conservation, diversification of energy sources, and the accelerated adoption of renewable energy to supplant fossil fuels in households, industries, and power generation.

1.1.6 Factors Affecting Building Carbon Emissions and Related Standards

There are multiple factors that significantly impact building carbon emissions, which encompass various aspects of building design, construction, and operation, including energy efficiency, heating and cooling systems, renewable energy sources, material selection, operational practices, transportation, and waste management. Some parameters of these can serve as quantitative standards for measuring the sustainable performance of buildings. Examples include primary energy factors, thermal transmittance (U-value), and more.

By considering and optimizing these factors and utilizing appropriate quantitative standards, the sustainable performance of buildings can be effectively evaluated and improved, leading to reduced carbon emissions and a more environmentally responsible built environment.

In European Union directive: EPBD stands for the Energy Performance of Buildings Directive, it’s easy to find the minimum requirements for buildings, building components and technical building systems, which varies with typology and climatic zones in Italy (figure 12), these requirements serve as valuable references for our design process.

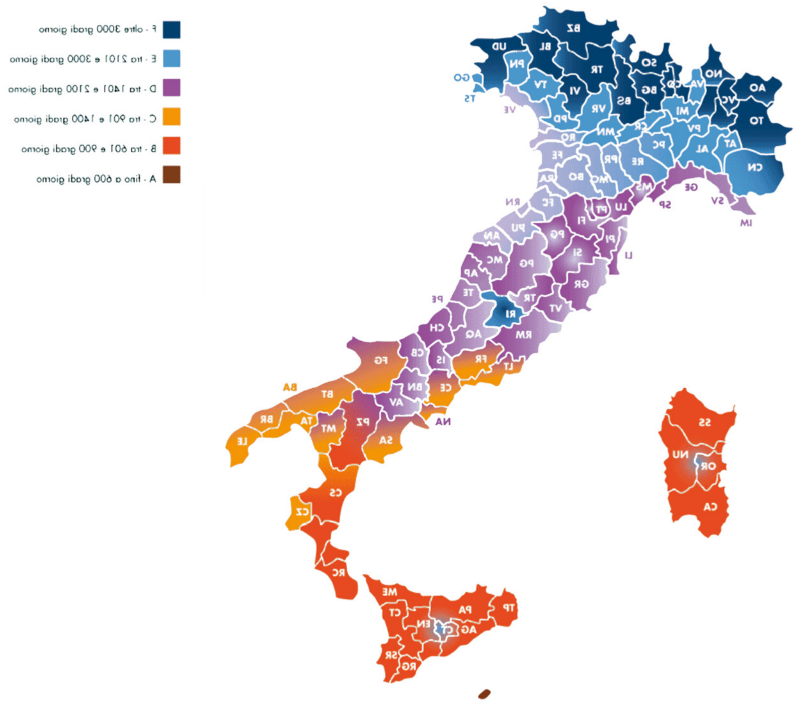


Figure 12: Climate zones in Italy
Source: ResearchGate

First of all, it sets out the standards of primary energy factors (table 1) and stipulate the factors that need to convert the delivered energy into primary energy when calculating the energy. Primary energy factors are the conversion factors used to calculate the primary energy consumption associated with different energy sources, which reflect the efficiency of the overall energy supply chain and provide a standardized method for comparing the environmental impact and energy performance of different energy sources, it will greatly assist designers in estimating building energy consumption.

Simultaneously, the energy parameters of building materials are accompanied by specific requirements tailored to different building components and climatic zones in which the buildings are located, and the thermal transmittance value (U-value) (a measure of the rate of heat transfer through a building component or assembly) is utilized as a reference for evaluation (table 2).

Additionally, EPBD also includes specific energy requirements for building systems and components as following:

The mean transmission heat transfer coefficient, H'T ($W/m^2. K$), is lower than the limit value for that given climatic zone and surface-area-to-volume ratio (S/V) of the building (table 3).

The ratio of summer effective collecting areas to the net floor area, Asol,est /Asup util, is lower than the limit value defined for residential and non-residential buildings (table 4).

The mean efficiencies of the technical systems for heating (ηH), cooling (ηC) and domestic hot water (ηC) are higher than those calculated for the reference building.

The mass of the external walls (except northeast to northwest) is larger than 230 kg/m^2 or, alternatively, their periodic thermal transmittance YIE is lower than 0.12 $W/m^2.K$.

The periodic thermal transmittance YIE of roofs and floors is lower than 0.18 $W/m^2.K$.

The U-value of the inter-building opaque components (floors and walls) is lower than 0.80 $W/m^2.K$

For new building, following conditions need to be met:

Be pre-arranged for a possible connection to district heating and cooling networks which are closer than 1 km from the designed building, or if district heating and cooling networks are predicted in approved plans and closer than 1 km. Otherwise the chosen solution has to be justified.

Be equipped with intelligent metering systems (according to EED implementation decree);

Satisfy a minimum level of automation for building control, regulation, and management in the case of non-residential buildings.

Energy Carrier	$f_{P,nren}$	$f_{P,ren}$	$f_{P,tot}$
Natural Gas (1)	1.05	0	1.05
LPG	1.05	0	1.05
Diesel fuel and fuel oil	1.07	0	1.07
Coal	1.10	0	1.10
Solid bio fuels	0.20	0.80	1.00
Liquid and gaseous bio fuels	0.40	0.60	1.00
Electricity (1)	1.95	0.47	2.42
District heating (2)	1.50	0	1.50
Solid urban waste	0.2	0.2	0.2
District cooling (2)	0.5	0	0.5
Thermal energy from solar collectors	0	1.00	1.00
Electricity produced by photovoltaics, mini wind turbines and small hydro systems	0	1.00	1.00
Geo- aero-, hydrothermal energy	0	1.00	1.00

Table 1: Primary energy factors

Elements /Components	Validity period	Thermal transmittance U [W/m^2.k] (including thermal bridges)				
		Climatic Zone				
		A and B	C	D	E	F
Envelope – walls	From 2015	0.42	0.36	0.32	0.28	0.26
	From 2019/2021	0.38	0.32	0.28	0.24	0.22
Envelope – roofs	From 2015	0.36	0.36	0.28	0.25	0.23
	From 2019/2021	0.34	0.34	0.24	0.22	0.20
Envelope – floors	From 2015	0.46	0.40	0.32	0.30	0.28
	From 2019/2021	0.42	0.36	0.28	0.26	0.24
Doors, windows and shutter boxes	From 2015	3.20	2.40	2.00	1.80	1.50
	From 2019/2021	3.00	2.20	1.80	1.40	1.10
Indoor partitions	From 2015	0.80	0.80	0.80	0.80	0.80
	From 2019/2021	0.80	0.80	0.80	0.80	0.80
		Total solar energy transmittance g_{gl+sh} [-]				
		A and B	C	D	E	F
Windows with shading devices	From 2015	0.35				
	From 2019/2021					

Table 2: Reference building - Performance of single building elements

Row N.	A/V ratio of the building	Climatic zone				
		A - B	C	D	E	F
1	S/V ≥ 0.7	0.58	0.55	0.53	0.50	0.48
2	0.7 > S/V ≥ 0.4	0.63	0.60	0.58	0.55	0.53
3	0.4 > S/V	0.80	0.80	0.80	0.75	0.70
4	Second level major renovation (>25% envelope)	0.73	0.70	0.68	0.65	0.62

Table 3: H'T maximum limit value

Building categories	All climatic zones
Residential buildings	≤ 0.030
Non-residential buildings	≤ 0.040

Table 4: Asol, est/Asup, utile maximum limit value
Source: EPBD implementation in Italy, 2018

1.2 Net Zero Carbon Building

1.2.1 The definition and evolution of net zero carbon building

The concept of net zero has come a long way in a very short time - it has gone from science to policy to mainstream in less than a decade. But it's the three decades ahead, particularly the first, that will determine whether the new window through which decarbonization is now viewed globally delivers what it promises to.

For the construction sector, despite the great number of studies about carbon emissions reduction, a shared definition and term for NZCBs is still lacking. but what is certain is that in NZCB buildings, carbon footprint must be taken into account, which is an important way to understand the main causes of greenhouse gas emissions and indicators to deal with climate change.

The NZCB concept appeared first in 2006 in the United Kingdom (DCLG, 2006), after which various countries and institutions have continuously improved its definition, the UK Green Building Council (UKGBC) has given the following definition:

"When the quantities of greenhouse gas emissions associated with the operational and embedded footprint of the building throughout the life cycle, including its disposal, are zero or negative" (UKGBC, 2019).

Since the part of the definition that considers the entire life cycle is still under discussion, a different formulation is also proposed by the institution divided into three successive steps: net zero carbon—construction (for embedded emissions), net zero carbon—operational energy (for the operational emissions) and net zero carbon—whole life (previous definition), as an end point to be reached in the future.

Then, The Net Zero Carbon Buildings Commitment was developed by the World Green Building Council (WorldGBC), a group that advocates for the halving of emissions produced by the building and construction sector by 2030 and totally decarbonizing by 2050. Green Building Councils (GBCs) and partners to define a net zero carbon building as:

A highly energy-efficient building with all remaining operational energy use from renewable energy, preferably on-site but also off-site production, to achieve net zero carbon emissions annually in operation.

WorldGBC has adopted this definition because it clarifies the focus on carbon and enables flexibility, market-by-market, regarding details such as energy source. Besides, WorldGBC also clarified some commonly used related terms, including:

Operating emissions: As the building is consuming energy to provide comfort conditions for its occupants and/or service its primary function, performance is verified annually by metered actual consumption and energy generation data, and emissions determined based on the energy source mix; our definition of net zero carbon currently focuses on this type of emissions.

Net zero energy: A building that relies on both energy efficiency and entirely on-site renewable energy production to reach its balance of energy-consumed and energy produced.

Energy positive: A building that produces annually more on-site energy that it requires to operate, and supplies the energy to the grid or neighboring functions.

Carbon neutral: Achieving net zero carbon emissions by balancing the amount of carbon released to meet operating energy demand, with offsetting an equivalent amount.

Embodied carbon: The greenhouse gas (GHG) emissions associated with the non-operational phase of the project, that is: extraction, manufacture, transportation, assembly, maintenance, replacement, deconstruction, disposal and end of life aspects of the materials and systems of a building. WorldGBC acknowledges that in time, as we progress net zero operating emissions, more emphasis will be placed on the whole lifecycle process of a building, and a definition of net zero carbon may evolve to incorporate this aspect.

According to a new report by the World Green Building Council (WorldGBC), there are currently 500 net zero commercial buildings and 2,000 net zero homes around the globe. As of 2017, ten GBCs are already working with stakeholders in their markets to: create or adopt voluntary net zero carbon building rating systems; catalyze projects; and support training. While each GBC is developing the program that is right for their market, each will respect the following principles:

1. use carbon as the key metric; 2. promote deep energy efficiency; 3. establish a hierarchical preference for on-site renewable energy, off-site renewable energy, and then offsets; 4. transparently disclose how each building achieves a carbon balance and promote continuous improvement of the building sector.

As WorldGBC's vision calls for total decarbonization for the built environment, they call the industry to adopt the whole life carbon approach that addresses emissions from operational energy use in buildings, and the embodied carbon which comes from the building materials and construction or renovation processes (figure 13).

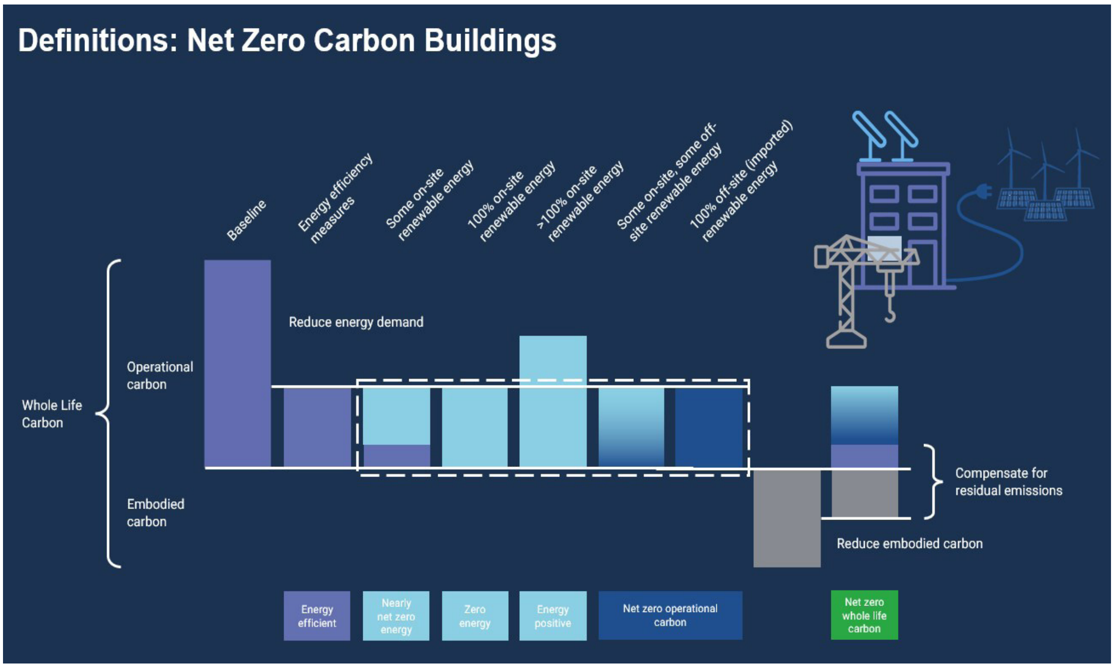


Figure 13: Definition of net zero carbon buildings
Source: World Green Building Council, 2022

1.2.2 NZCB compared to other energy and carbon target classifications

Besides net zero carbon building, Scientific literature offers many types of classification for low/zero-energy and low/zero-carbon buildings, each classification has its specific focus, for example, energy efficiency, carbon emissions (embodied or operational), renewable energy production or life-cycle behavior from a sustainability perspective.

According to Berardi, while the number of sustainability assessment rating schemes available worldwide exceeds 600 and is still evolving, they can be grouped according to the following three systems (Berardi, U. 2012).

1. cumulative energy demand (CED) systems (focus on energy consumption) 2. the life-cycle analysis (LCA) systems (more devoted to environmental aspects) 3. the total quality assessment (TQA) systems (evaluate ecological, economic and social aspects)

NZCB is more inclined to the life-cycle analysis (LCA) systems proposed by Berardi, which explores the carbon emissions of buildings from the entire life cycle of a building. In following paragraphs, several similar building classifications according to low/zero-energy and carbon standards will be introduction and comparison (figure 14)

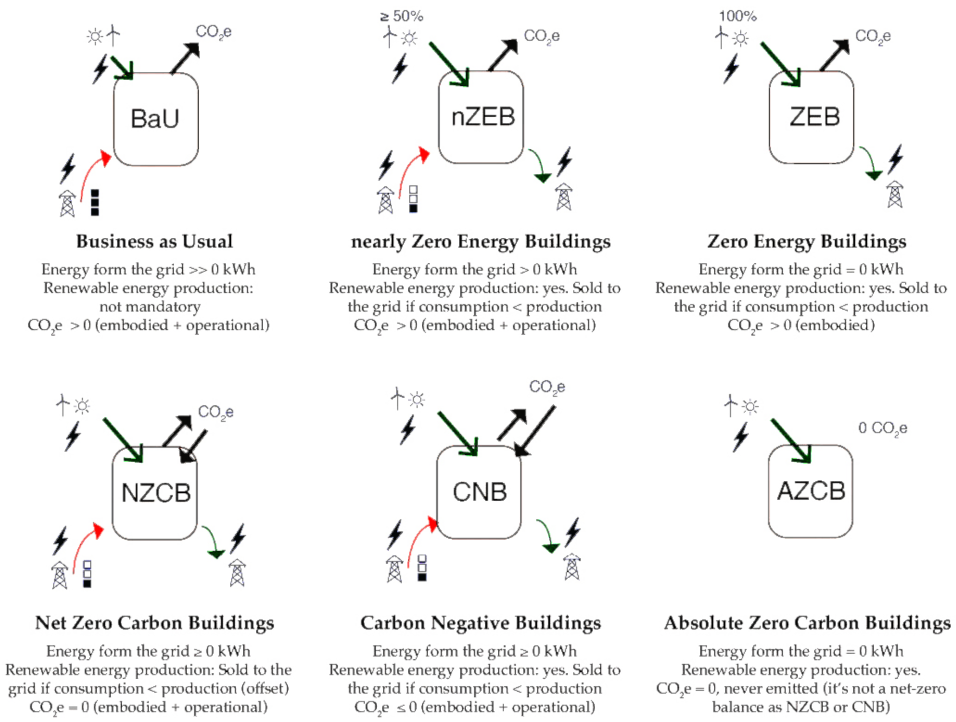


Figure 14: NZCB compared to other energy and carbon target classifications
Source: Tirelli D, Besana D. 2023

Business as Usual (BaU)

The reference configuration of a building is commonly referred to as business as usual (BaU), under this classification, a building that has been designed in compliance with energy performance standards but does not pay particular attention to the reduction in greenhouse gases emissions, either operational or of those embodied (Jeong, Y.S. 2017). The reference building consumes an average of about 220 kWh/m^2, has an amount of operational GHG emissions of about 70 $kgCO_2e/m^2$/year and embodied carbon emissions in the production and construction phases (upfront carbon) of about 1000 $kgCO_2e/m^2$ (WBCSD, 2021).

Nearly Zero Energy Building (nZEB)

The notion of nZEB is included in Art. 2(2) of the EPBD: an nZEB "means a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby". Which is also a mandatory requirement for new and updated buildings in Europe, as prescribed by the Energy Performance of Buildings Directive (EPBD) 2010/31/EU in Art. 9: "Member States shall ensure that: (a) by 31 December 2020, all new buildings are nearly zero-energy buildings; and (b) after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings" (European Union, 2010).

However, the directive encountered some problems during its implementation, it failed to define embodied energy and embodied carbon (WBCSD, 2021), meanwhile, finding the cost-optimal level of NZEB is a daunting task.

Zero Energy Building (ZEB)/Net Zero Energy Buildings (NZEB)

In the definition of Net Zero Energy Buildings (NZEB), renewable energy replaces fossil fuels as supply energy, while it also focuses on improving energy efficiency. The word "net" refers to the overall balance of energy obtained from and supplied back to the grid by this type of building within a certain period of time (Andresen, I. 2017). The U.S. Department of Energy states that “There are a number of long-term advantages of moving toward ZEBs, including lower environmental impacts, lower operating and maintenance costs, better resiliency to power outages and natural disasters, and improved energy security”. Nonetheless, the definitions of NZEB and ZEB lack embodied energy or embodied carbon assessments, which have a greater negative impact on the environment than energy production (Chastas, P. 2016).

Beyond Carbon Neutrality

Carbon-negative buildings (CNBs) or beyond carbon neutrality is a more ideal situation building, which means that the compensation for carbon emissions is bigger than their release into the atmosphere. For CNB, embodied carbon is still the main problem. Therefore, the materials used in the design must be carefully selected, but Current possible solution lacks of market feasibility due to its high cost. Thus, the emissions reduction goal for the local governments is in conflict with the building sector stakeholders (Pokhrel, S.R. 2021).

Absolute zero carbon buildings (AZCB), which means avoiding emissions directly without the use of offsets, but are so difficult to achieve that they can only be imagined at a conceptual level. Is an asymptotic condition to strive for but currently conceivable only at a conceptual level.

Above all, we can conclude that NZCB is a classification that is more in line with the current technical basis and considers carbon emissions more comprehensively, it is important to include both operational and embodied carbon deriving from construction, maintenance and the end of life of the building.

As shown in several studies, embodied carbon can exceed 50% of overall emissions and be greater than operational carbon, so avoiding embodied carbon emissions is an important issue for NZCB to consider

1.2.3 Challenges and drivers for developing net zero carbon building

As seen in the previous paragraph, the NZCB is a tough target to reach in the construction sector but of vital importance to attempt to mitigate climate change and global warming by 2 ◦C and preferably by 1.5 ◦C. To achieve the goal of 100% of all buildings operating at net zero carbon by 2050, there must be a rapid rate of change from our current market state. In particular, we must ensure that every new building built is net zero as soon as possible, as every new building not built to these standards today will need to be retrofitted tomorrow.

Therefore, for new and existing buildings, WorldGBC setting the following milestones to ensure progress towards the 2050 goals at a global level (Laski J, Burrows V. 2017):

From 2030, all new buildings globally must be built to net zero carbon standards, ensuring that no new carbon emissions are emitted from building operations.

The International Energy Agency (IEA) estimates that the current global buildings stock is 223 billion square meters (Global Status Report, 2016) and this will rise, on average, 5.5

billion square meters per year, resulting in a global building stock in 2050 of approximately 415 billion square meters.

Therefore, we face a huge challenge: Between now and 2050, existing buildings must be renovated at an accelerated rate and to net zero carbon standards, so that all buildings operate at net zero carbon by 2050 (figure 15), At the same time, all new buildings must meet the net-zero carbon building standard (figure 16).

In addition to the large building stock, net zero carbon building faces three interrelated challenges, perceptual barriers, technical barriers and financial barriers (Laski J, Burrows V. 2017).

In terms of perceptual, high-performing net zero buildings have not been embraced as business-as-usual, assumptions spread that these buildings must be technically difficult and not solid financial investments. Ambiguity and uncertainty result in market confusion that has stalled momentum.

For the technical part, net zero carbon buildings require expertise, client demand and technical know-how to deliver a building that actually achieves net zero carbon emissions in operation. The technical skills needed throughout the building design and operation process are not necessarily widespread, even in more established markets.

For the financial aspect, while there is evidence that net zero buildings currently have a higher upfront cost than other green buildings and non-green buildings, most of the research and evidence has focused on net zero energy buildings – which is much harder and likely more expensive to achieve than net zero carbon buildings.

In response to the above challenges, WorldGBC believes that it is possible to collectively propel the market from the under 1% of all buildings achieving net zero carbon to the 100% needed by 2050, by introducing voluntary net zero certification and through coordinating efforts from three ma jor groups – business, government and NGOs.

voluntary net zero certification can set, accelerate or make more ambitious the trajectory for the market. It can stimulate further market transformation through business commitments that lead to action, government policy and programs, and technological change.

This has been proven by the success of green building certification to date. So far, around the globe, WorldGBC member Green Building Councils have certified more than 1 billion square meters of green building space. that these certified buildings have stimulated growth in the market for green buildings; and we have seen evidence in Certain markets that initial certification can create greater market demand for further certification.

In addition to the help of green building certification, due to the promotion of various policies, the market has higher and higher expectations for the carbon performance of assets and products, resulting in the risk of stranded high-carbon buildings that have not been decarbonized. Stakeholders should be aware of this risk and assess their stranding risk step by step.

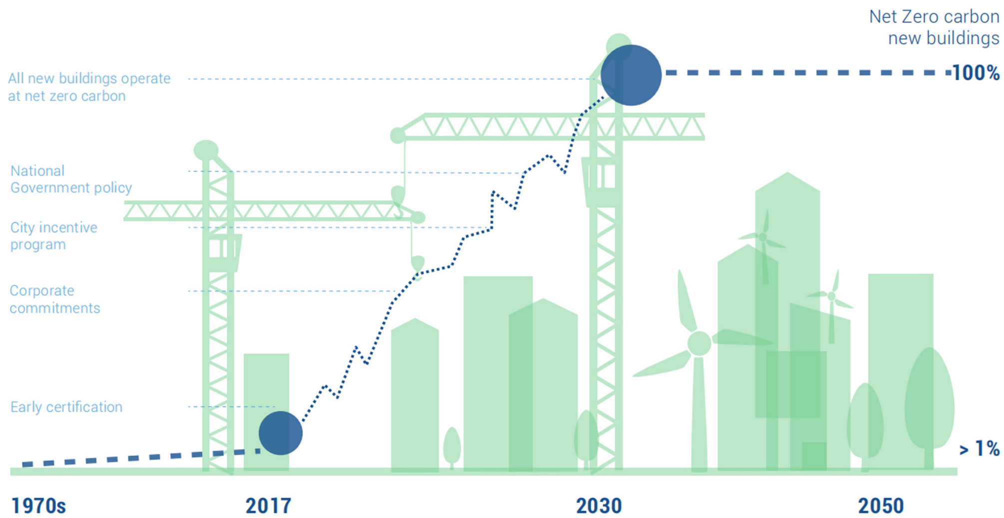


Figure 15: Trajectory for New Buildings to Achieve Net Zero Carbon

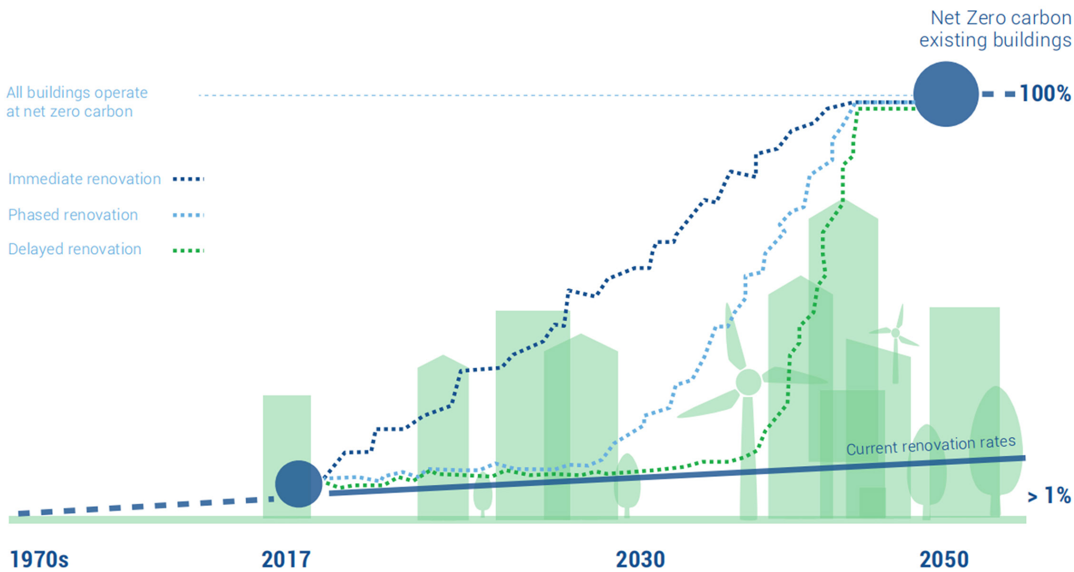


Figure 16: Trajectory for Existing Buildings to Achieve Net Zero Carbon
source: Laski J, Burrows V. 2017

1.2.4 The Significance of net-zero-carbon student communities

According to the survey, a high percentage of energy is used in non-residential buildings, including schools, hospitals, and administrative offices, accounting for an average of 25% in terms of energy consumption and corresponding greenhouse gases (GHG) of the global building stock. Among them, the educational sector accounts for 17%, showing a 1.1% increase in energy consumption rates per year due to the growing number of new technological appliances, such as IT devices and new telecommunications and air conditioning systems. Therefore, it is necessary to study net zero carbon design strategies for such buildings

In addition, In the education sector, student communities represent a challenge to creating a more environmentally friendly way of living. First, the quality of these buildings and the processes required to create them can encourage students cultivate a more sustainable way of living, learning and working, and this new way of life will spread to every corner through the student group.

Then, reducing and controlling building operating costs, especially energy and maintenance costs, is highly attractive, especially for public university campuses, which often have challenging annual budgets and rising energy costs.

Besides, the net zero building will be both good for the environment and the economy, resulting in reduced energy consumption and many, high-quality jobs in markets around the world, the net zero building will be both good for the environment and the economy, resulting in reduced energy consumption and many, high-quality jobs in markets around the world.

In the following paragraphs, this thesis will conduct a series of case studies of net-zero carbon buildings, and use the student community design of the Politecnico di Milano Leo campus as a design practice to discuss the design strategies and its performance of net-zero-carbon student community.

2. RELAVENT CASE STUDIES ON ENERGY EFFICIENT BUILDING DESIGN

2.1 Residential Building in Madrid

Architect: Guillermo Yanez

Figure 17: Over view of project
Source: Gonzalo, 2006

This is a social housing project in San Fermin, an emerging district on the periphery of Madrid, which was completed in 2004, had 3939 square meters of residential space (figure17).

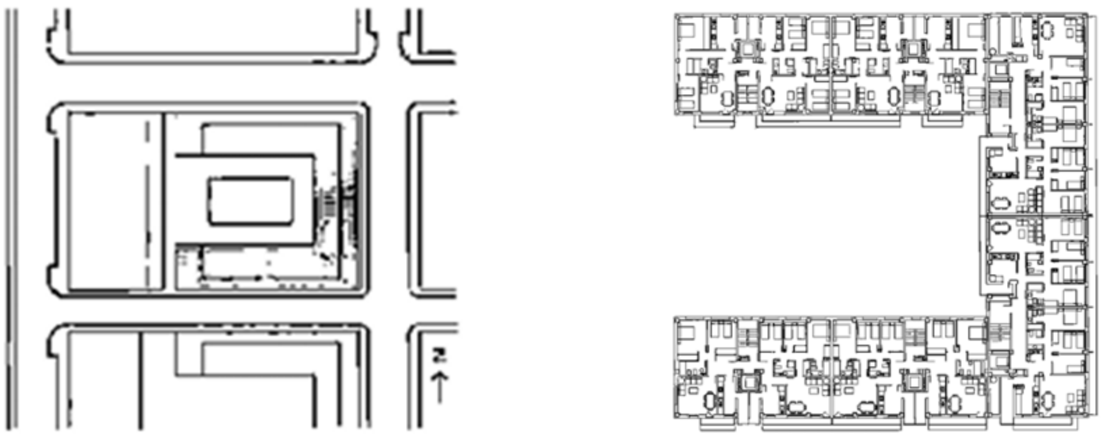


Figure 18: Masterplan and typical floor plan
Source: Gonzalo, 2006

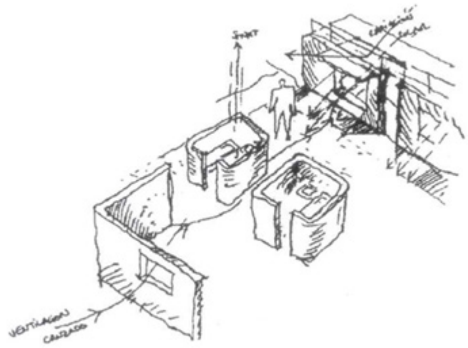
The building adopts the existing U-shape with two parallel north-south blocks linked by one east-west block (figure 18). To the west, the block is complemented by a higher neighboring building, which protects the courtyard against the noise from a six-lane traffic artery (figure 19).

Figure 19: Section south elevation (courtyard)
Source: Gonzalo, 2006

2.1.1 Cross ventilation

In addition to the use of solar energy in winter, shading and natural ventilation were essential criteria for the planning and construction concept of this building. Both criteria are fulfilled with constructional means and in the arrangement of the apartments within the plan. The units are oriented toward two sides to ensure cross-ventilation (figure 20). Within the three sides of the U-shaped development, the apartments are arranged in a differentiated manner according to orientation: living spaces are located on the south or west side, while bedrooms face north or east.

The courtyard is landscaped with local plant species chosen to improve the microclimate, especially in summer. Irrigation of the plants in the afternoon cools the outside air by means of evaporation. This factor plays a key role for natural ventilation in summer. It enhances the effect of both the cross-ventilation in all apartments and the convection ventilation provided via solar shafts. Ventilation shafts in the central core provide cooling for the apartments with east-west orientation. Air is extracted from the living spaces through the roof, while fresh air from the courtyard flows through the windows into the apartments. The sum of all these measures resulted in energy savings of over 40 percent and half the C02-emissions by comparison to conventional buildings that meet the established standards (figure 21).



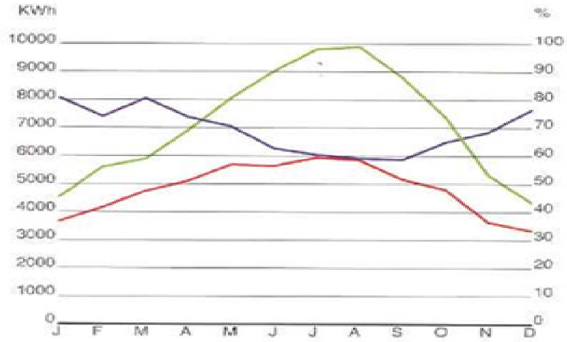


Figure 20: Functional diagram of cross-ventilation
Figure 21: Energy gain from collectors (KWh, red), warm-water requirements (KWh, blue) and average percentage of supply covered by the system (%, green)
Source: Gonzalo, 2006

Figure 22: Roof elevation with south facing solar collectors; shading on west facade (courtyard) provided with folding shutters with adjustable louvers
Source: Gonzalo, 2006

2.1.2 Renewable energy

Each unit has individual radiators. Gas-operated boiler is used for warm-water processing, supplemented by a solar system comprising twenty-four collectors, each covering an area of 2.5 m^2. The collectors are installed on the flat roof at a 40° angle and face south. The system covers roughly 70 percent of the total warm water requirements (figure 22) and has a calculated amortization rate of 12.4to 9.5 years, depending on the projected costs for the conventional energy sources. The energy contribution of the system translates into a reduction in C02-emissions of nearly thirteen tons. Like the openings, the exterior walls are also designed in response to orientation. On the east and west sides, they are designed as single-skin walls composed of thermal insulating, lightweight and porous brick. On the south and the fairly solid north side, the walls are fitted with an external thermal insulation layer.

2.1.3 Shading design

All openings are equipped with shading elements (figure 23), specifically designed according to orientation. These elements allow sunshine to penetrate into the interior when needed or, conversely, to block it, an essential feature given the extreme conditions in summer. It is important to note that the shading elements do not diminish the efficiency of the natural ventilation. The south facing balconies, with translucent glass panels in the parapet 3rea, are designed to act as suntraps (figure 24, 25). Horizontal louvers provide shading in summer on this side. Folding shutters with horizontal, adjustable louvers protect the west-facing balconies against the low evening sun during the hot season. Bedrooms facing north and east feature smaller windows (figure 26), whereby the east-facing windows are equipped with shading in the form of fixed horizontal and vertical elements (figure 27).

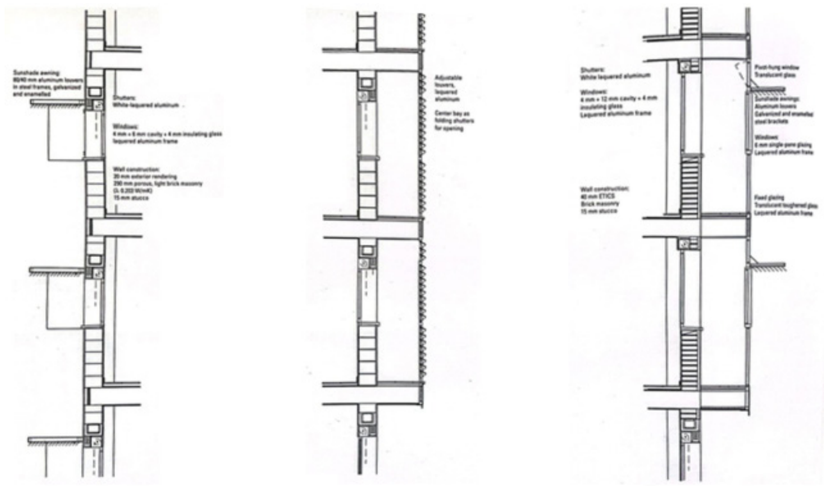


Figure 23: Detail drawings of facade
Source: Gonzalo, 2006

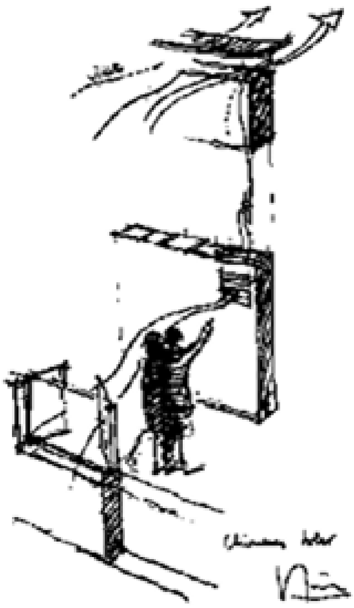


Figure 24: Functional diagram of ventilation with solar stack
Figure 25: Functional diagram of shading systems in front of balconies on the west side (courtyard)
Source: Gonzalo, 2006

Figure 26: West elevation (courtyard}: facade with shading by means of folding shutters and adjustable louvers
Figure 27: East elevation (street): smaller opening with combined horizontal and vertical shading
Source: Gonzalo, 2006

2.2 Silver Star Apartments

Architect: FSY Architects, Los Angeles, CA

This project is intended in particular to provide housing for military veterans who are homeless and living with disabilities (figure#). The apartment has 48 one-bedroom units and one two-bedroom unit for the resident with a number of sharing spaces (figure 28, 29).

Figure 28: Overview of project
Source: Dean, Edward. 2018

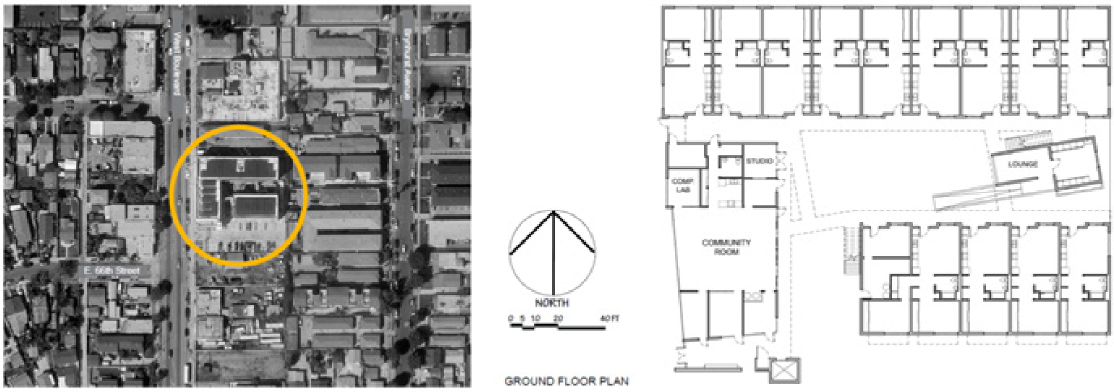


Figure 29: Masterplan and Ground floor plan
Source: Dean, Edward. 2018

2.2.1 Building envelope - insulation and windows

The project is wood-frame construction using advanced framing techniques. For all three buildings, the walls and roofs are insulated to a level higher than required by code, with R-21 for the walls and R-30 for the roofs. Continuous insulation in the form of rigid board was not applied to the outside of the wall studs to eliminated thermal bridging.

2.2.2 Heating, ventilating and cooling systems

A ducted mini-split system is installed in each unit. The condenser units for each are located on the roof. Ceiling fans are installed in the major rooms of each apartment to increase occupant comfort at higher indoor air temperatures and thereby reduce the use of the mini-split systems.

2.2.3 Domestic hot water – the solar thermal system

There are 26 panels making up the solar thermal system that essentially preheats the domestic hot water before delivering it to four storage tanks with heat pumps attached. The temperature is boosted there by the heat pumps.

Because of the moderate climate and relatively low heating and cooling loads, the energy demand for water heating is often a dominant part of the total energy demand in these types of buildings—estimated at one-third of the total. The design team chose a solar thermal system instead of solar PV panels combined with heat pump water heaters. Solar thermal systems are 80% efficient in converting solar energy to hot water whereas solar PV is only about 18% efficient converting solar energy to electrical energy. Therefore, it was determined that the solar thermal system makes more efficient use of roof space and that it would use the renewable energy more effectively (figure 30, 31).

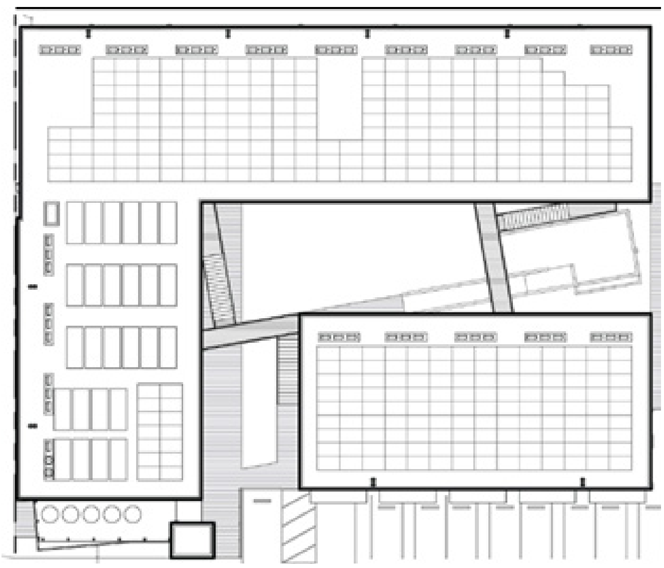
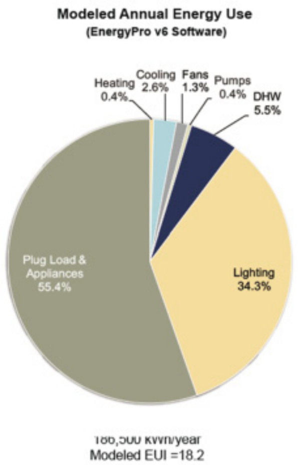


Figure 30: The roof of the apartment
Figure 31: Roof plan
Source: Dean, Edward. 2018

The solar thermal system provides enough energy to offset 80% of that required for all the DHW of the project. The heat pump water heaters, which are used to raise the water temperature to that required for use, therefore consume only 20% of the electric energy normally required for all the water heating. (figure 32, 33), where DHW represents only 5% of the modeled energy use for the entire complex.



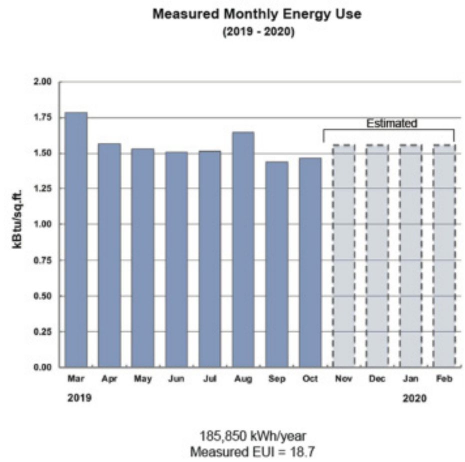


Figure 32: Modeled Annual Energy use
Figure 33: Measured monthly energy use
Source: Dean, Edward. 2018

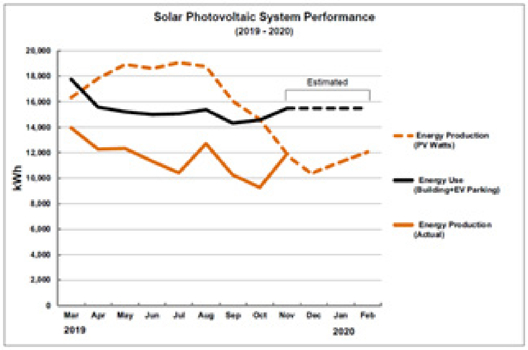
2.2.4 Energy performance

The chart (figure 34) displays the monthly energy use totals for the project, for illustration purposes, the PV Watts prediction for the system as desigmed for the entire year.

The chart clearly shows that the system is performing at a level of about 35% less than designed and less than the project goal.

As with the other case studies, The Cumulative Net Energy Production, the bottom chart on the opposite page, essentially shows the progression of the energy performance toward ZNE by adding each month’s net energy performance to the previous month’s total—if, at the end of the 12-month period, the curve returns exactly to the zero-axis, the project is performaing at Net Zero (ZNE).

This chart clearly shows the impact of the operational issues with the solar PV system on this project (figure 35). The ideal system performance is given by the curve that represents that predicted by PVWatts for the system as designed, which just achieves ZNE at the end of the year, The actual system performance, however, falls significantly short of ZNE.



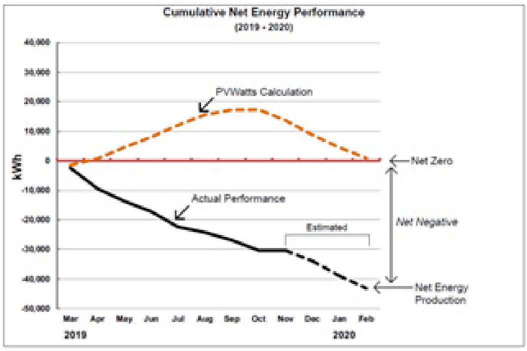


figure 34: Solar Photovoltaic System performance
figure 35: Cumulative net energy performance
Source: Dean, Edward. 2018

2.3 Stories apartment

Architect: FSY Architects, Los Angeles, CA

The Stories apartment building planned by Olaf Gipser Architects is 46 meters high and has 13 floors (figure 36). The upper ten floors are constructed using timber frame techniques, and the façade is clad in a refined white steel with tall plant niches. The building has 29 individually designed apartments and 6 commercial units. The apartments have a ceiling height of 2.90 m and an area of 43 to 235 m².

Figure 36: Overview of project
Source: ArchDaily. 2022.

2.3.1 Laminated timber

The tower is constructed of laminated wood, which significantly reduces carbon emissions compared to steel and concrete structures. Each layer has 15 load-bearing elements with a thickness of 160 to 240 mm forming a grid with an axial dimension of 4,80 m. These wooden portals have large openings that allow for the flexible arrangement of up to six apartments per floor (figure 37).

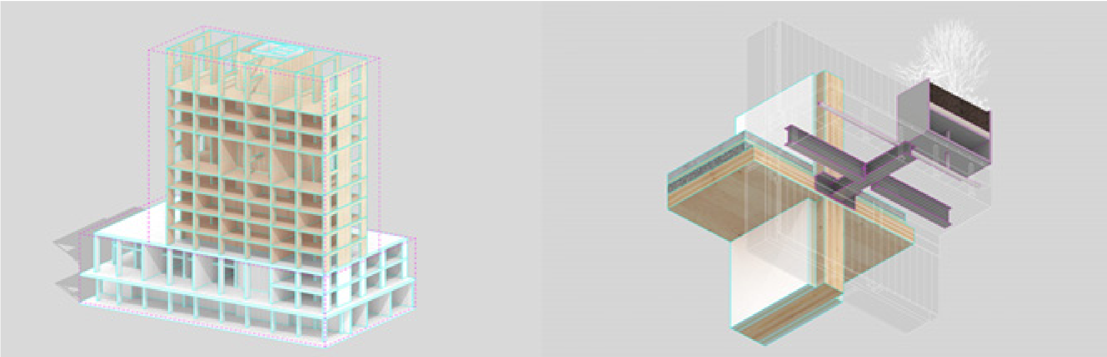


Figure 37: Laminated timber structure and prefabricated steel facade
Source: UrbanNext, 2023

Figure 38: Interior material design
Source: UrbanNext, 2023

Figure 39: Interior material design
Source: UrbanNext, 2023

The interior of the apartment features wooden floors, wooden ceilings and white walls to create an open and airy space. Larger apartments benefit from wrap-around balconies, and each room has exterior access through glass sliding doors (figure 38, 39).

Figure 40: Balcony and plant niches
Source: ArchDaily. 2022.

2.3.2 Floating garden

The architect's goal was for the deep green facade to function not only as an outdoor space, privacy screen, sunscreen and particle filter, but also as a living space for insects and birds. Seen from the apartment, the green alcove looks like a small floating garden. From the perspective of passers-by, the steel façade first creates a light, elegant architectural landscape that is constantly changing with the seasons thanks to the different foliage colors of the five tree species (figure 40).

2.4 Charles David Keeling Apartment

Architect: James Timberlake, FAIA

The Charles David Keeling Apartments are located on the souhwestern edge of the UC San Diego campus overlooking the coastal cliffs of La Jolla (figure 41). The apartments employ a suite of tactics to address Southern California's pressing environmental challenges of storm water management, water scarcity, and carbon emissions.

Figure 41: Overview of project
Source: AIA Top Ten. 2013

Three apartment buildings are arranged in a C shape around a courtyard, creating a new social area. To optimize cooling and eliminate the need for air conditioning, the shape and size of the building massing and window openings were adjusted from a landscape-scale CFD model to best capture ocean breezes. By relying on natural ventilation, the project saved 38% in energy consumption. Because of the condominium’s exceptional location, expansive ocean and mountain views can be enjoyed from all interior spaces of the condominium, external walkways and the large roof terrace, which have become popular meeting places (figure 42).

Figure 42:Masterplan and different views of project
Source: AIA Top Ten. 2013

2.4.1 Site ecology

The apartments use the natural slope of the site to provide limited natural infiltration, reducing the quantity of water and increasing the quality of the water released into the ocean. Water from the roof and a nearby parking lot is channeled through retention basins and bioswales.

Figure 43: Vegetated roof
Source: AIA Top Ten. 2013

A vegetated roof, an unusual feature in this dry climate, absorbs and evaporates rain that falls on that portion of the building, with overflow directed to the courtyard retention basins. Within the basins and bio swales, native vegetation slows runoff, allowing sediment and pollutants to settle before water leaves the site (figure 43).

2.4.2 Bioclimatic design

To optimize the cooling effect, the building mass and window openings were shaped and sized to best capture the breezes based on landscape-scale CFD modeling (figure 44). This analysis, coupled with the operability of nearly every window, proved that the passive strategies work effectively. To reduce the buildup of heat inside the apartments, solar radiation is moderated through an extensive network of integrated shading and railing panels and highly efficient low-e glass on the west facades, while the exterior walkways, located on the south or west of the buildings, provide additional protection from peak solar radiation.

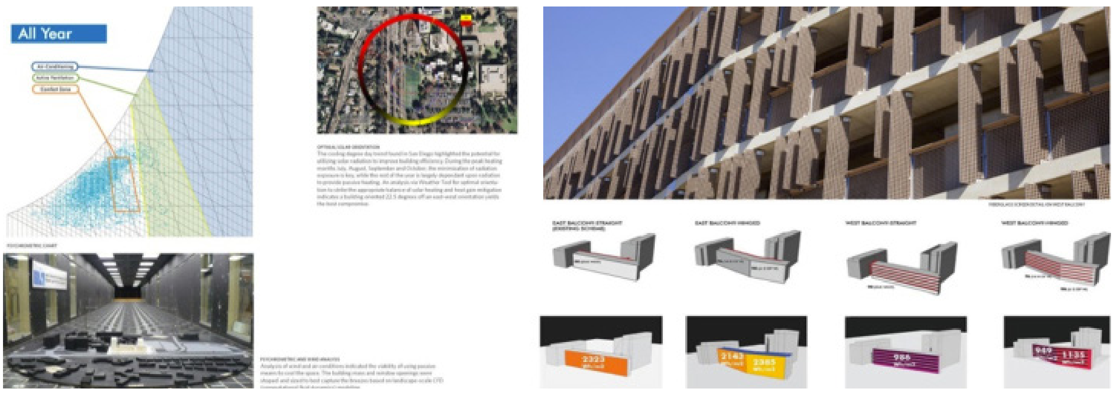


Figure 44: CFD simulation
Source: AIA Top Ten. 2013

2.4.3 Lighting

To optimize the cooling effect, the building mass and window openings were shaped and sized to best capture the breezes based on landscape-scale CFD modeling. This analysis, coupled with the operability of nearly every window, proved that the passive strategies work effectively. To reduce the buildup of heat inside the apartments, solar radiation is moderated through an extensive network of integrated shading and railing panels and highly efficient low-e glass on the west facades, while the exterior walkways, located on the south or west of the buildings, provide additional protection from peak solar radiation (figure 45).

Figure 45: The lighting of the project
Source: AIA Top Ten. 2013

2.4.4 Water recycle

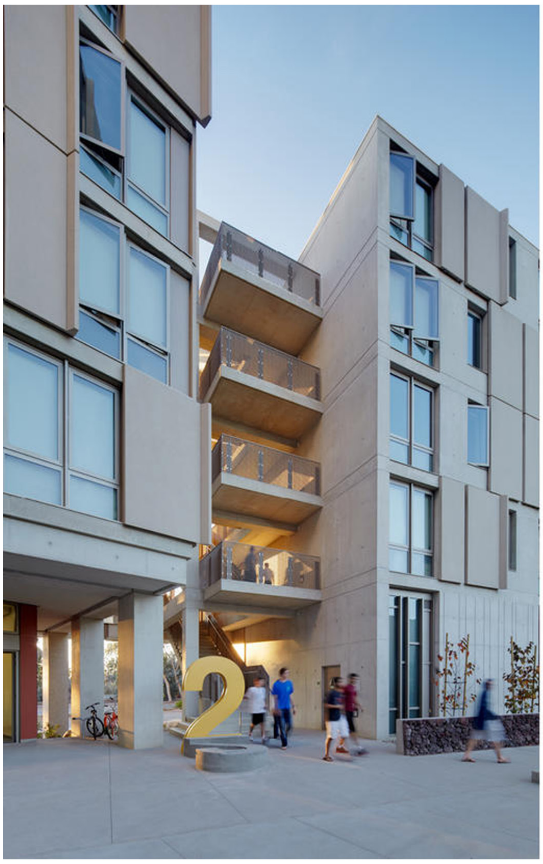
Water conservation was a top priority for this project, as it is both a scarce resource in Southern California and requires a significant amount of energy to transport from its distant source. The design response was two-fold, first focusing on conservation, and second on recycling. The conservation measures included water-efficient landscaping and a full suite of efficient plumbing fixtures, such as low-flow toilets (figure 46).

2.4.5 Energy performance

The most significant reduction of energy on this project comes from the elimination of air conditioning. Both building mass and envelope are designed to manage solar gain and nighttime cooling and to ensure effective natural ventilation.

The design incorporates single-loaded corridors, exterior walkways, operable windows, and a building orientation aligned to best capture cooling breezes from the Pacific Ocean. Heating efficiencies are achieved by thermal mass, and an innovative “backwards constructed” rain screen and air-barrier exterior wall that reduces heat loss and water vapor infiltration. Any

mechanical heating needed is provided with a localized arrangement of individually controlled radiant panels. The lighting energy demand is largely met by daylighting, which satisfies LEED daylight and view requirements. Daylighting is complemented in public spaces with occupancy-controlled lighting systems.
The total energe use of this building is 97.8 KWh/m^2 year.On-site renewable energy comes from a PV array that supplies 6% of the building’s total energy.



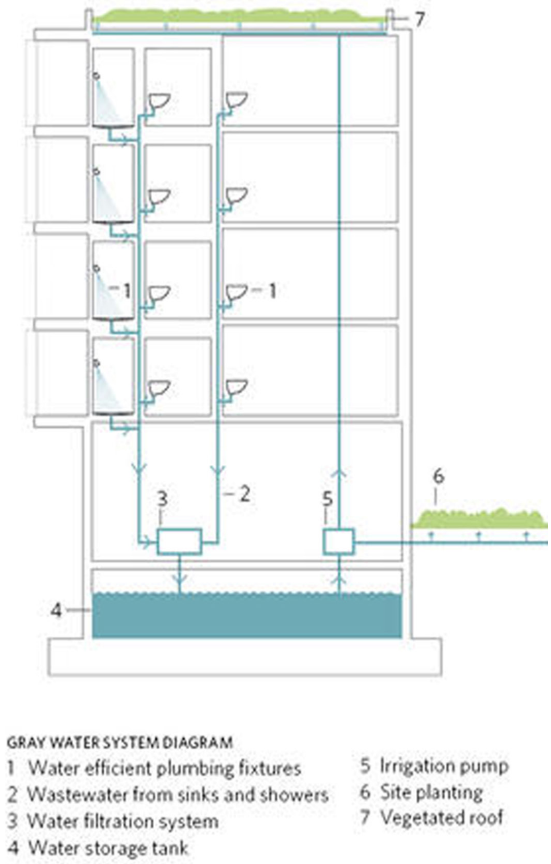


Figure 46: Water recycle system
Source: AIA Top Ten. 2013

2.5 Pioneer and Crescent Halls

Architect: Lee Kut Cheung,Toyo Ito

Within the green network at the Nanyang Technological University’s (NTU) Garden Campus are eight tree-like blocks that serve as student dormitories— each one has a three-directional planar formation that resembles branches stemming from a tree trunk. Despite a spatial constraint of the site, the blocks are positioned in such a way that maximise their interaction with greenery, wind and water (figure 47, 48).

Figure 47: Overview of project
Source: Archigardener, 2015

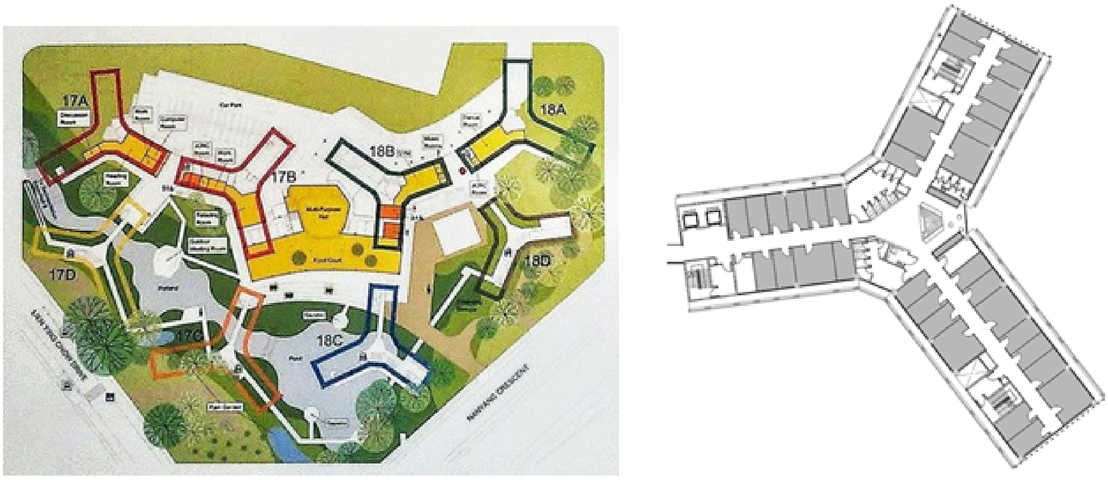


Figure 48: Master plan and typical plan
Source: Archigardener, 2015

2.5.1 Ecological strategy

What used to be an open, swampy drain that cuts across the valley of the site and a muddy lotus pond at the top of the valley have now been transformed. Instead of a conventional cut and fill, the architects wanted to respect the original terrain and has modified the existing drain into water bodies that are capable of cleansing storm water. The lotus pond has been converted into a sedimentation basin while the open drain is now a wetland and a retention pond, with rain gardens and cleansing biotope added. These water bodies are not only visually pleasing but also act as a holistic treatment train that cleanses storm water before it enters the public drains. The integration of naturalized water bodies and living quarters creates a Green environment where flora and fauna can thrive, enhancing the biodiversity of the site as compared to its former state.

2.5.2 The breathing facade

The student bedrooms are designed with a double skin façade that regulates sunlight and wind. On the outer skin, the grid-like aluminum louvers minimize direct solar glare and heat gain, and are positioned horizontally or vertically in order to optimize the shading intensity according to the solar glare simulations for the façade's respective orientations. On the inner skin, the double-glazed casement windows catch the wind when opened and allow an increased airflow through the bedrooms. This 'breathing' façade system not only gives the building texture and depth, but also provides physical comfort and wellness to the residents. In addition, the roof is fully cladded with photovoltaic and solar hot water panels, which help maximize energy savings (figure 49).

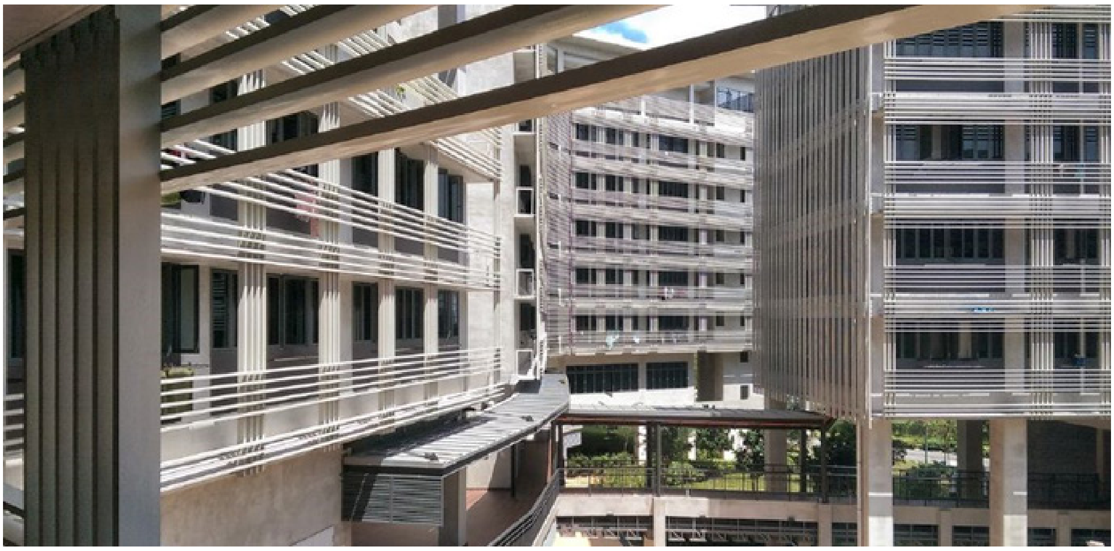


Figure 49: Building elevation
Source: Archigardener, 2015

2.5.3 Renewable energy

Solar photovoltaic panels and photothermal panels are installed on 70% of the roof of the dormitory building to provide electricity and hot water for the dormitory building to meet the energy and hot water needs of the residents (figure 50). The installed 300 solar panels can generate 107,100kWh per year, saving up to 2.4% of annual electricity consumption. Solar power provides ample power for all public restrooms, parking lots and driveways.

Figure 50: Solar panels on the roof
Source: Archigardener, 2015

2.5.4 The garden in the buildings

The lush green environment not only effectively reduces the heat island effect, but also provides a good living environment for local animals and plants (figure 51). There are interwoven boardwalks on various green spaces and water bodies, allowing people to walk among them and get in touch with nature. There are multiple aerial ecological gardens at the junction of each dormitory building, providing convenient spaces and places for student activities and exchanges

Figure 51: The green space in the building
Source: Archigardener, 2015

3. OVERALL UNDERSTANDING OF CITTA STUDI IN MILAN

3.1 Site Analysis

3.1.1 Geographical location

Citta Studi is located in Milan, a vibrant and cosmopolitan capital of the Lombardy region in northern Italy, which is widely recognized for its captivating history, vibrant culture, and its appeal to a substantial student population (figure 52).

Citta Studi stands as a cutting-edge university campus, fostering a highly active and vibrant community. It embraces sustainability and promotes an open dialogue with the city, remains accessible to the public, even during school holidays, serving as a dynamic hub of engagement and activity.

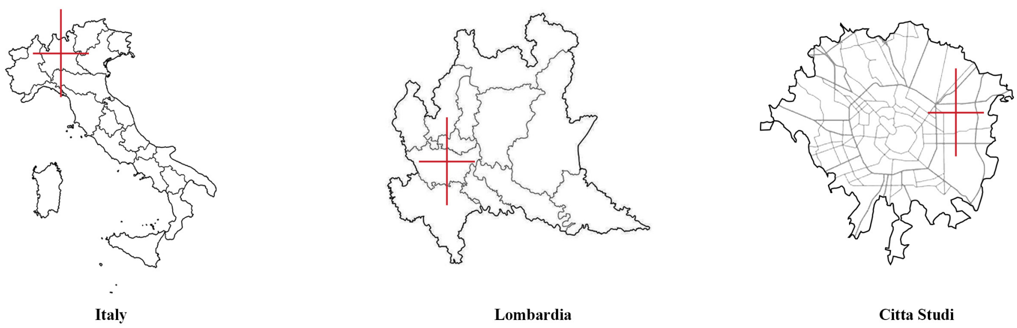


Figure 52: Location of Citta Studi
Source: by Author

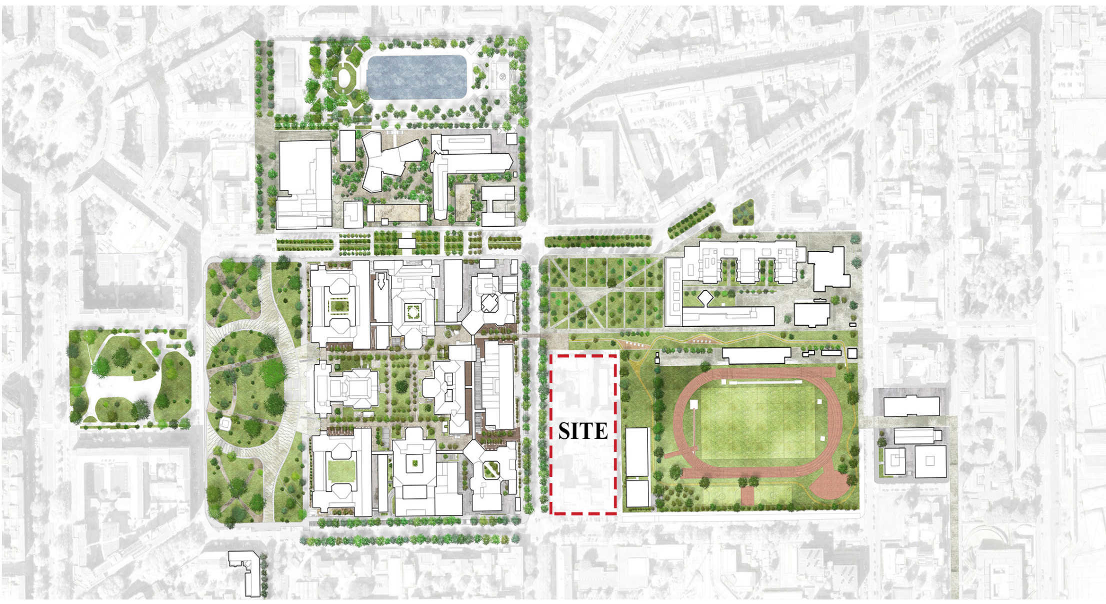


Figure 53: Location of Site
Source: Politecnico

Site is located at the intersection of the Leonardo Campus of Politecnico di Milano and the University of Milan, surrounded by numerous residential areas (figure 53). It is an area bustling with vibrant crowd activities. The envisioned project aims to create a net-zero student community, emphasizing sustainable living in this dynamic location.

3.1.2 Climate analysis

Milan features a mid-latitude, four-season humid subtropical climate (Cfa), according to the Köppen climate classification. Milan's climate is similar to much of Northern Italy's inland plains, with hot, humid summers and cold, foggy winters. Following will explores Milan's climate from multiple perspectives to ensure that architectural designs are energy efficiency, sustainability and well-suited to the local climate.

Temperature:
The average high temperature in Milan in summer ranges from 25°C to 30°C. Occasionally there will be heat waves that push the temperature above 35°C, Hence, it is crucial to consider the design of summer spaces. The temperature in autumn and spring is relatively mild, and the winter is relatively cold. The average temperature is 3°C to 8°C, need to consider the insulation performance of the building (figure 54).

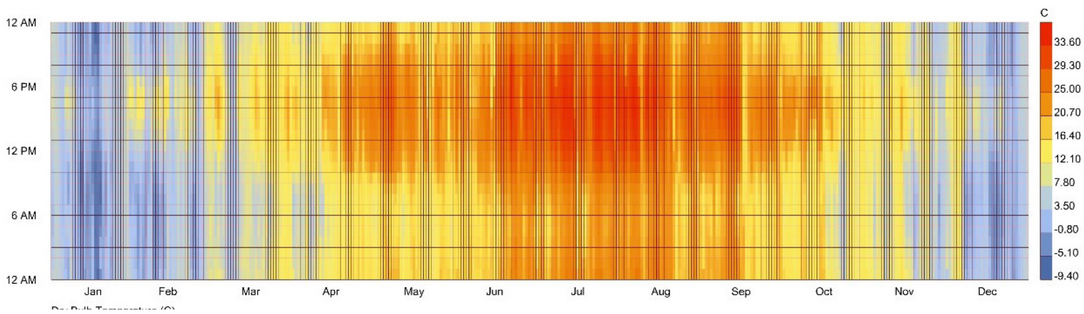


Figure 54: Dry bulb temperature in Milan
Source: Simulate by grasshopper

Rainfall:
Milan experiences a moderate annual rainfall of approximately 900-1,000 mm. The wettest periods typically span May, June, October, and November, as depicted in the accompanying figure. The summer months frequently bring thunderstorms, often accompanied by intermittent heavy rainfall. Considering these precipitation trends, the introduction of a rainwater collection system in Milan emerges as not only viable but also advantageous from the standpoint of promoting sustainable water management practices (figure 55).

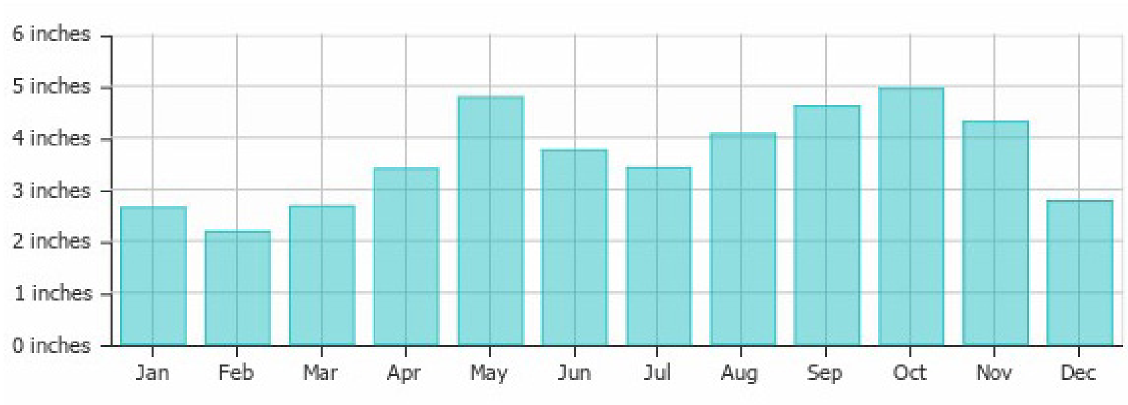


Figure 55: Average monthly snow and rainfall in Milan
Source: World Weather & Climate Information, 2023

Sunshine and Daylight:

Milan revels in ample sunshine, particularly in the extended days of summer. The average duration of daylight spans roughly 9 hours during winter and expands to about 15 hours per day during summer. With this solar abundance in mind, building design necessitates a deliberate focus on ensuring that interior spaces receive generous sunlight not only during summer but also during the winter months (figure 56).

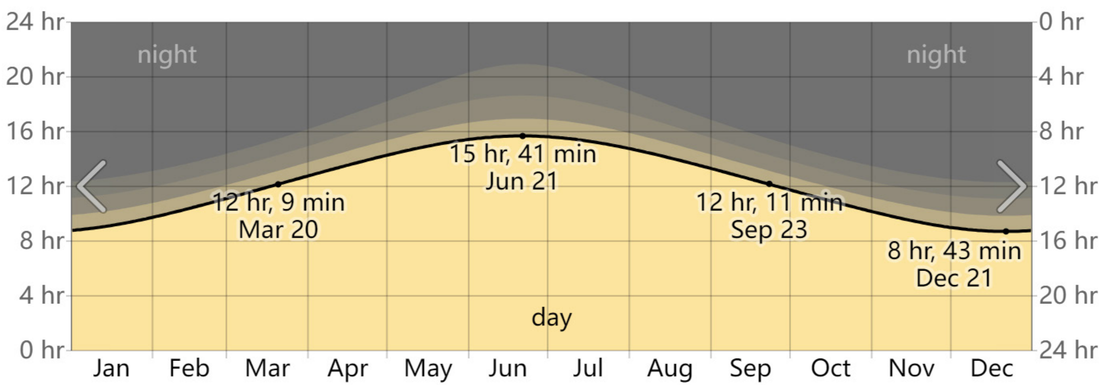


Figure 56: Hours of Daylight and Twilight in 2022 in Milan
Source: Weather Spark, 2022

Humidity:

Milan maintains a moderate level of humidity, with a favorable balance between temperature and humidity (figure 57). Relative humidity usually fluctuates between 60% and 80%, with potentially higher levels during the summer. To address this, employing measures such as proper ventilation, humidity regulation, insulation, and the utilization of HVAC systems can collectively contribute to effective cooling, dehumidification, and efficient air circulation.

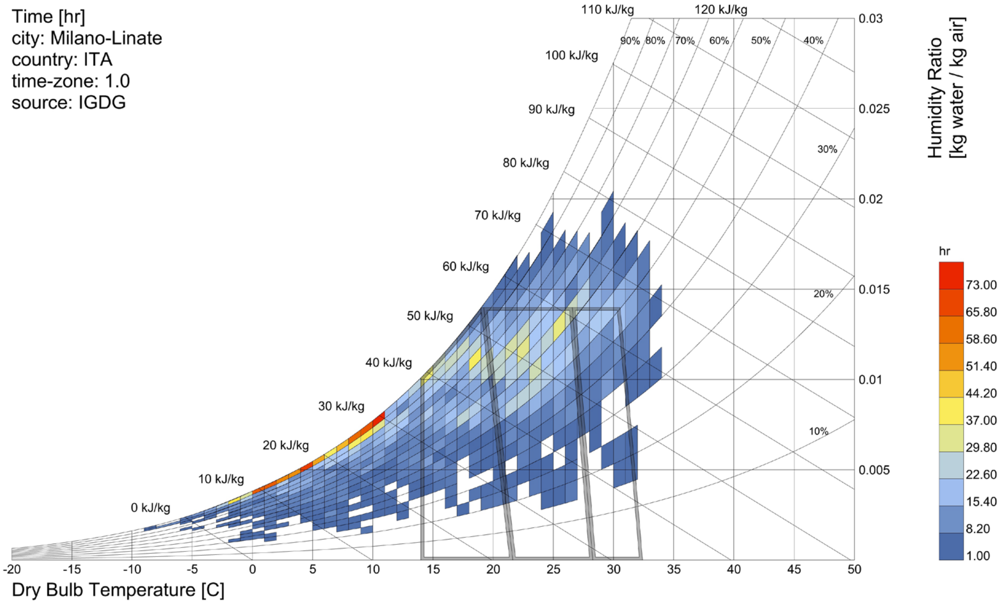


Figure 57: Psychrometric Chart
Source: Simulate by grasshopper

Wind:

Milan generally experiences moderate wind speeds year-round, occasionally accompanied by stronger gusts. The prevailing wind direction in the region is typically from the southwest, although it can vary due to weather systems. When it comes to architectural design, while specific attention to wind direction may not be necessary, it remains crucial to prioritize effective building ventilation (figure 58).

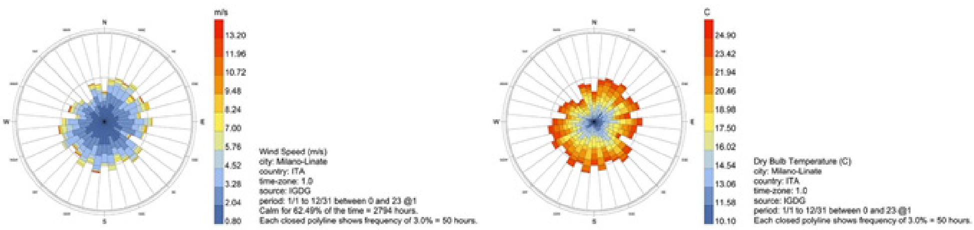


Figure 58: Wind rose diagram
Source: Simulate by grasshopper

Thermal Comfort:

Milan has a relatively good thermal comfort (figure 59). Most of the time of no thermal stress in various weathers accounts for more than 50% of the time throughout the year. The time of strong cold is relatively small, and sometimes it is hot in summer. When choosing building materials Need to pay attention to its thermal insulation performance.

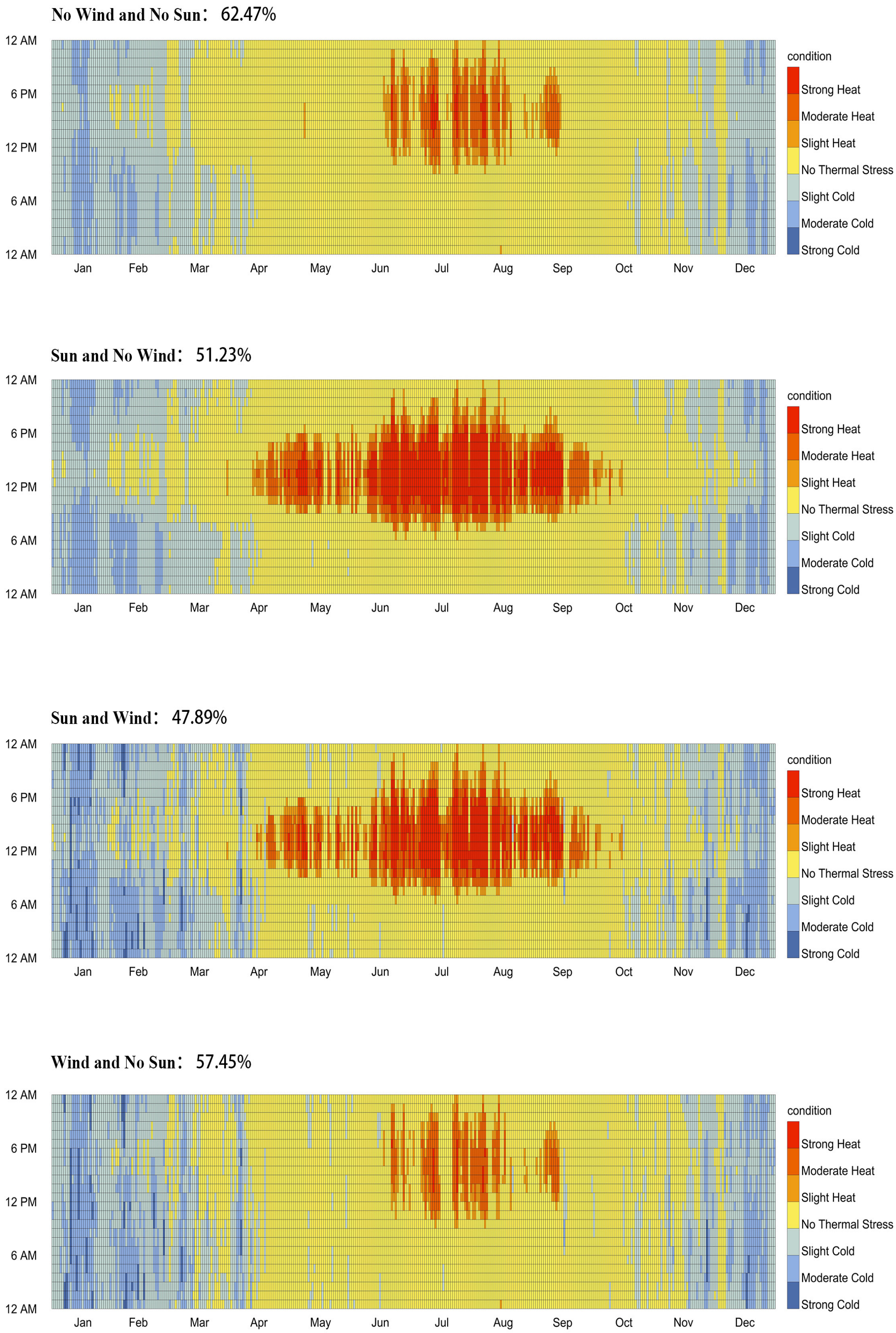


Figure 59: Outdoor comfortable analysis in Milan
Source: Simulate by grasshopper

Climate changes:

Like many other cities around the world, Milan is also affected by climate change. Rising temperatures and changing precipitation patterns are expected consequences, and the city has been implementing various sustainability measures and initiatives to mitigate the effects of climate change, including efforts to reduce greenhouse gas emissions and promote renewable energy.

Figure 60 shows an estimate of the mean annual temperature for the larger region of Milan . The data illustrates a clear warming trend in Milan's climate over time. This observation underscores the urgency of addressing carbon dioxide emissions and the need to reduce them.

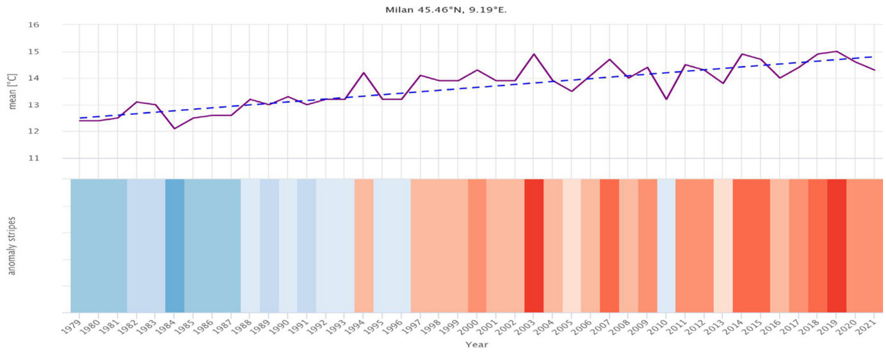


Figure 60: Outdoor comfortable analysis in Milan
Source: Meteoblue, 2023

Simultaneously, there is compelling evidence of a gradual increase in daily temperatures in Milan since 1979, with warmer months represented by red and colder months by blue, as well as sporadic occurrences of precipitation anomalies where wetter months are denoted by green and drier months by brown (figure 61).

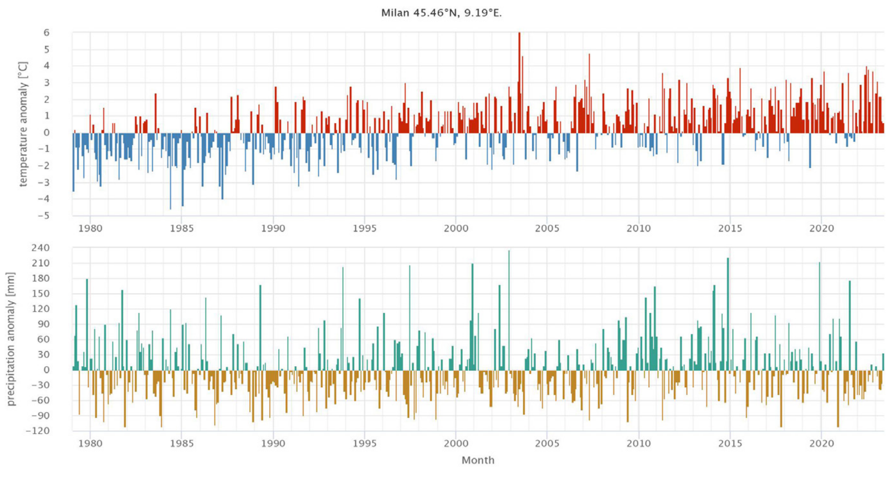


Figure 61: Monthly anomalies for temperature and precipitation 1979-2023.
Source: Meteoblue, 2023

Energy Use and Carbon Emission:

Energy in Italy comes mostly from fossil fuels. Among the most used resources are petroleum (mostly used for the transport sector), natural gas (used for electric energy production and heating), coal and renewables. Italy has few energy resources, and most supplies are imported (IEA, 2020).

It is worth noting that Milan has abundant geothermal resources and Milan's district heating network is extensive, which gives it great potential in the use of sustainable energy. In 2008, Milan allowed a reduction in infrastructure charges for new and retrofitted buildings that respect fixed standards concerning energy efficiency and/or renewable energy sources, including connection to district heating (figure 62).

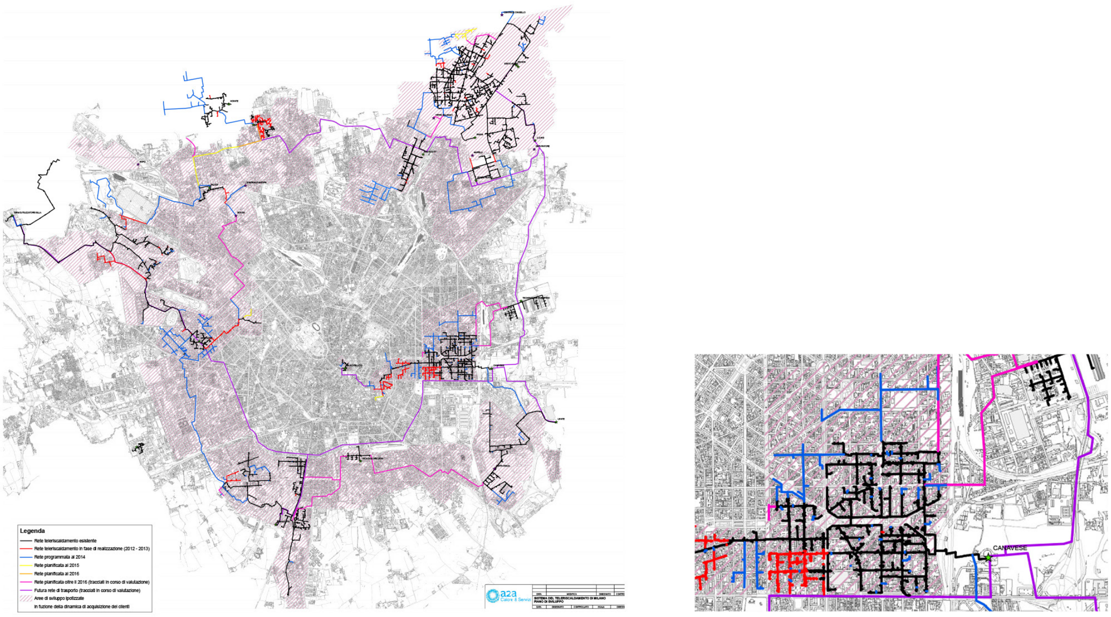


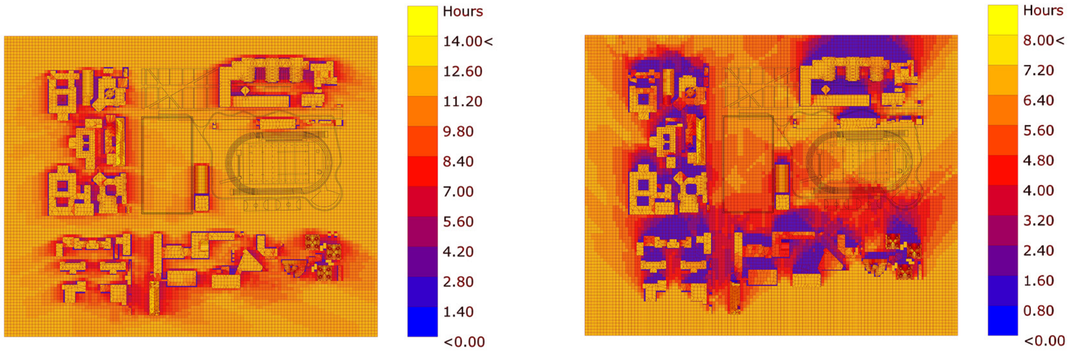
Figure 62: Development of Milan’s district heating system
Source: Djaheezah Subratty, 2017

To benefit from the incentives provided by the infrastructure charge reduction measure and as such switching from diesel oil boilers to other sources such as district heating is indirectly subsidized.

Milan has an ambitious plan for connecting its segregated nodal networks into one large network with a transmission ring around the city (figure#). As shown, the red, black, and blue lines represent network development as of 2014. The yellow line indicates the development in 2015. Orange and purple lines indicate future developments. Part of the district heating network in Milan, connected to the Canavese CHP plant. Milan's isolated network is being interconnected and expanded to form three large heating networks that will eventually be interconnected by the Ring City (Djaheezah Subratty, 2017).

Climate Analysis on Site:

Based on the sunlight analysis conducted using the Grasshopper platform, it is evident that the surrounding buildings have little shading impact on the site's interior. Therefore, the design con-siderations should primarily focus on the mutual shading between the buildings within the site. Additionally, during the summer season, specific attention should be given to shading issues (figure 63).



Sunlight Analysis on Summer Solstice

Sunlight Analysis on Winter Solstice

Figure 63: Sunlight analysis on site
Source: Simulate by grasshopper

Furthermore, based on the current site conditions, it could obtain recommendations regarding the optimal height of buildings within the site (figure 64) and the height of solar panels (figure 65). These recommendations aim to minimize mutual shading among buildings and enhance the efficiency of solar energy collection.

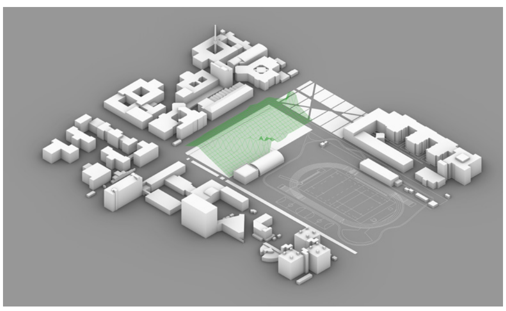


Figure 64: Solar right envelope
Source: Simulate by grasshopper

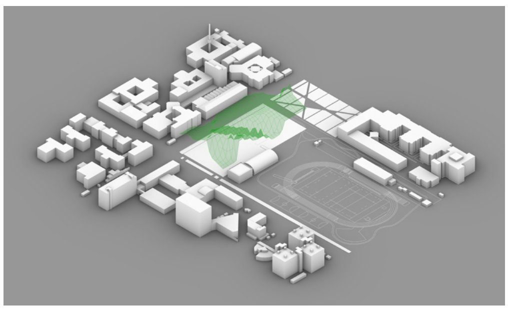


Figure 65: Solar collection envelope
Source: Simulate by grasshopper

3.1.3 Site surroundings analysis

The project site enjoys proximity to both the Politecnico di Milano and University of Milan campuses. The surrounding urban context forms a matrix, offering convenient transportation and comprehensive infrastructure, which includes supermarkets, bars, pharmacies, and more. Despite the vibrancy of the surrounding areas, there is a notable lack of connectivity between them (figure 66).

Figure 66: Urban context analysis
Source: by Author

The main crowded around the site consists of teachers and students from neighboring universities, creating a dynamic atmosphere enriched by the presence of numerous young individuals. This dynamic mix forms a solid foundation for invigorating the site's vitality (figure 67).

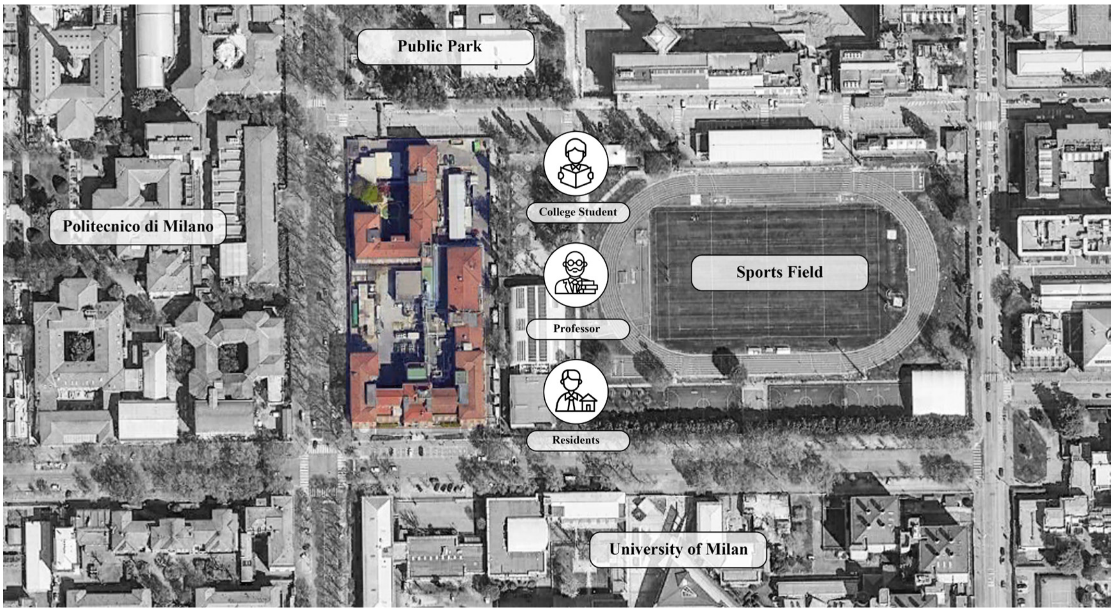
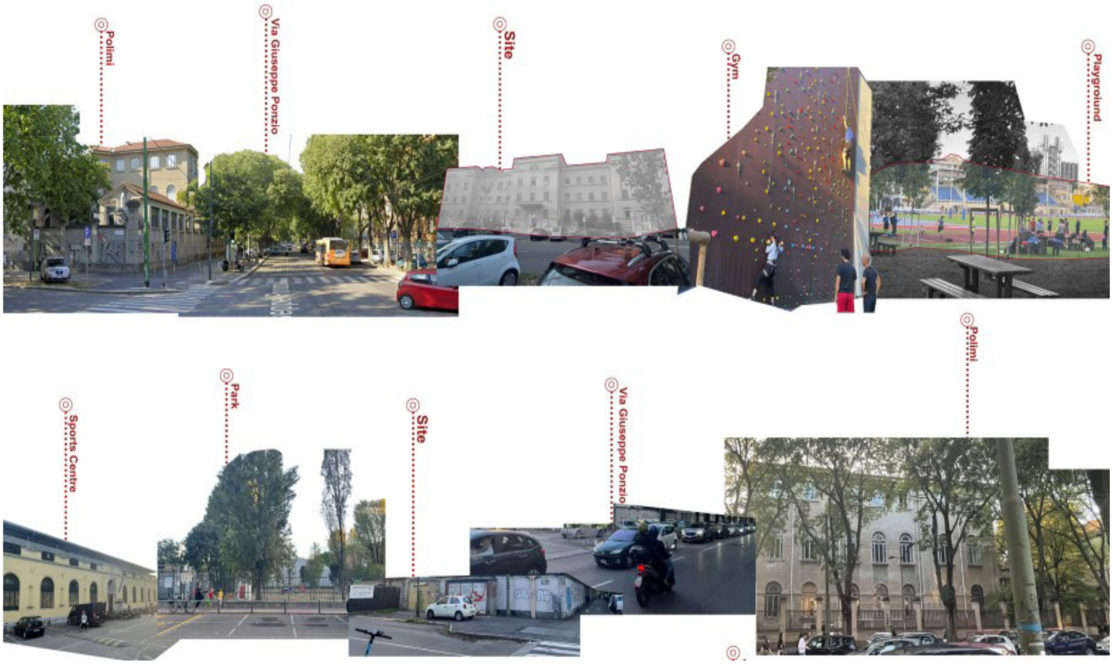


Figure 67: Surroundings and main crowded
Source: by author

By the street elevations (figure 68) we can observe various functions surrounding the site. To the north, a city park connected to the planned Politecnico di Milano campus, providing a tranquil space for relaxation and entertainment. On the eastern side of the site stands the Politecnico di Milano stadium, a place for student sports activities. Moving to the northeast, a children's park attracts children and families. Finally, the west and south sides of the site are dedicated to cultural and educational spaces.



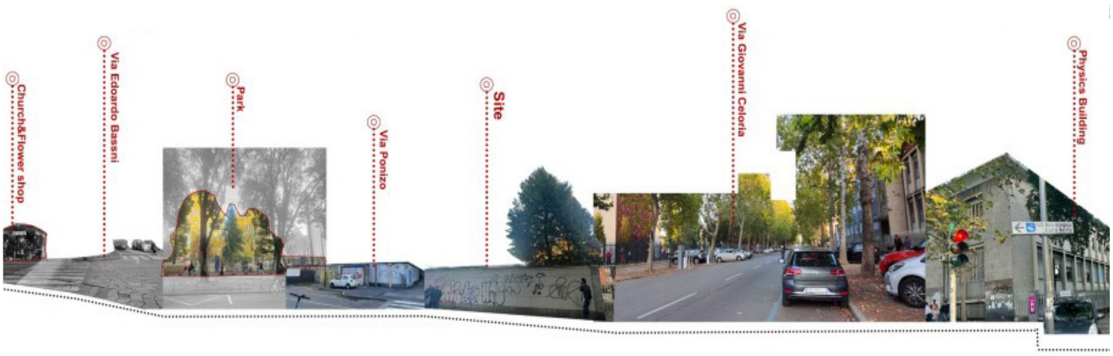


Figure 68: Street elevation around site
Source: by Author

Through the analysis of the urban context around the base, the surrounding green spaces are divided into the following types (figure 69):

Type1: Public urban park (such as the space on the north side of the site).

Type2: A large green space attached to a certain group of buildings.

Type3: Private courtyard surrounded by buildings.

Type4: Greening around roads and roads.

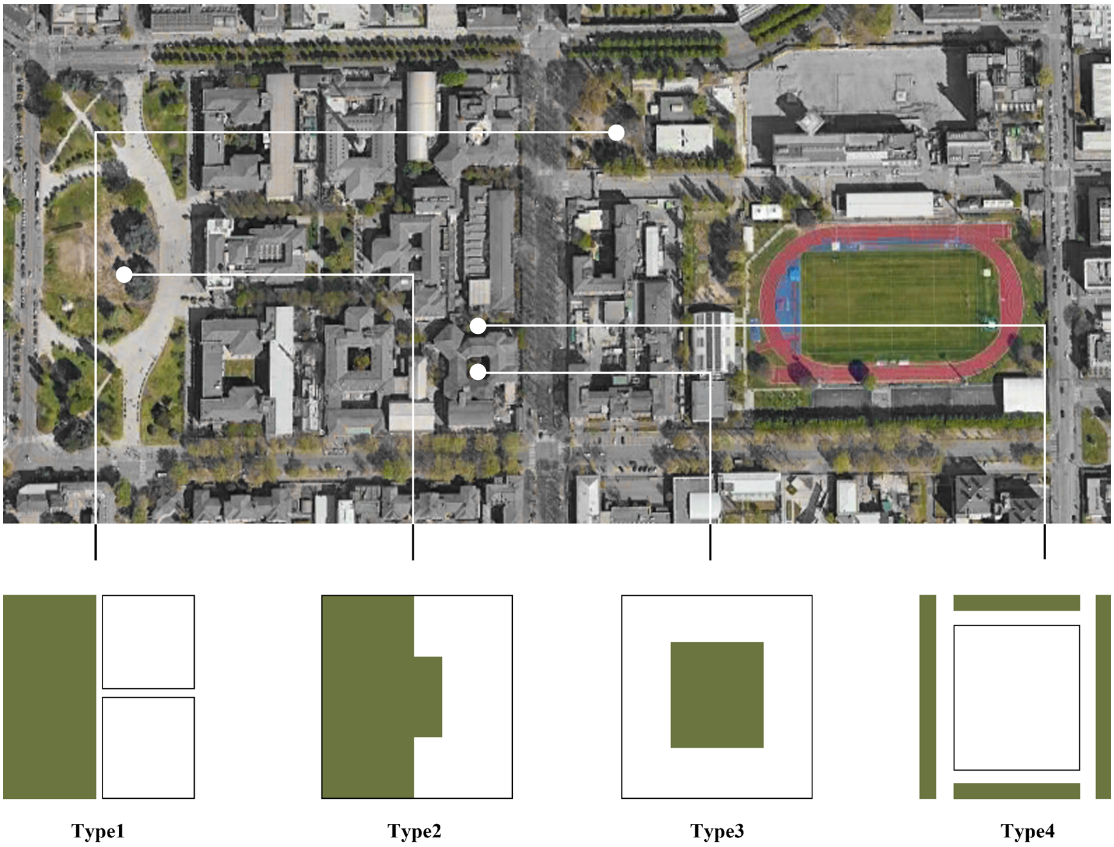


Figure 69: Green space around site
Source: by Author

3.2 The Context of College Students

3.2.1 Mental health challenges of college students

The growing prevalence and severity of mental health difficulties across student populations in higher education is an issue of significant concern for universities. University students are a 'high risk' population for mental health difficulties given that the prevalence of mental disorders is highest in the 16-24 year old age group. However, empirical studies suggest that young people undertaking university study may be experiencing higher levels of psychological distress than their age-matched peers in the general community (APS, 2014; Stallman, 2010).

With the rapid development of society and technology, contemporary college students spend more and more time indoors. As teens spend a lot of time on social media, they are having fewer face-to-face conversations and connections as they are all experiencing it online. According to the survey, 6.3% of the world's population is addicted to mobile phones, a large part of which comes from teens. Figure 70 shows the results of some college students' daily use of mobile phones. We can clearly see that a large part of college students spends more than 4 hours a day on their mobile phones.

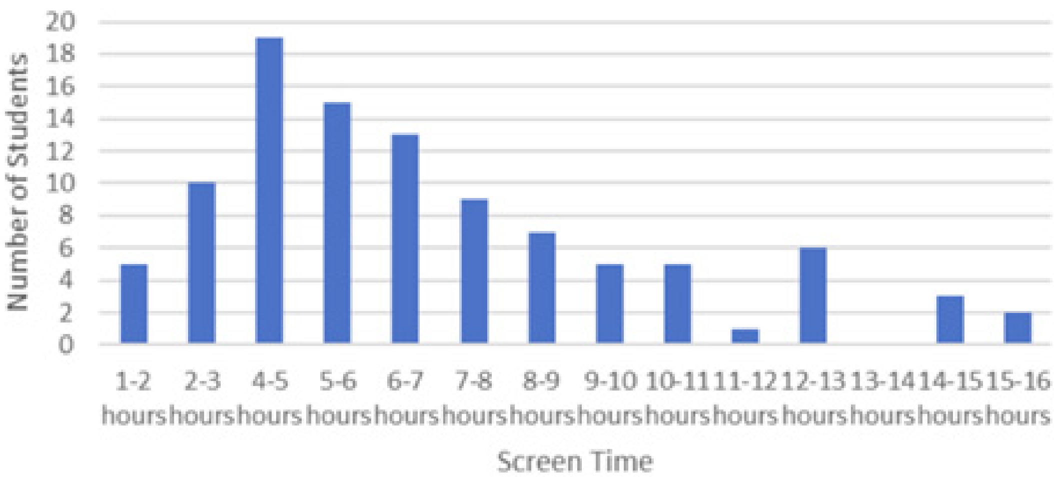


Figure 70: A Study of college Students Screen Time
Source: (Abd' Malik Hakeem-Olowu, Harrisburg University, 2022)

3.2.2 The effect of physical exercise on alleviating social anxiety

Anxiety is produced by the accumulation of adrenaline, but a certain intensity of aerobic exercise can consume the adrenaline of the human body, thus achieving the purpose of relieving anxiety. Regular exercise can not only help people keep fit and increase vitality, but also improve their appearance and build up self-confidence. What is more, during the process of exercising, exercise also helps to release the tension of anxiety, so that both the body and mind are greatly relaxed. As such, moderate physical exercise has a positive effect on relieving the anxiety of college students.

A research survey on physical exercise among college students shows that short-term exercise has no effect on alleviating anxiety, and only by cultivating long-term physical exercise habits can a good attitude be maintained. Because anxiety is not a short-term anxiety state, it exists in the personality structure of the individual for a long time.

However, in the survey (figure 71), it was found that half of the people in Italy basically do not like sports, and only a small number of people have good exercise habits. This is limited by various factors, such as the price of the gym is too expensive, there are not enough sports venues in the city, and the study and work are too busy, etc.

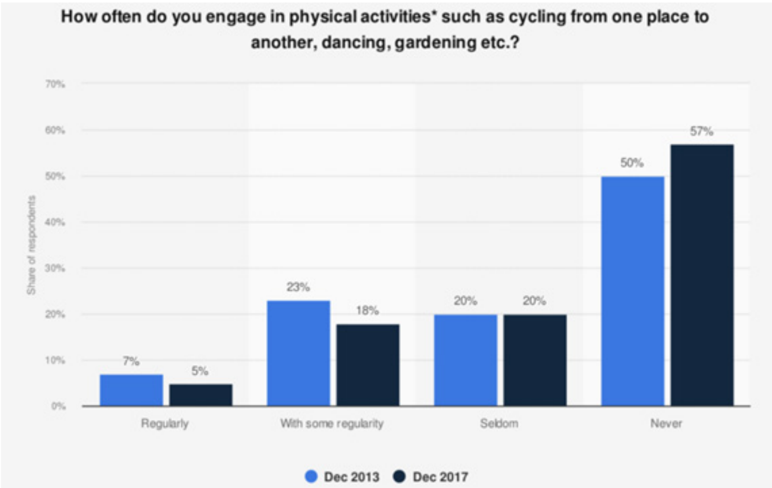


Figure 71: Frequency of exercise among some Italian populations
Source: Statista. 2022.

4. STUDENT COMMUNITY DESIGN IN CITTA STUDI

4.1 Initial Design

4.1.1 Issue and solution

The number of international and off-campus students applying for student accommodation has increased significantly over the years (figure 72). This has led to more and more students choosing to live in university dormitories to make their study and life more convenient. In this context, the construction of more student dormitories has also begun, and the problem is the establishment of an internal environment for these dormitories to serve the student population. One of the main issues students face when they are away from their hometowns is accommodation. The housing is the space where the communication of the individual environment is most strongly perceived. In student halls of residence, students with different habits, cultures and values come together to a community, student communities should be designed so that they can feel safe rather than isolated.

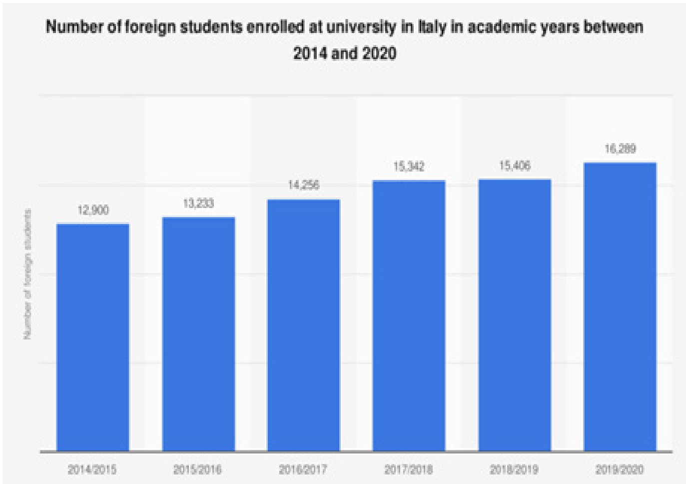


Figure 72: Growth trend chart of the number of foreign students studying in Italy
Source: Ministry of Education, University and Research, 2021

Through the thorough site analysis, we have identified the issue we faced: the absence of connectivity between different functional zones and the adjacent green spaces and The present lifestyle of college students often fosters anxiety.. Our project aims to address this issue by acting as a unifying element, fostering the vitality of the area and promoting a healthier lifestyle, to achieve this goal, we have to:

1. Develop an integrated space design that fosters a connection with surroundings
2. Through thoughtful spatial and functional arrangements create a space that supports anxiety relief.
3. Incorporate greener building practices to align with future development trends.

4.1.2 Design concept

Considering the current context surrounding the site (a city park to the north, cultural spaces to the west and south, and sports facilities to the east), our concept is designing a student community anchored by an enclosed courtyard that integrates sports, residential, cultural, and green spaces (figure 73).

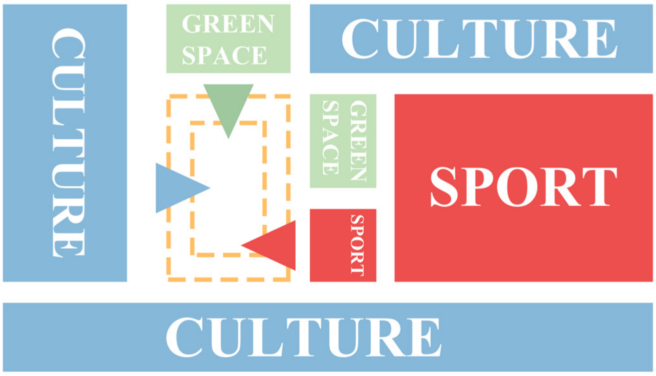


Figure 73: Design concept
Source: by author

Sport, both as a form of competition and a means of socialization, plays a pivotal role in our design. By introducing sports facilities, while fostering greater cohesion between the project and its surroundings, it will encourage communication among students, promote the cultivation of a healthier lifestyle, and contribute to the reduction of anxiety. The overall enclosed layout provides the basis for the transformation of space between public and private.

4.1.3 Project layout generation

According to the surrounding urban texture, determine the basic enclosure form and dimension of the building, and combine the campus of the Politecnico di Milano with the playground through the creation of open buildings to stimulate regional vitality. Finally, the building is varied according to different functional requirements (figure 74).

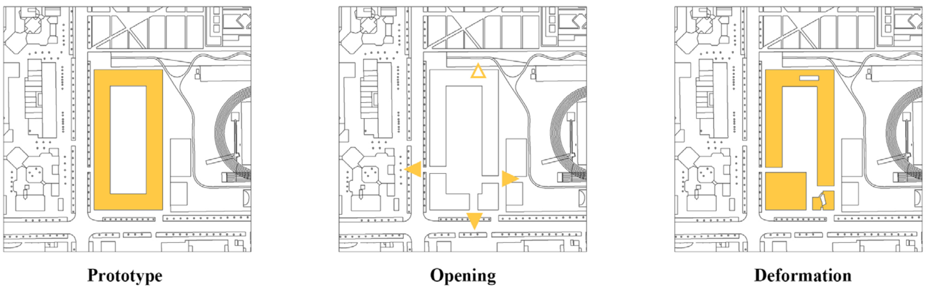
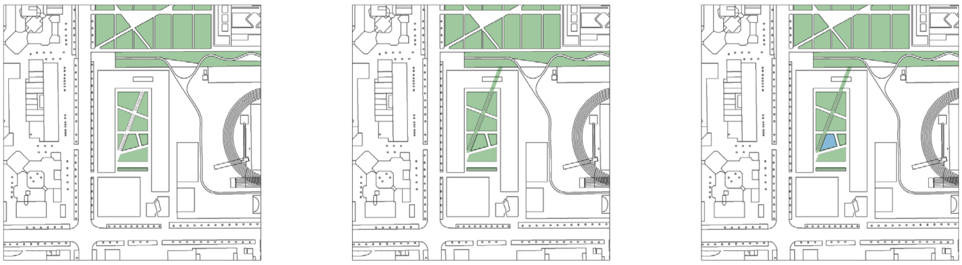


Figure 74: Building layout
Source: by author

In terms of landscape design, first extract the surrounding elements of the site to divide the landscape to achieve city continuity, then integrate the divided landscape with building, use bridges and sunken courtyards as connections between the building and the exterior. Finally, greenery is planted on Facade and part of the roof to achieve the continuous penetration of landscape (figure 75).

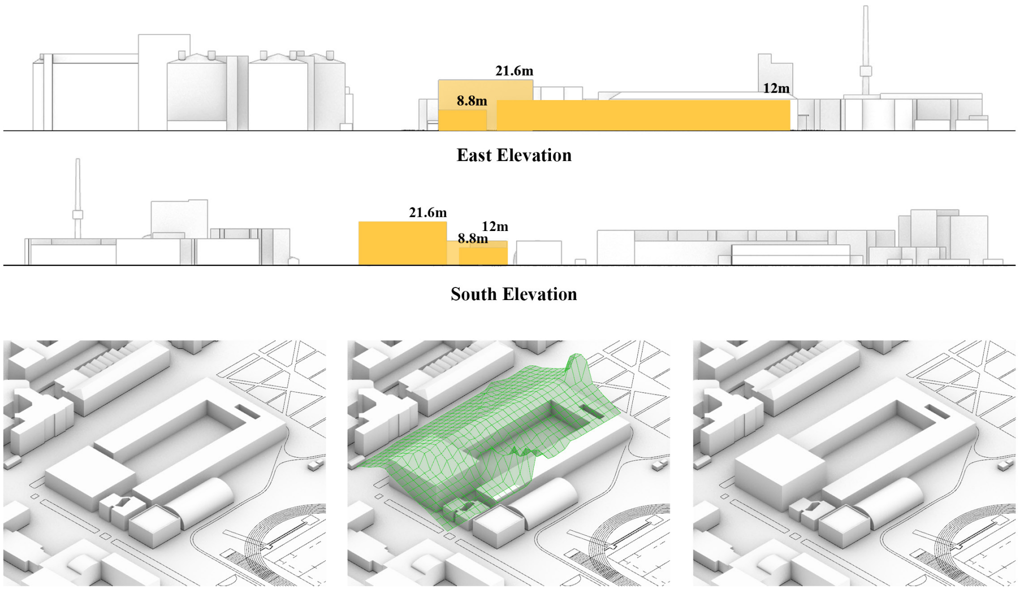


Axis **Connection** **Water Pool**

Figure 75: Landscape layout
Source: by author

4.1.4 Building height

After the basic building height is determined according to the surrounding buildings (12m), it is adjusted with reference to the value obtained by the grasshopper's solar benifit simulation. The maximum building height is 21m, and in order to enrich the spatial experience of the community, some buildings are reduced to 8.8 m, and this also makes the project more closely connected with the playground on the east side of the site (figure 76).



Basic Height **Simulate by Grasshopper** **Final Height**

Figure 76: Building height determination
Source: Simulate by grasshopper

4.1.5 Function

The student community is mainly divided into two functions: student housing and sport hub, to realize the richness of students' daily life. At the same time, some commercial spaces, service spaces, shared spaces, etc. are also interspersed in the community to connect various functions and stimulate vitality (figure 77).

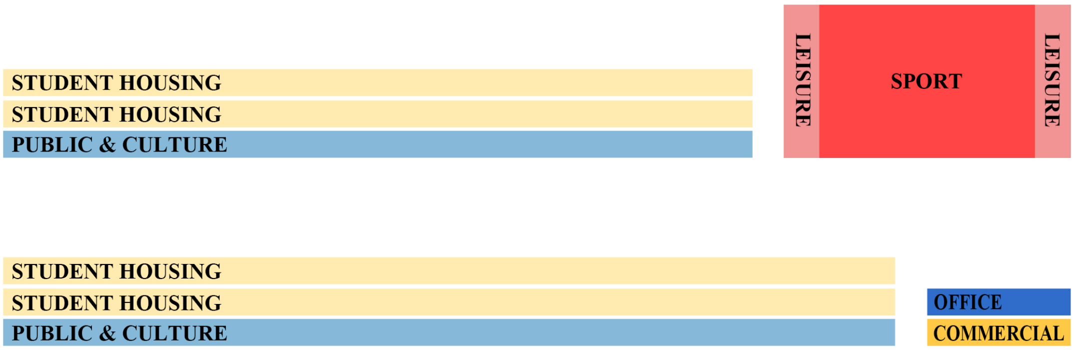


Figure 77: Growth trend chart of the number of foreign students studying in Italy
Source: Ministry of Education, University and Research, 2021

According to the sunlight analysis of the existing building layout, the landscape is divided into different functions according to the difference in sunlight hours in summer and winter, such as planting areas with sufficient sunlight, summer park with shading in summer, and outdoor exhibitions with insufficient sunshine hours in winter. The rainwater collection park for rainwater collection, in addition, the pool is also introduced into the landscape to regulate the local microclimate of the community (figure 78).

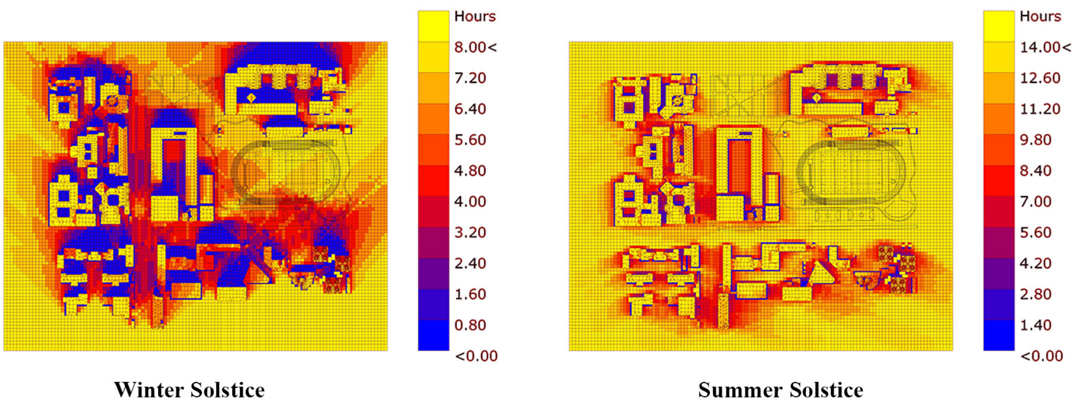


Figure 78: Growth trend chart of the number of foreign students studying in Italy
Source: Ministry of Education, University and Research, 2021

4.2 Technical Drawings

4.2.1 Masterplan

The building serves as both a complement and an extension to its surrounding functions. it primarily serves as student housing but also includes a sports facility in the lower left corner and commercial/office space in the lower right corner. The primary building entrance is located on the northern side, featuring a sunken square for added appeal. This entrance acts as a gateway, connecting the city park and the internal courtyard of the building via a bridge. To cater to various needs, additional secondary entrances are strategically positioned in other directions of the building, serving as access points for both the main flow of people and logistical support, with a notable entrance on the east side (figure 79).

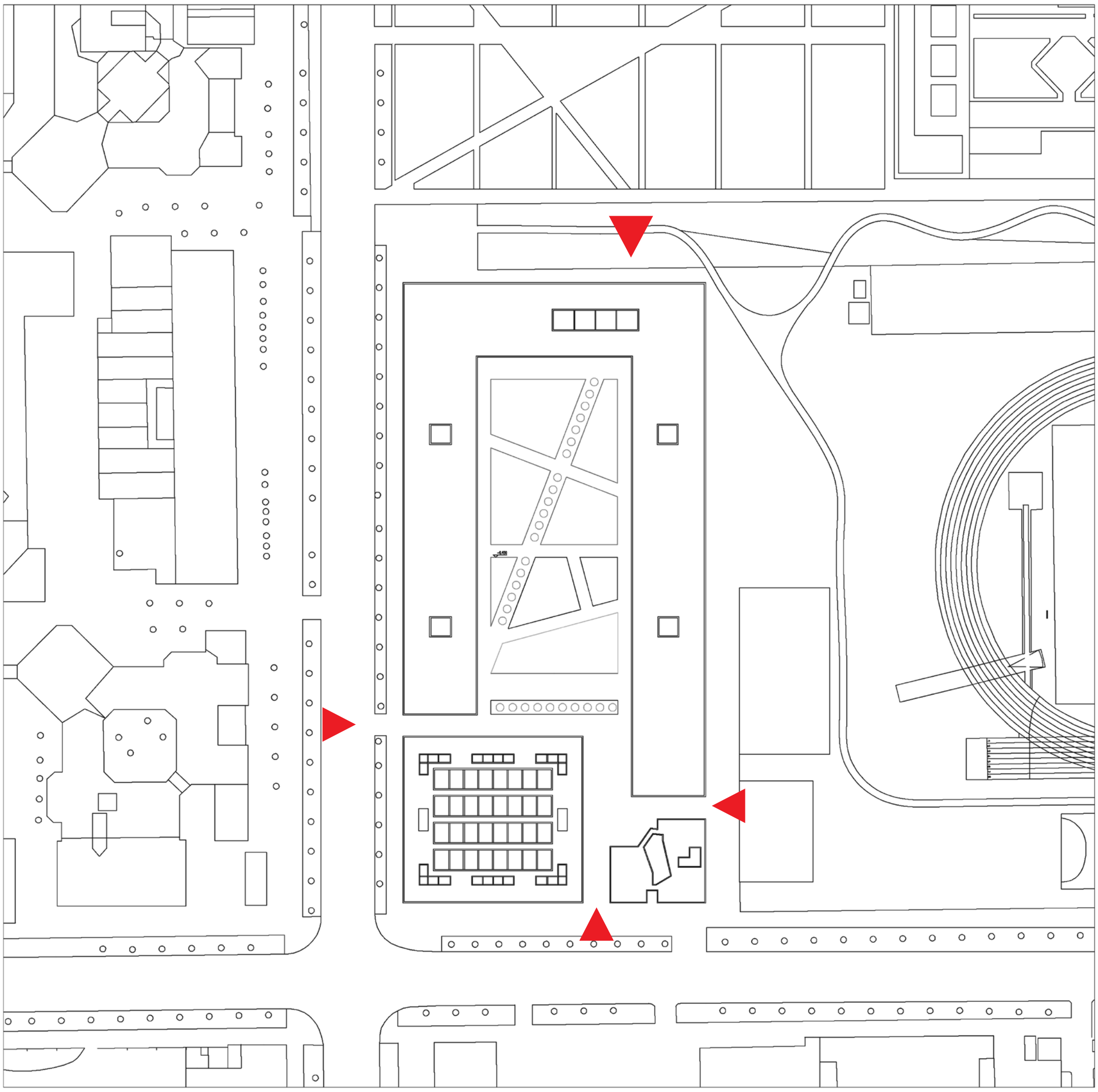


Figure 79: Masterplan
Source: by Author

4.2.2 Plan

Ground floor plan

The main function of ground floor is public share space and workshop. The building's interior and exterior are connected through corridors, offering users a diverse and immersive spatial experience that blends indoor and outdoor elements (figure 80).

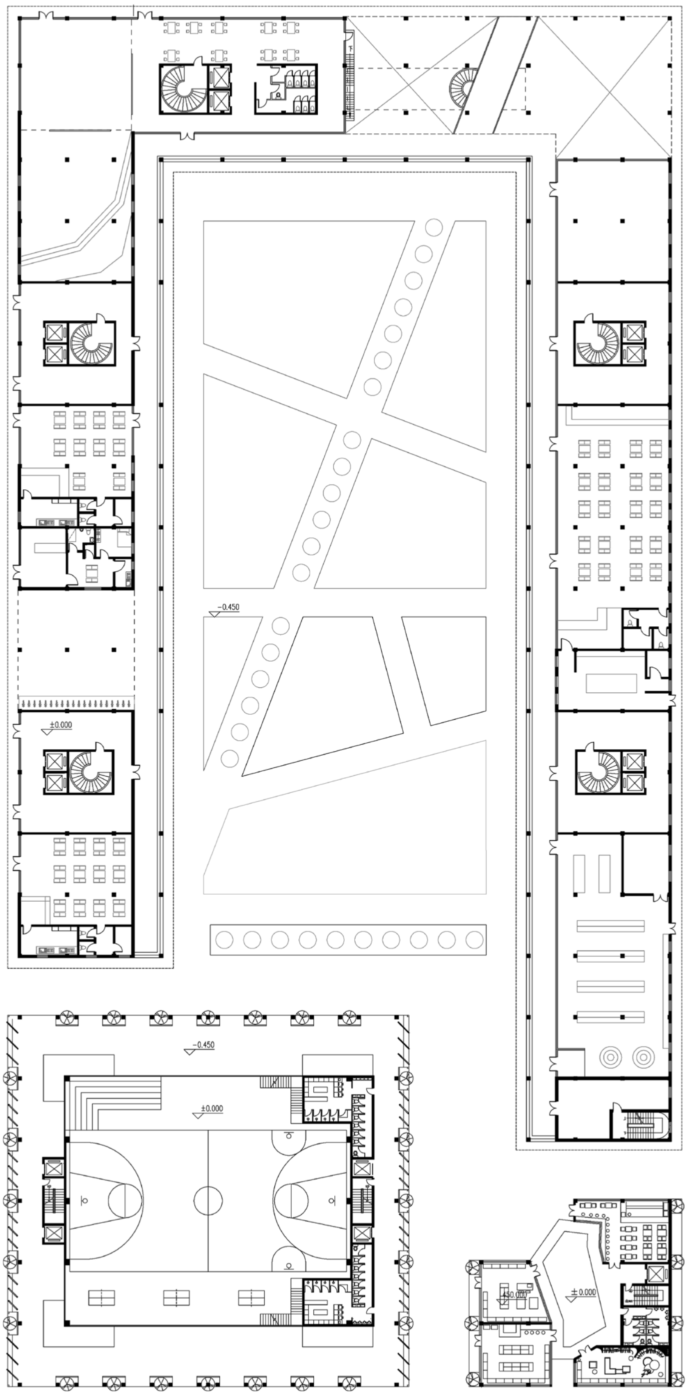


Figure 80: Ground floor plan

Source: by Author

First floor plan

The first floor is mainly for single-room student housing and share space. The interspersion of public spaces provides better lighting and ventilation for rooms with a single corridor layout (figure 81).

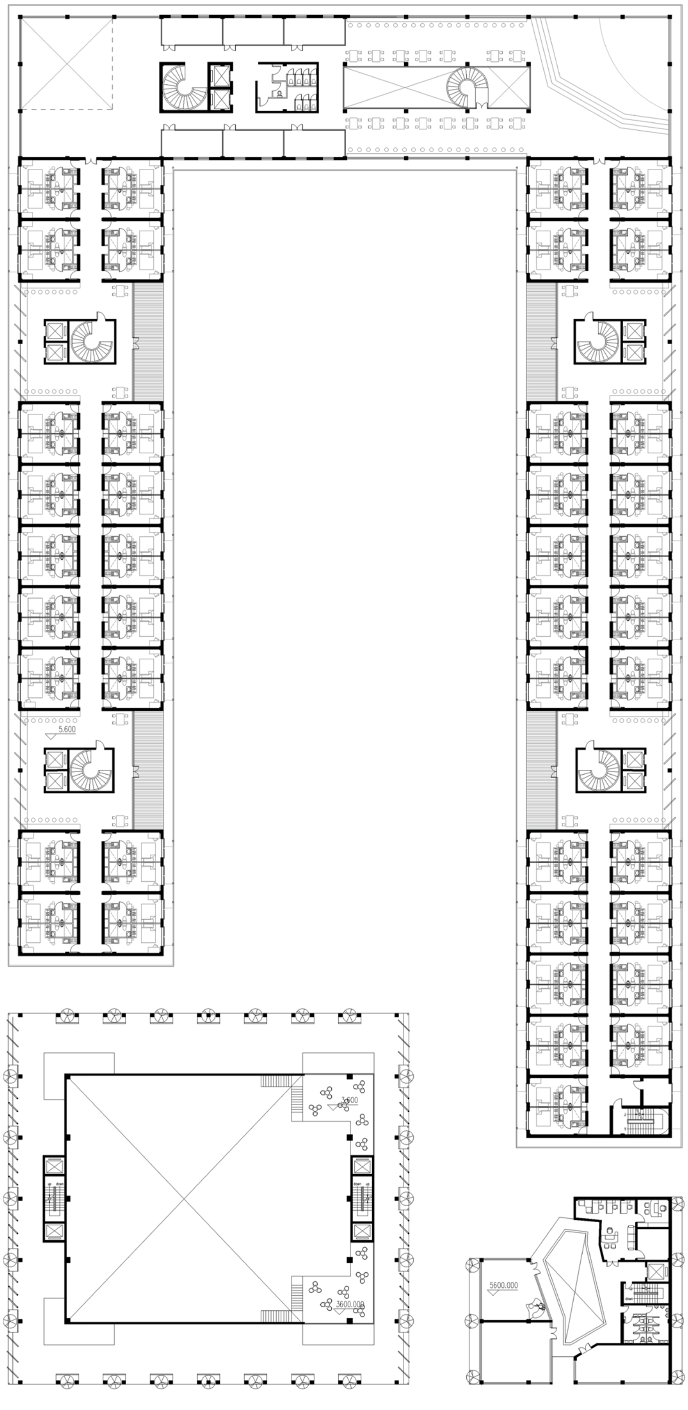


Figure 81: First floor plan
Source: by Author

Second floor plan

The main function of the second floor is a three-room student housing. The space layout is more intensive, and the lighting and ventilation of the space are still achieved through the public space interspersed therein (figure 82).

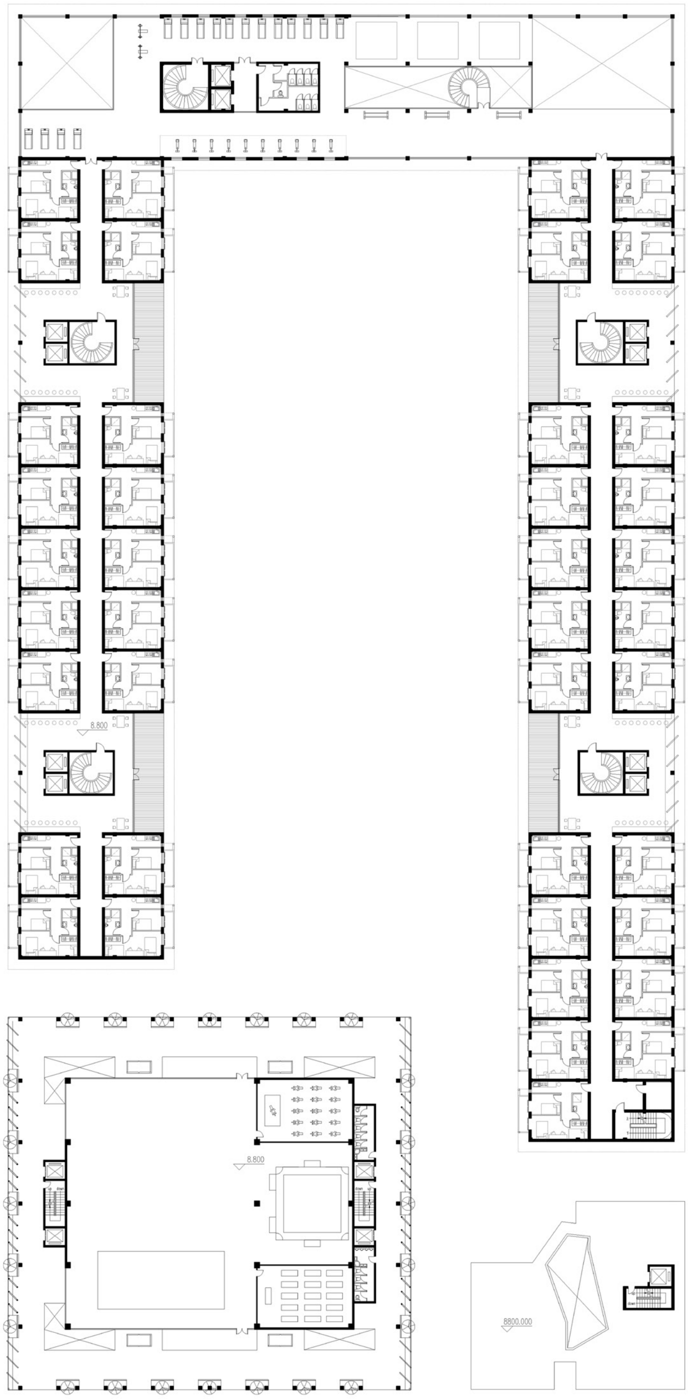


Figure 82: Second floor plan
Source: by Author

Student housing - single room

Two single-room student housing are arranged side by side in groups to achieve optimal water supply and drainage efficiency. Every two rooms are equipped with a shared balcony. The glass sliding door on the balcony increases the indoor lighting area in winter, and Sun shading in summer is achieved by canvas blinds (figure 83).

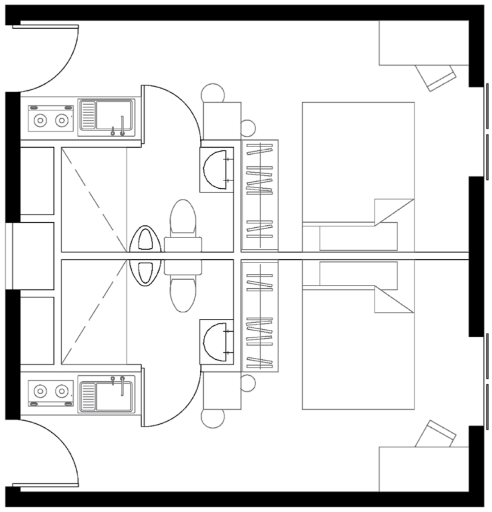


Figure 83: Single room plan
Source: by Author

Student housing - double room

The three-person student housing contains a single room and a double room. The balcony is shared by three people. The lighting in the corridor is improved by the opening of the kitchen window (figure 84).

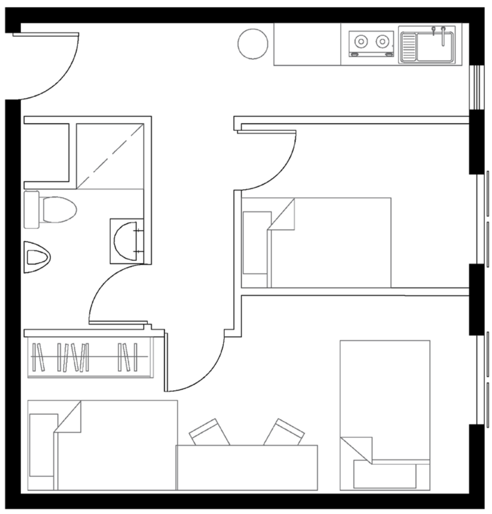


Figure 84: Triple room plan
Source: by Author

Sport center

The sports building structure adopts a long-span wooden structure. In terms of functional layout, the center is a basketball court, and other spaces that require large spans are surrounded by small leisure spaces (figure 85, 86).

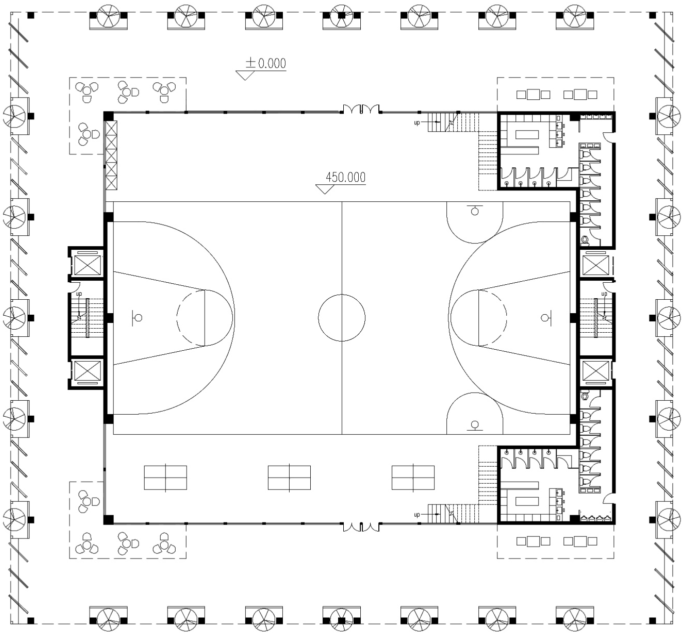


Figure 85: Sport center - Ground floor
Source: by Author

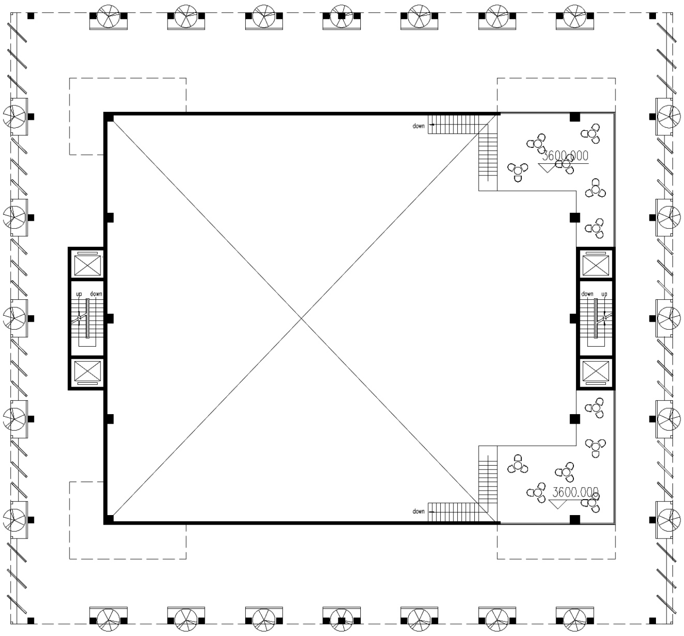


Figure 86: Sport center - Second floor
Source: by Author

The first floor of the sport center is a large-span space with a mezzanine. The upper floors are used for badminton courts, and the lower floors are arranged with boxing rings, bouldering climbing gyms, yoga rooms, etc. The leisure space on the periphery of the mezzanine is set up as a gym. The interweaving of various spaces provides a better way for visual interaction. Many possibilities (figure 87, 88).

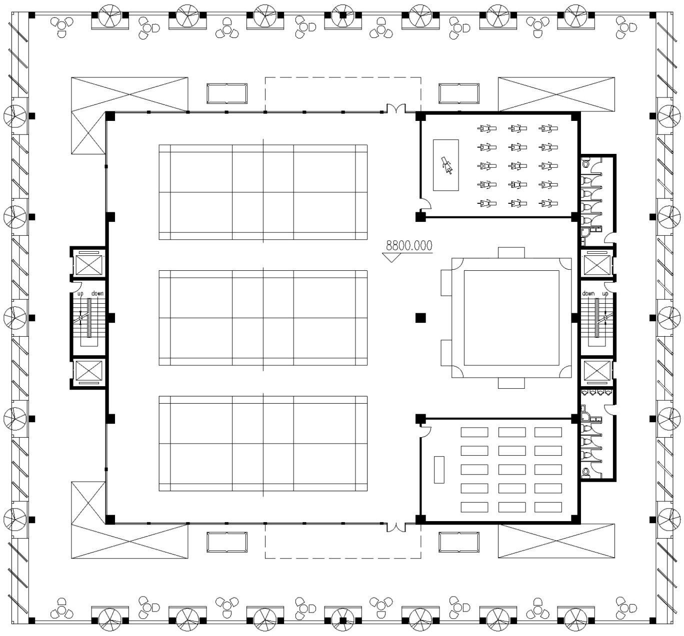


Figure 87: Sport center - Third floor
Source: by Author

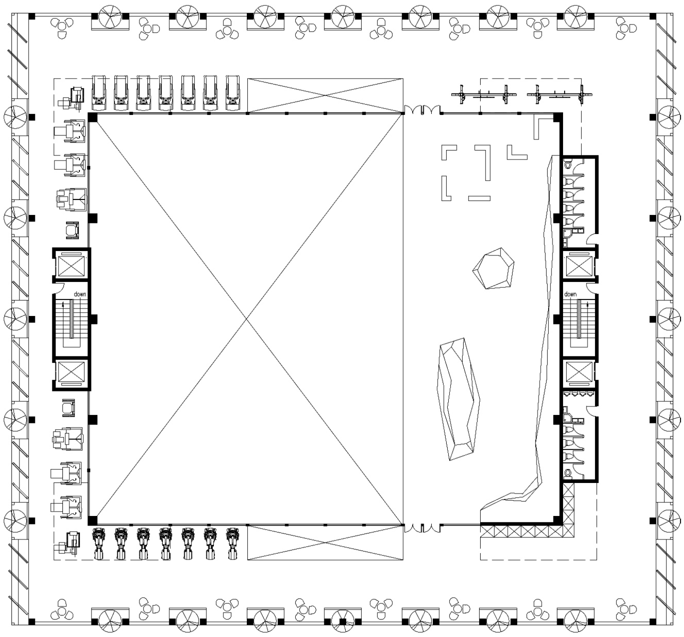


Figure 88: Sport center - Fourth floor
Source: by Author

4.2.3 Facade

The facade of the building is composed of steel frame, arranged with a series of plant niches, which realizes the continuation of green space from the ground to the facade. The extended balcony not only enriches the light and shadow of the facade, but also plays a horizontal sunshade role (figure 89, 90, 91).

Figure 89: West Elevation
Source: by Author

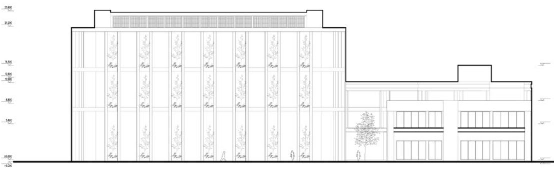


Figure 90: South Elevation
Source: by Author

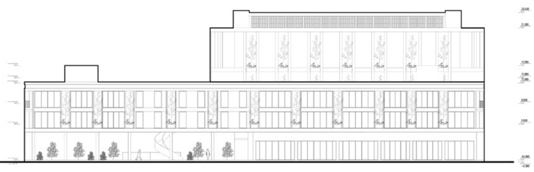


Figure 91: North Elevation
Source: by Author

4.2.4 Section

Most of the structure of the student community is a beam-column wooden structure, and the sport center part is a long-span wooden structure combined with shear walls. The interspersed full-height spaces improve the overall ventilation of the building through the chimney effect, and also strengthen the visual connection between the indoor spaces on each floor (figure 92, 93, 94, 95).

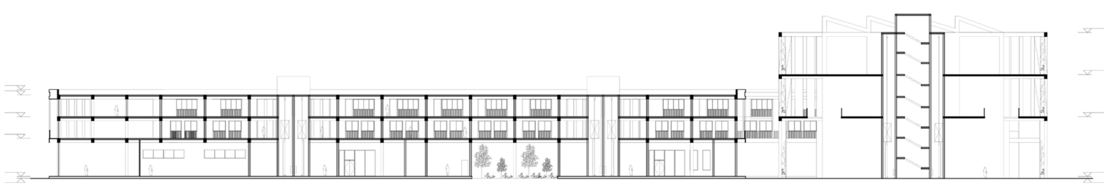


Figure 92: 1-1 Section
Source: by Author

Figure 93: 2-2 Section
Source: by Author

Figure 94: 3-3 Section
Source: by Author

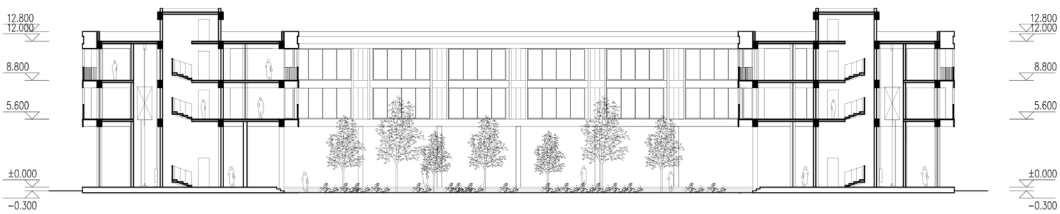


Figure 95: 3-3 Section
Source: by Author

4.2.5 Detail drawings

The main structure of the building is a wooden structure, and the material layout of the walls, floors, and roofs refers to the U-value required by Italy. The external steel frame is connected to the wooden structure in the form of riveting, and the roof drainage system is connected to the water collection pipe for rainwater collection (figure 96).

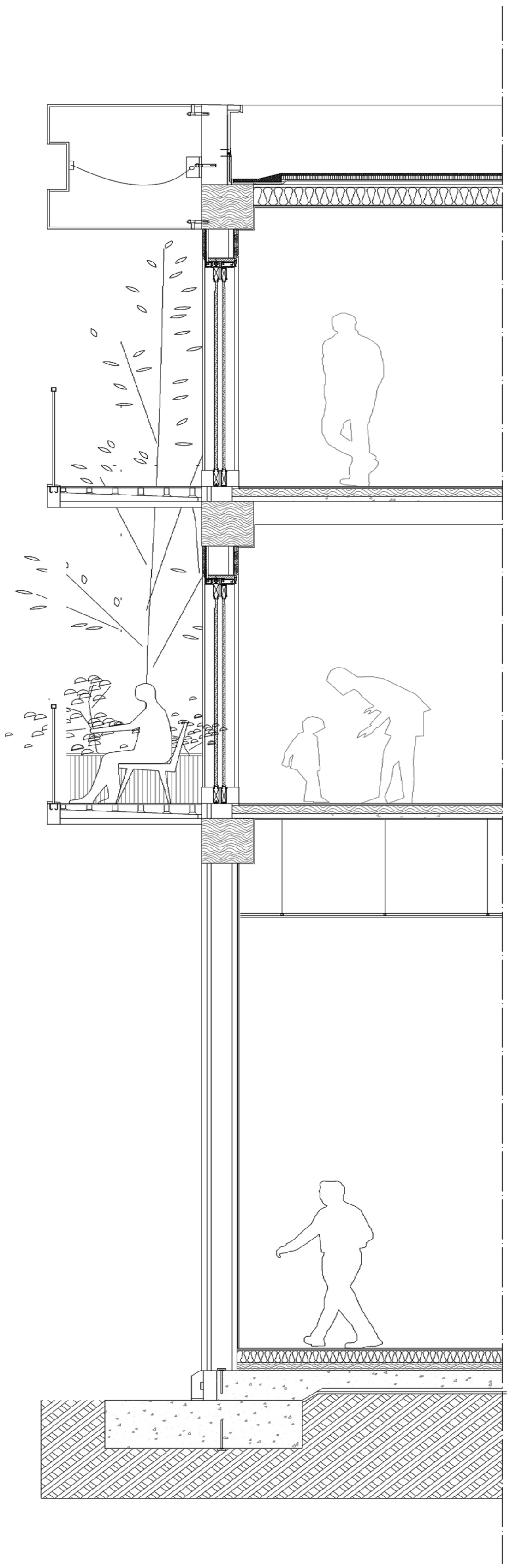


Figure 96: Facade detail drawings
Source: by Author

4.3 Rendering

4.3.1 Exterior rendering

The building has an enclosed layout that integrates with the surrounding area. The plant niches on the facade realize the continuation of the green space (figure 97, 98).

Figure 97: Overview rendering
Source: by Author

Figure 98: Facade
Source: by Author

The large courtyard in the middle serves as a connector between the site and the surrounding areas, providing a leisure space and absorbing part of the carbon dioxide. The waterscape in the courtyard not only assists in rainwater collection, it also plays a role in regulating the microclimate. The colonnade around the courtyard realizes the transition between indoor and outdoor spaces and provides shade space in summer (figure 99, 100).

Figure 99: Courtyard water pool
Source: by Author

Figure 100: Courtyard
Source: by Author

4.3.2 Interior rendering

The entrance on the north side of community is transitioned by a sunken courtyard, and a bridge along the dividing axis of the city park connects the community with city (figure 101).

Figure 101: Sunken courtyard
Source: by Author

The main function inside the community is student housing, with good lighting and shared balconies. The main material is CLT wooden boards (figure 102).

Figure 102: Single room
Source: by Author

The primary structure of the sports center consists of a long-span timber framework with shared walls to accommodate expansive areas such as basketball and badminton courts. Additionally, smaller spaces are strategically arranged around the larger ones, creating a staggered layout (figure 103, 104).

Figure 103: Basketball court
Source: by Author

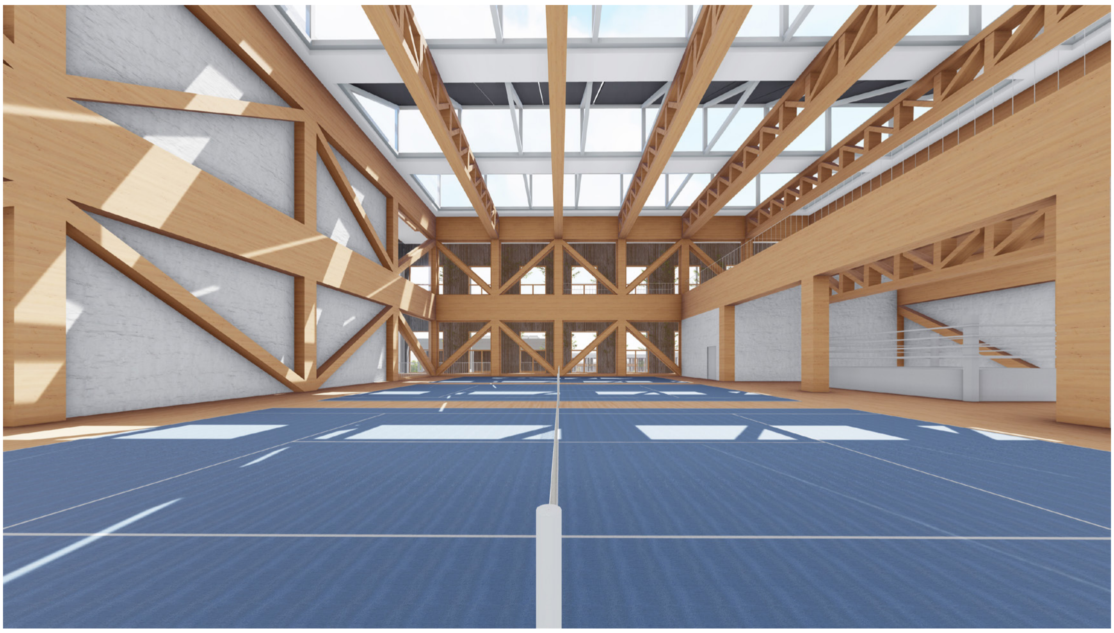


Figure 104: Badminton court
Source: by Author

In the east-west orientation of the sports center, a rotating shading system has been incorporated. The corridor not only provides glimpses of the expansive interior space but also serves a dual purpose as a fitness and leisure area (figure 105).

Figure 105: Corridor in sport center
Source: by Author

5. SUSTAINABLE SYSTEM DESIGN IN STUDENT COMMUNITY

5.1 Material Selection

5.1.1 Structure

The project uses the cross laminated timber structure as the main material. The timber structure has the advantages of environmental protection, great thermal insulation performance, and excellent earthquake resistance. The Structural Timber Association had a research said that substituting timber for steel structures can reduce global carbon content by 20%.

Julie Hansted Andersen made a comparison between CLT(cross laminated timber) and concrete buildings, they found that CLT buildings scored lower in environmental negative impact than concrete buildings in 11 of 18 categories. It showed CLT buildings contribute much less to global warming and increased use of CLT in construction, rather than commonly materials such as concrete, can help mitigate climate change.

Cross-laminated timber (CLT) is a structural two-way spanning solid wood panel product that can be used to form wall, roof, and floor panels. It is produced by stacking several layers of timber, known as lamellas, at 90o to the layer below and subsequently glued to create panels of up to 24 meters in length and 2,950mm in width, which can encompass between three and seven layers. Each floor uses 400*400 wooden load-bearing elements to form a structural grid of 5m*6.5m.

5.1.2 Wall

The wall is composed of prefabricated wooden skeleton elements. The insulation layer (figure 106) uses 160mm thick AGEPAN Flex, an environmentally friendly insulation material, which can effectively adapt the building to the extreme climate of Milan and meet the U-value standard of EU buildings for walls (table 5). An air layer and a waterproof membrane are installed near the insulation for drying. The external surfaces of the walls will be protected by a cladding of 40mm thick spruce slats that have been heat-treated and fire retardant treated. In front of the wall is a 1.2-meter-deep steel frame, and the balconies are stacked two by two and separated from adjacent balconies by 6-meter-high plant niches. In order to create a suitable indoor light environment, the wall is equipped with a large area of Low-E glass. Low-E glass can not only keep heat but also insulate heat, and it can also reduce the carbon. (Using Low-E glass, due to the reduction of heat loss, can greatly reduce the fuel consumption for heating, thereby reducing carbon emissions).

#	Material	Dicke [cm]	λ [W/mK]	R [m²K/W]
	Thermal contact resistance inside (Rsi)			0,130
1	Fermacell Gypsum Fibre Board 10mm	1,00	0,320	0,031
2	Breather membrane sd=0,1m	0,05	0,500	0,001
3	Cross Laminated Timber	4,00	0,130	0,308
4	AGEPAN Flex	16,00	0,038	4,211
5	Breather membrane	0,05	0,500	0,001
	Thermal contact resistance outside (Rse)			0,130

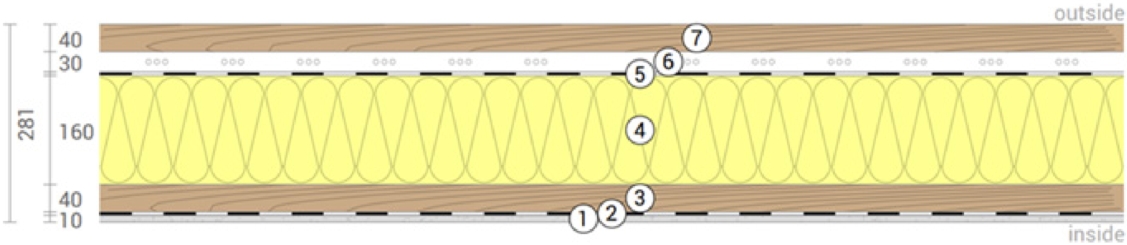


Figure 106: Material selection of external wall
Source: Simulate by Ubakus

Elements /Components	Validity period	Thermal transmittance U [W/m².k] (including thermal bridges)				
		Climatic Zone				
		A and B	C	D	E	F
Envelope – walls	From 2015	0.42	0.36	0.32	0.28	0.26
	From 2019/2021	0.38	0.32	0.28	0.24	0.22
Envelope – roofs	From 2015	0.36	0.36	0.28	0.25	0.23
	From 2019/2021	0.34	0.34	0.24	0.22	0.20
Envelope – floors	From 2015	0.46	0.40	0.32	0.30	0.28
	From 2019/2021	0.42	0.36	0.28	0.26	0.24
Doors, windows and shutter boxes	From 2015	3.20	2.40	2.00	1.80	1.50
	From 2019/2021	3.00	2.20	1.80	1.40	1.10
Indoor partitions	From 2015	0.80	0.80	0.80	0.80	0.80
	From 2019/2021	0.80	0.80	0.80	0.80	0.80
		Total solar energy transmittance g_{gl+sh} [-]				
		A and B	C	D	E	F
Windows with shading devices	From 2015	0.35				
	From 2019/2021					

Table 5: Reference building - Performance of single building elements
Source: EPBD implementation in Italy, 2018

5.1.3 Roof

The roof ceiling element (figure 107) is paved with 50mm thick foam concrete, and 40m thick laminated panels are used as sound insulation layer. In terms of insulation, 180mm thick AGEPAN Flex insulation layer is used to make the whole roof meet the latest EU roof Insulation standard. The ceiling is made of spruce wood so that users can personally feel that they are in a wooden structure building (figure 108).

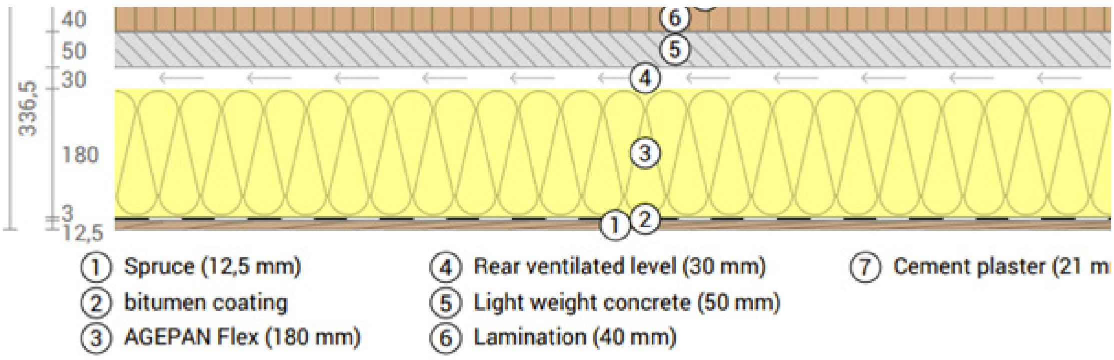


Figure 107: Material selection of roof
Source: Simulate by Ubakus

Figure 108: Material of interior space
Source: By author

At the same time, we analyzed the material life cycle of building walls and roofs, and the materials of this project extract more greenhouse gases from the atmosphere than they produce (figure 109).

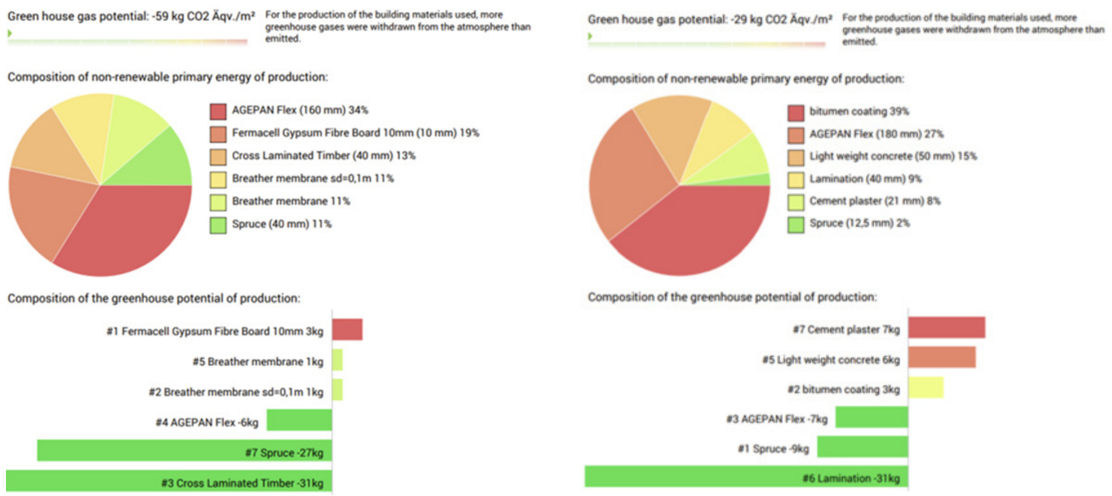


Figure 109: Material analysis
Source: UrbanNext, 2023

5.1.4 Embodied carbon reduction

Embodied carbon refers to the carbon emissions associated with the entire life cycle of building materials, from extraction and manufacturing to transportation and construction. To achieve net-zero carbon buildings, our project choose materials that are readily available in the region to reduce transportation-related emissions. At the same time, wood and steel are also materials that are easily recycled and reused (figure 110).

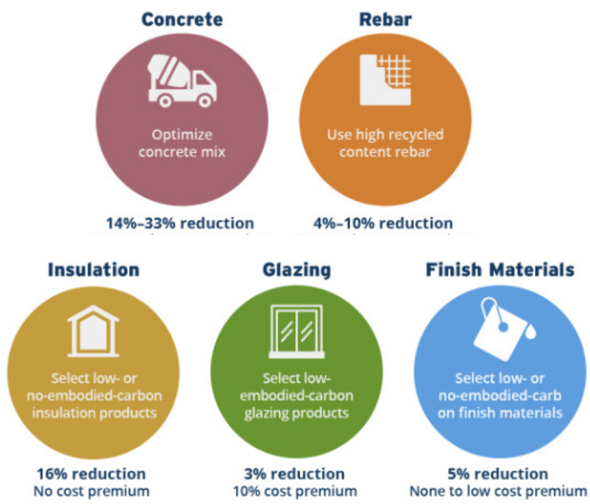


Figure 110: Ways to reduce embodied carbon
Source: Mills, R. 2023.

5.2 Sustainable Facade Design

5.2.1 Steel frame with plant niche

The building's facade features a 1.2-meter-deep steel frame that extends outward from the structure, which serves a dual purpose, offering both practical functionality and aesthetic appeal (figure 111).

Firstly, it acts as an overhanging platform, providing horizontal sunshade for the building's interior spaces. Enhancing energy efficiency by reducing the amount of direct sunlight that enters the building while creating a play of light and shadow on the facade.

Additionally, the steel frame serves as a thermal buffer, helping to regulate the building's temperature. By deflecting the sun's rays and reducing heat gain, it contributes to a more comfortable indoor environment, while also reducing the building's reliance on energy-intensive cooling systems.

The true standout features of this façade are the plant niches that adorn the entire length of the

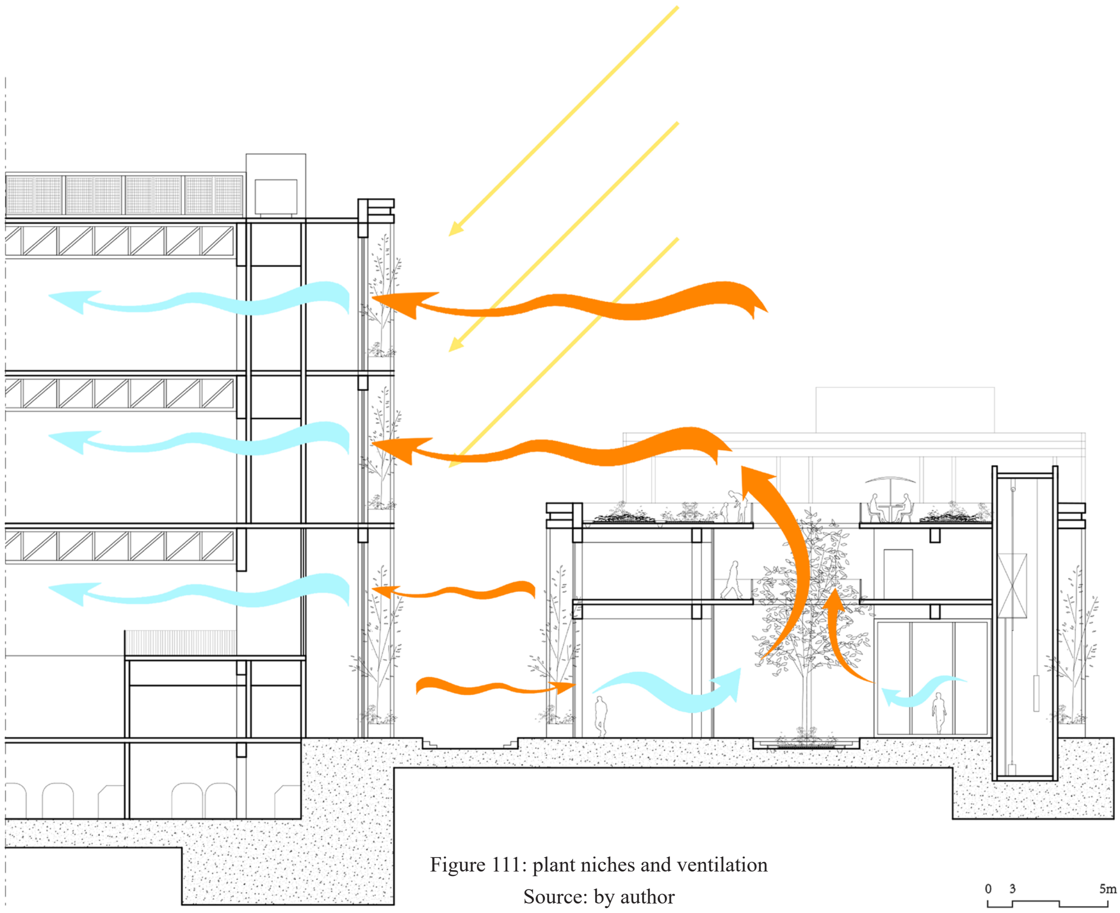


Figure 111: plant niches and ventilation
Source: by author

Figure 112: Plant niches on facade
source: by author

steel structure. These niches are thoughtfully integrated into the facade, seamlessly blending nature with architecture. Each niche houses a thriving ecosystem of greenery, including multi-trunked trees, lush shrubs, aromatic herbs, and swaying grasses. they function as vertical sunshades, casting dappled shadows on the building's exterior, further enhancing its energy efficiency by providing natural shade. Also, it act as particulate filters, helping to purify the air by trapping dust and pollutants, contributing to a healthier urban environment. Moreover, these plant niches are ingeniously integrated with a rainwater recycling system, excess rainwater is collected and channeled to create small, sustainable floating gardens within the niches.

The eastern and western facades of the student housing complex showcase a arrangement of balconies, each organized in pairs and punctuated by plant niches. This architectural composition not only adds a touch of aesthetic finesse but also serves multiple practical purposes (figure 112).

The transparent balcony doors and windows are meticulously designed for flexibility, allowing residents to adapt their living spaces to the ever-changing environmental conditions. Whether it's a gusty wind, inclement weather, or external noise disturbances, these adaptable openings ensure the structural integrity of the building and the comfort of the apartments' external spaces.

The combination of canvas shutters and horizontal sunshades constitutes the primary methods of sun protection within this facade. These elements work in harmony to shield the interior spaces from the harsh sun's rays. The canvas shutters can be adjusted to provide shade when needed, further enhancing the comfort and usability of the balconies and windows.

In this context, the facade serves a multifaceted purpose, functioning not only as an outdoor area and privacy barrier but also as a shading mechanism and ecological demarcation. These combined roles play a vital function in regulating the overall comfort of the interior spaces (figure 113).

Figure 113: Sunlight analysis of rotate shading
Source: Simulate by grasshopper

5.2.2 Dynamic facade shading system

To seamlessly address the sustainable, functional, and aesthetic aspects of the building's design, the eastern and western facades incorporate a remarkable and dynamic rotating shading system, which known as Motion H, has been developed by Kinetic Facades.

The Motion H shading system is characterized by individual sashes that pivot around a vertical axis. These sashes are not only visually captivating but also highly functional. They offer the flexibility of independent operation, which can be achieved effortlessly through either powered mechanisms or manual control. This adaptability ensures that the shading system can cater to the specific needs and preferences of the building's occupants.

Each of these sashes can handle window frames up to 2m wide and 5m high, ensuring a seamless integration with the building's exterior. The shading system's design seamlessly blends with the external cladding, enhancing architectural coherence.

An advantage of this system is its compactness. The track is just 60mm deep, with a mounting depth of 150mm. This makes it ideal for urban spaces where space is limited. Furthermore, Motion H operates with a hidden track, preserving the building's clean and minimalist facade aesthetic.

Managing the shading system is an effortless and convenient experience. Residents can control it through either a wall switch or a remote control, offering both individual and group control modes. This flexibility empowers residents to tailor their shading preferences to the changing weather and lighting conditions, ensuring optimal comfort within their living spaces.

The main material of the sunshade is aluminum composite panel, supplemented by frosted glass. This configuration allows the soft diffusion of natural light while meeting the needs of privacy protection and daylighting. The flexibility is in perfect harmony with the overall aesthetic of the building, combining function and style (figure 114).

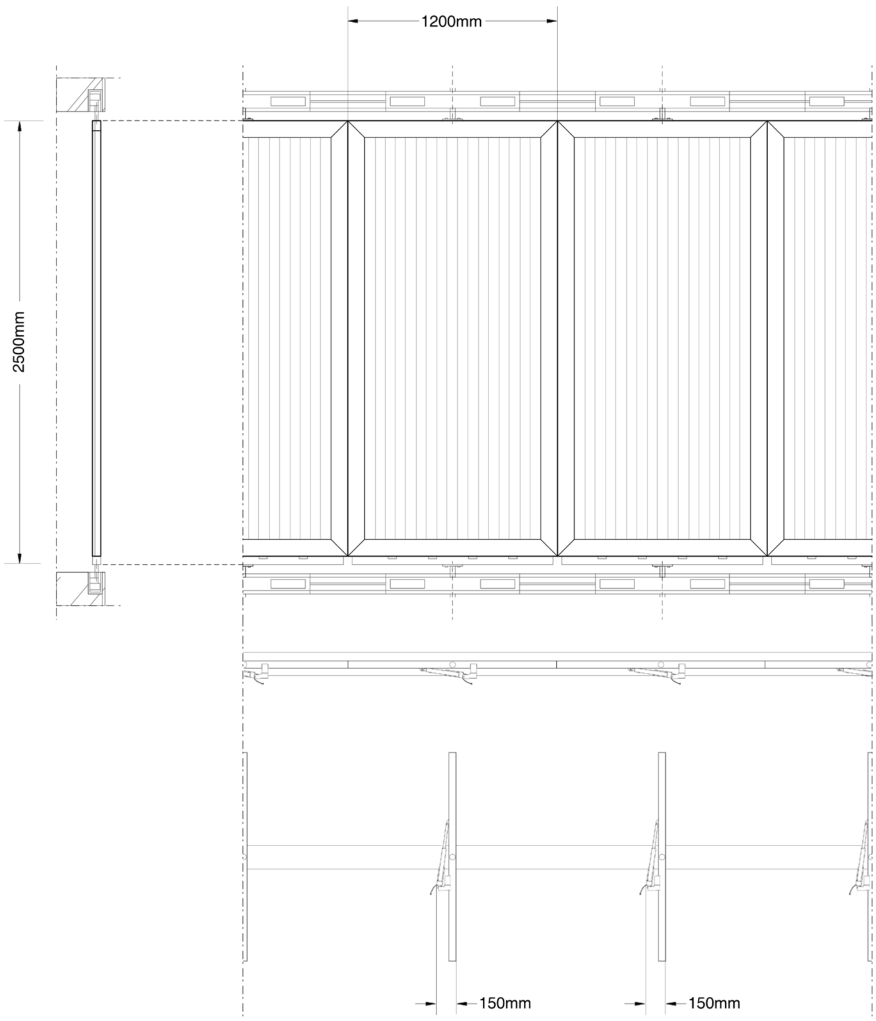
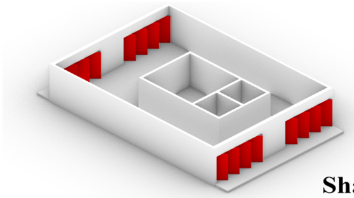
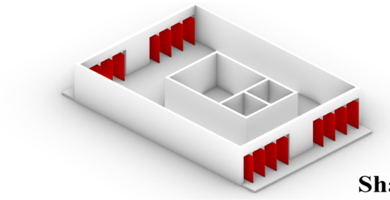


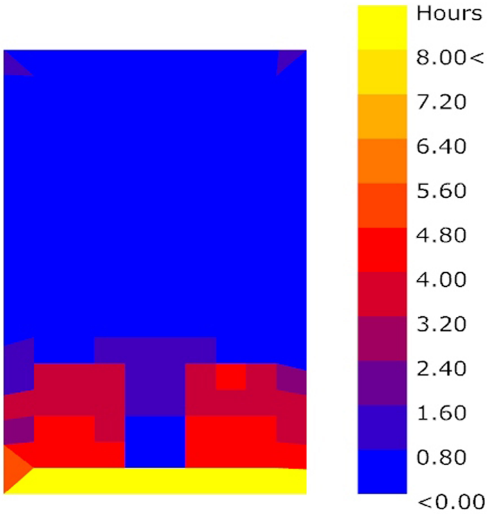
Figure 114: Dynamic facade shading system
Source: by author



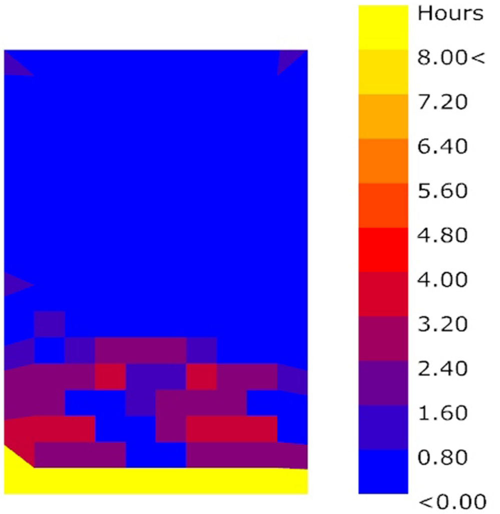
Shading Half Open



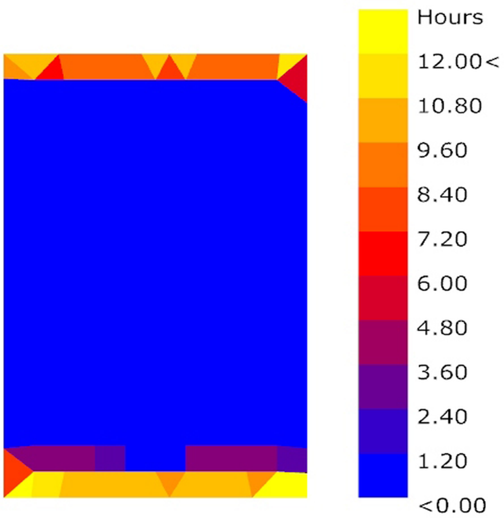
Shading Open



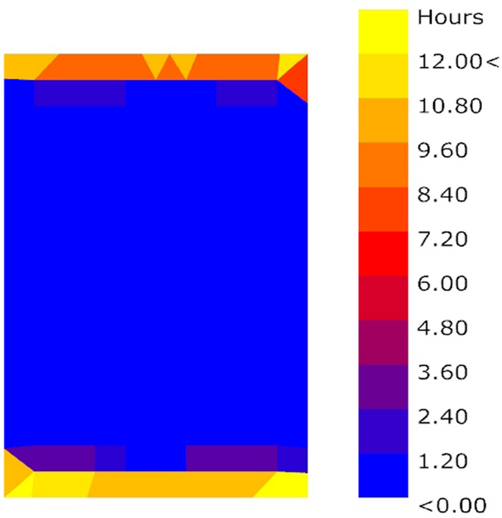
Sunlight Analysis in Winter Solstice
Shading Half Open
Total Sunlight Duration: 226.98h
Floor Area: 192.6m^2



Sunlight Analysis in Winter Solstice
Shading Open
Total Sunlight Duration: 265.47h
Floor Area: 192.6m^2



Sunlight Analysis in Summer Solstice
Shading Half Open
Total Sunlight Duration: 324.91h
Floor Area: 192.6m^2



Sunlight Analysis in Summer Solstice
Shading Open
Total Sunlight Duration: 317.92h
Floor Area: 192.6m^2

Figure 115: Sunlight analysis of rotate shading
Source: Simulate by grasshopper

We have chosen a public space spanning 192.6 square meters, oriented along a north-south axis, for sunlight simulation. Our observations have revealed interesting insights into how shading configurations impact lighting conditions during different times of the year.

Our analysis revealed some intriguing findings. During the winter solstice, fully opening the shading system to a 90° angle significantly improved lighting conditions, emphasizing the importance of maximizing natural light during darker months. Surprisingly, during the summer solstice, the 90° fully open position outperformed the 45° half-open angle in shading effectiveness. This highlights the advantage of a flexible rotating shading system, which adjusts to the sun's angle, ensuring superior shading efficiency year-round (figure115).

5.3 Sustainable Systems

5.3.1 HVAC system and renewable energy integration

HVAC systems frequently rank as significant energy consumers within buildings. To mitigate energy usage and diminish a building's carbon footprint, our project incorporates solar panels as a key component, capitalizing on excess heat generated by the HVAC system to complement hot water heating. in terms of Ventilation, sustainable systems employ demand-controlled ventilation, adjusting fresh air intake based on occupancy and indoor air quality, ensuring optimal ventilation while conserving energy. In the equipment selection process, we opt for more efficient units of suitable size to optimize energy utilization to the fullest extent. Through these measures, we ensure a comprehensive approach to enhancing energy efficiency and sustainability.

Modern HVAC systems offer zoning capabilities that allow different areas of a building to be heated, cooled, or ventilated independently. Sustainable design principles encourage the use of these features to optimize energy use and provide individualized comfort for occupants. Smart controls and sensors can further enhance energy efficiency by adapting HVAC operations based on occupancy and environmental conditions.

Simultaneously, our project has worked to minimize reliance on mechanical systems through the application of passive design strategies. Elements like yard layout, shading systems, and landscaping are all instrumental in alleviating the demands on the HVAC system. By integrating these elements seamlessly, we create a holistic environment that optimizes natural resources and minimizes the energy load required by the HVAC systems, ultimately fostering a more sustainable and energy-efficient building ecosystem (figure 116).

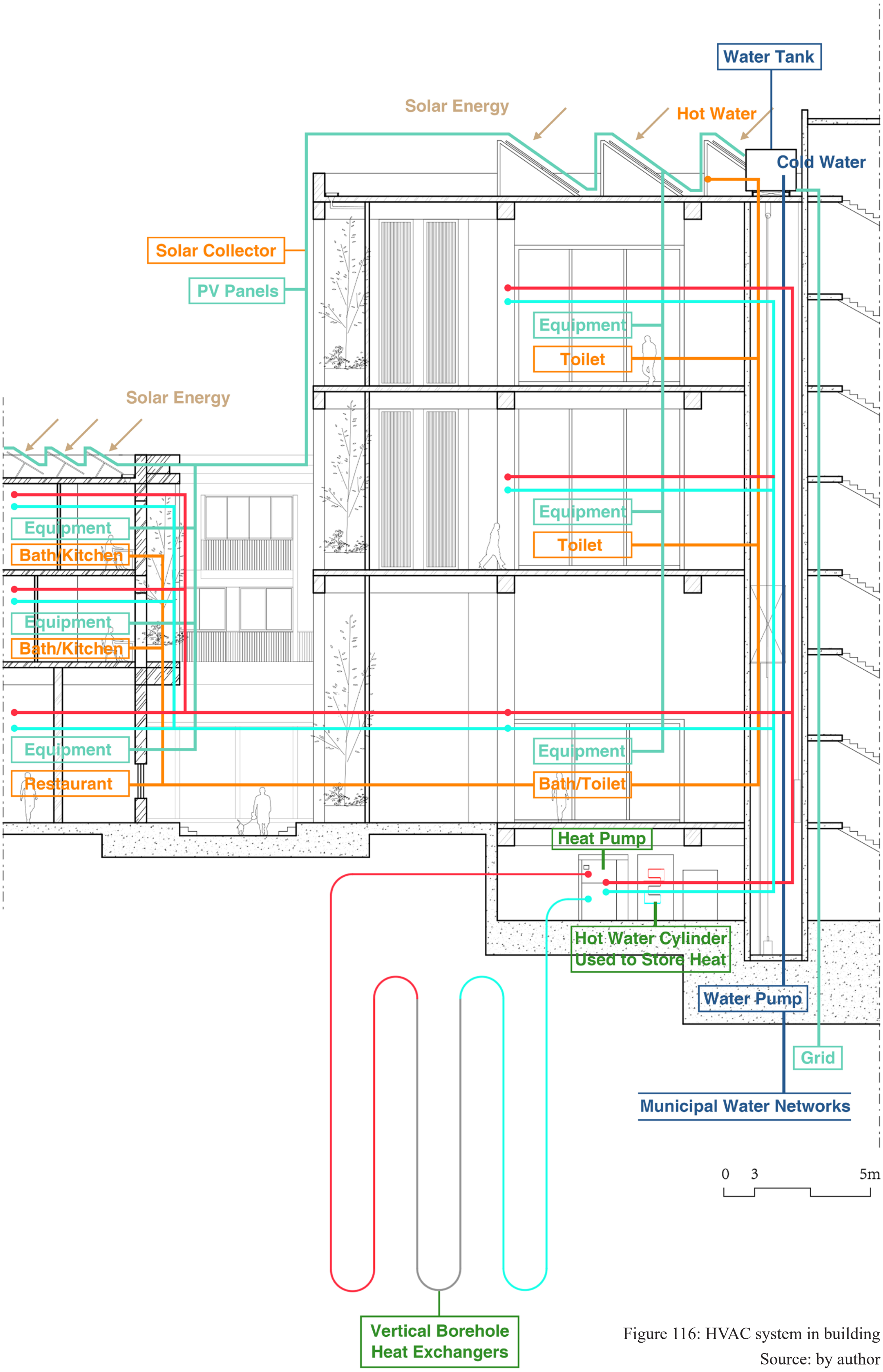


Figure 116: HVAC system in building
Source: by author

5.3.2 Water conservation and management

Water conservation and management are critical components of sustainable architecture design, aiming to reduce water consumption, minimize waste, and enhance the overall efficiency of water use within buildings and their surroundings. By implementing strategies that optimize water resources, sustainable design can help mitigate water scarcity and promote responsible water stewardship. The following are the water conservation and management strategies used in our project (figure 117):

Efficient fixtures and appliances

Selecting low-flow faucets, showers, toilets, and water-efficient appliances helps reduce water consumption without compromising functionality. At the same time, installing sensor-based fixtures that activate only when needed further conserves water by preventing unnecessary usage.

Rainwater harvesting

Rainwater harvesting systems capture and store rainwater for daily uses such as irrigation, toilet flushing, and cooling systems. This reduces the demand on municipal water supply and prevents stormwater runoff, which can carry pollutants into water bodies.

Graywater recycling:

Graywater, wastewater from sources like sinks and showers, can be treated and reused for irrigation or toilet flushing, properly treated graywater can offset the need for using potable water for non-potable purposes. In our project, rainwater, clean water, gray Water, waste water, etc. have realized cyclic conversion.

Cooling tower water management:

Cooling towers in HVAC systems can consume significant amounts of water. Implementing water-efficient cooling tower designs and strategies, using advanced water treatment technologies, can reduce water usage.

Water-efficient building materials

Water-efficient building materials play a crucial role in sustainable architecture by reducing the water footprint associated with construction and promoting responsible water management throughout a building's lifecycle. These materials are designed to minimize water usage during production, transportation, installation, and maintenance, contributing to overall water conservation efforts.

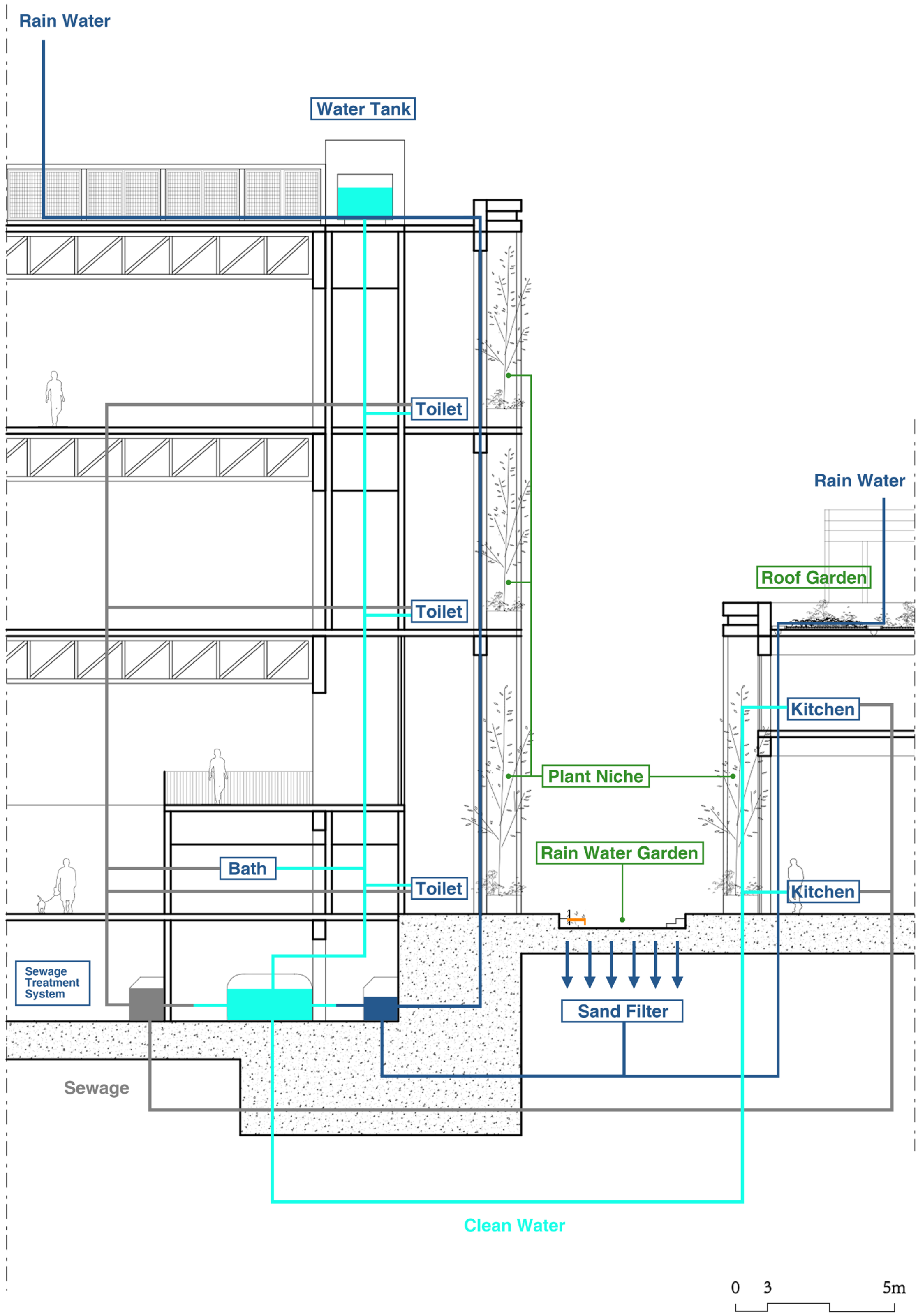


Figure 117: Water management in building
Source: by author

5.3.3 Smart home system

Smart home systems, involve the integration of digital and automated systems into the infrastructure of building to enhance comfort, convenience, security, and energy efficiency. These technologies leverage sensors, actuators, data analytics, and connectivity to create intelligent environments that respond to user preferences and environmental con, following technologies are applied according to different needs:

Home Automation

Smart Lighting: Lighting systems that can be controlled remotely or automatically adjusted based on occupancy, time of day, and natural light levels. Mainly used in public space lighting.

Smart Thermostats: HVAC systems that learn user preferences and adjust heating and cooling accordingly to optimize energy consumption.

Automated Blinds and Shades: Window treatments that respond to sunlight and time of day to regulate natural light and temperature. Mainly used in the control of rotating sunshades in public areas.

Thermochromic Glass: smart glass changes its tint or transparency based on temperature changes. It can automatically adjust its state to control solar heat gain and glare. Mainly used in the glass curtain wall of sport center.

Energy Management

Smart Meters: Advanced electricity meters that provide real-time data on energy usage to homeowners and utility providers.

Energy Monitoring Systems: Devices that track energy consumption of individual appliances and systems, helping users identify energy-hungry devices.

Demand Response Systems: Technologies that allow homeowners to participate in energy demand management programs by adjusting energy usage during peak times.

Home Monitoring and Maintenance

Smart Leak Detectors: Sensors that detect water leaks and send alerts to prevent water damage.

Smart Home Energy Auditing: Tools that analyze energy usage patterns and suggest improvements for efficiency.

Through the integration of smart technologies into buildings, the student community can experience heightened energy efficiency, convenience, and safety. Additionally, occupants have the opportunity to engage in energy management, fostering a deeper awareness of sustainability.

5.3.4 Sustainable landscape system

In order to let the student community harmonize with nature, conserve resources, and reduce environmental impact while enhancing aesthetics and functionality, we have also carried out an eco-conscious design on the outdoor landscape, the following are some of the methods involved in our design:

Plant Selection:

Trees are highly efficient in sequestering carbon due to their large size and long lifespan. In our project, we have chosen to plant the European beech (Fagus sylvatica), a native tree species well-suited to Milan's climate, known for its significant carbon absorption capacity. Additionally, we have selected boxwood (Buxus sempervirens) for shrubs; these evergreen shrubs are both robust and effective in carbon sequestration. We have also incorporated elderberry (Sambucus nigra), a native shrub that produces fragrant flowers and berries while aiding in carbon absorption. As for perennials and ground cover, catnip (Nepeta x faassenii) has been chosen for its low-maintenance characteristics and its ability to attract pollinators while assisting in carbon sequestration. Finally, for grasses, we have opted for specific Miscanthus species known for their significant potential in carbon sequestration (figure 118).

Fagus Sylvatica | Buxus Sempervirens | Sambucus Nigra | Nepeta x Faassenii | Miscanthus

Figure 118: Plant selection
source: wikipedia

Water Efficiency

Water-saving irrigation systems such as drip irrigation and intelligent controllers are used in sustainable landscapes, combined with rainwater collection systems to create waterscapes, which also play a role in regulating the temperature and humidity of the garden in summer while collecting water.

Permeable Surfaces

Sidewalk areas use permeable materials: gravel, permeable brick, and porous concrete, which allow stormwater to infiltrate the soil rather than cause stormwater runoff.

Soil Health

Proper soil management, including soil testing and amendments, helps improve fertility and water retention, reducing the need for chemical fertilizers. Techniques like mulching also aid in soil health and moisture conservation.

6. ENERGY ASSESSMENT OF PROJECT

6.1 Evaluation of Building Energy Performance

6.1.1 Basic data for building simulation

The building is located in Milan, the ground area is 5812 m^2 ,total building surface area is 16229 m^2.

The energy consumption of the community was calculated using Designbuilder software. We built the test model in the software (figure 119). The main functions of the community are the sports center, studying space and the residential. We divided the community into three main thermal divisions and other fragmented divisions according to function (figure 120). According to different functions, we set different usage parameters for each room, including occupancy density, hot water usage per unit area, basic room illumination, etc. (table 6, figure 121)

After the thermal zoning had been defined. We gave the wall materials and U-value refer to the calculations in section (table 7, figure 122 - 125). In terms of glass selection, we use double-layer LOWE glass to greatly improve the thermal performance of the building and reduce heat loss (figure 126).

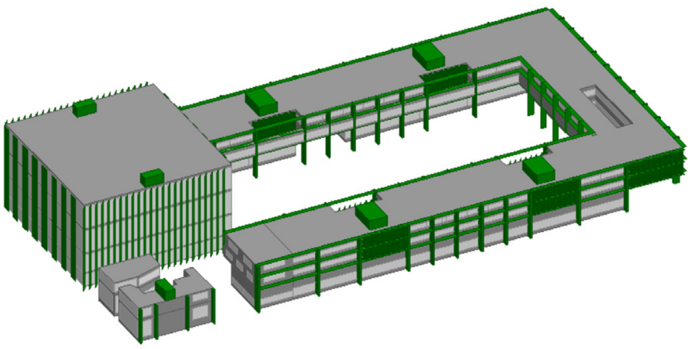


Figure 119: Test model in design builder
Source: Simulate by design builder

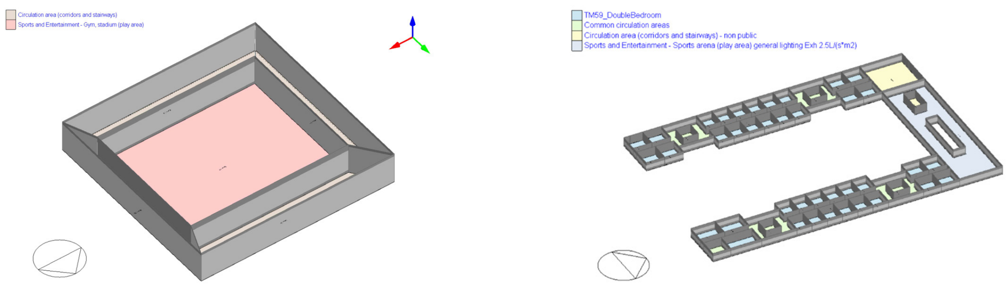


Figure 120: Thermal divisions in design builder
Source: Simulate by design builder

	Area[m2]	Volume[m3]	Occupancy Density[people/m2]	DHW(L/m2-day)	Lighting（Target lux）
Sports Space	4148	18375	0.32	0	300
Single Room	1640	5248	0.04	0.5	100
Triple Room	1640	5248	0.06	0.7	100
Studying Space	2446	13697.6	0.05	0.35	300
Workshop	420	5040	0.06	0.2	500
Restruant	780	4368	0.3.	12	150
Common Space	3615	43380	0.02	0	100
Corridor+Stairways	1540	13200	0.12	0	100

	Temperature Point(℃)			
	Heating	Heating set back	Cooling	Cooling set back
Sports Space	20	13	26	32
Single Room	18	12	25	28
Triple Room	18	12	25	28
Studying Space	20	13	26	32
Workshop	18	12	25	28
Restruant	23	12	25	28
Common Space	18	12	25	28
Corridor+Stairways	20	12	23	28

Table 6: Test model in design builder
Source: Simulate by design builder

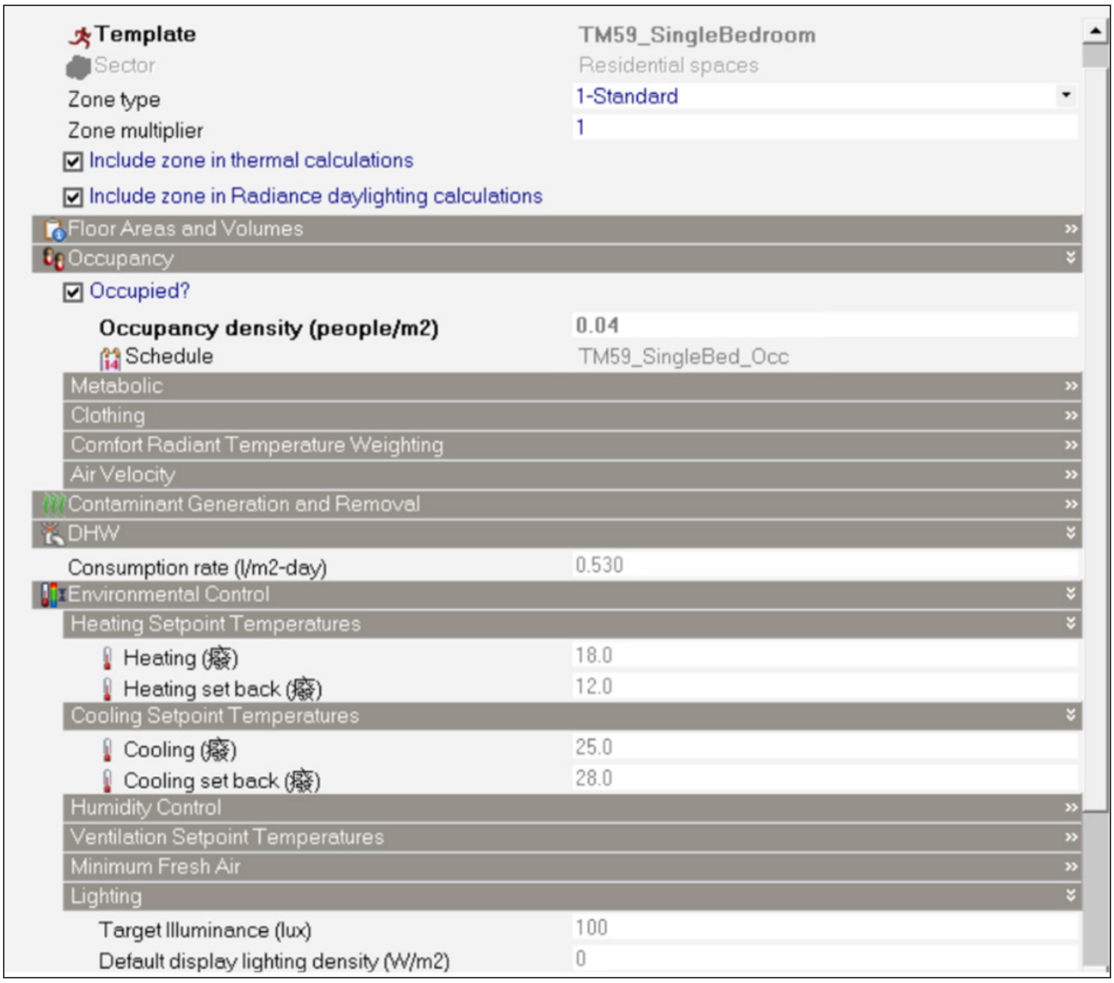


Figure 121: Basic parameters of single room
Source: Simulate by design builder

U-value of Building Envelope		
ROOF	0.2	W/(m²k)
External wall	0.21	W/(m²k)
Indoor partition	0.79	W/(m²k)
Ground floor	0.24	W/(m²k)

Table 7: U-value of building evelope
Source: by author

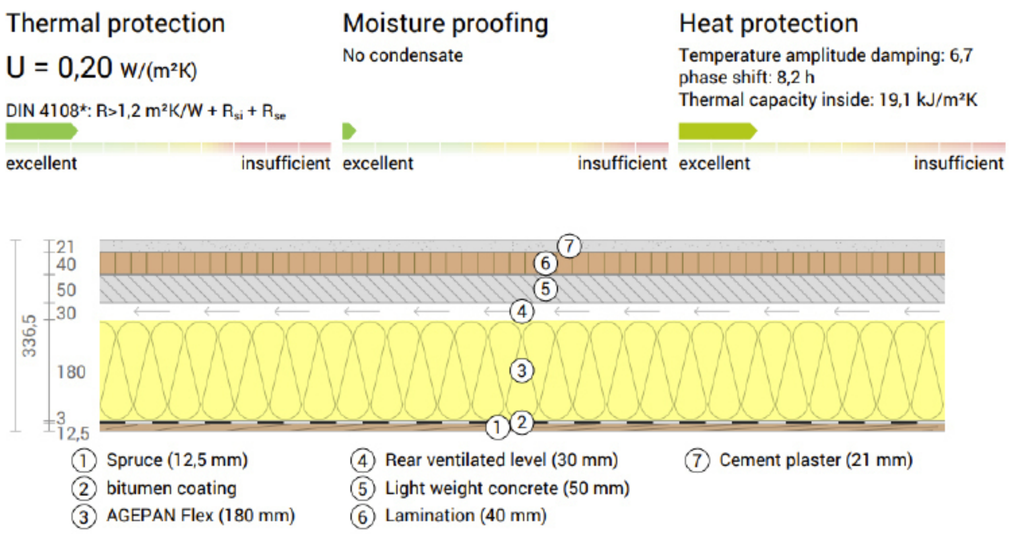


Figure 122: Roof U-value
Source: Simulate by ubakus

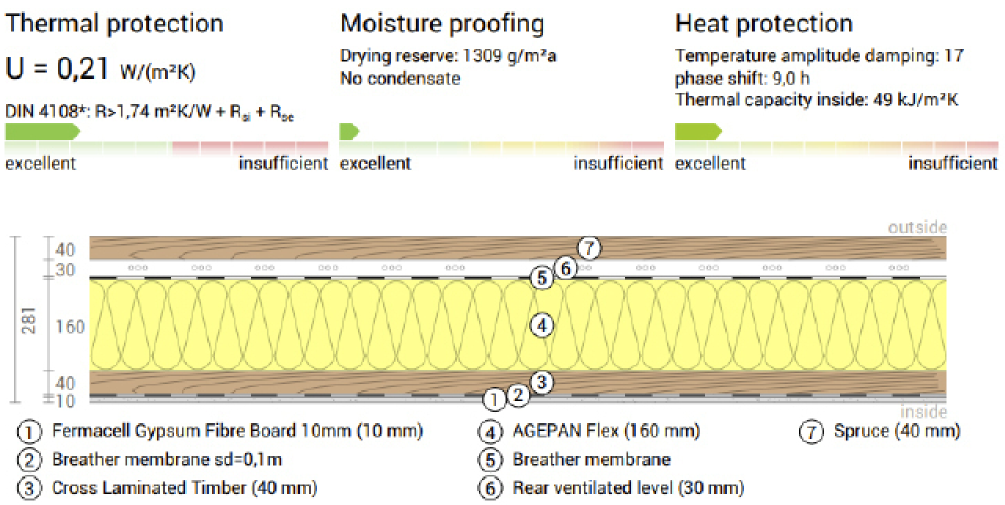


Figure 123: External wall U-value
Source:Ubakus

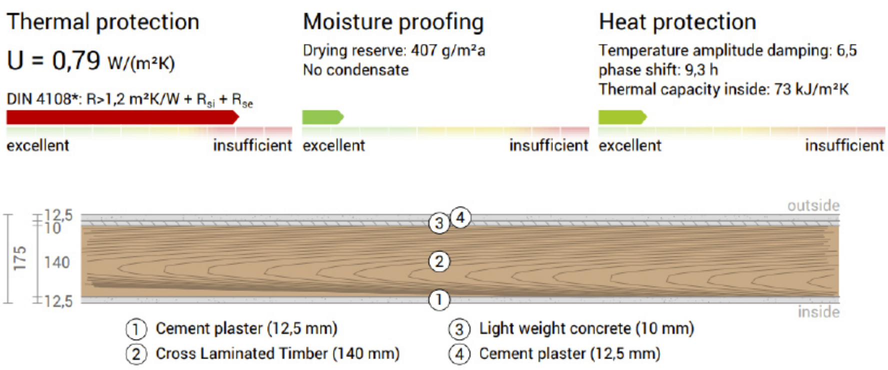


Figure 124: Indoor partition U-value
Source: Simulate by ubakus

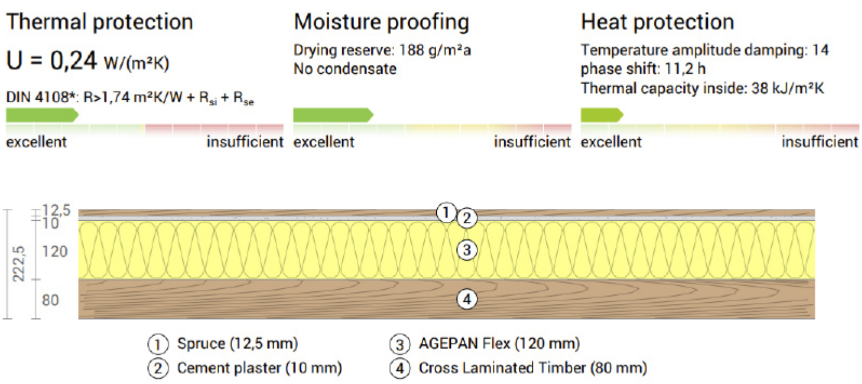


Figure 125: Ground floor U-value
Source: Simulate by ubakus

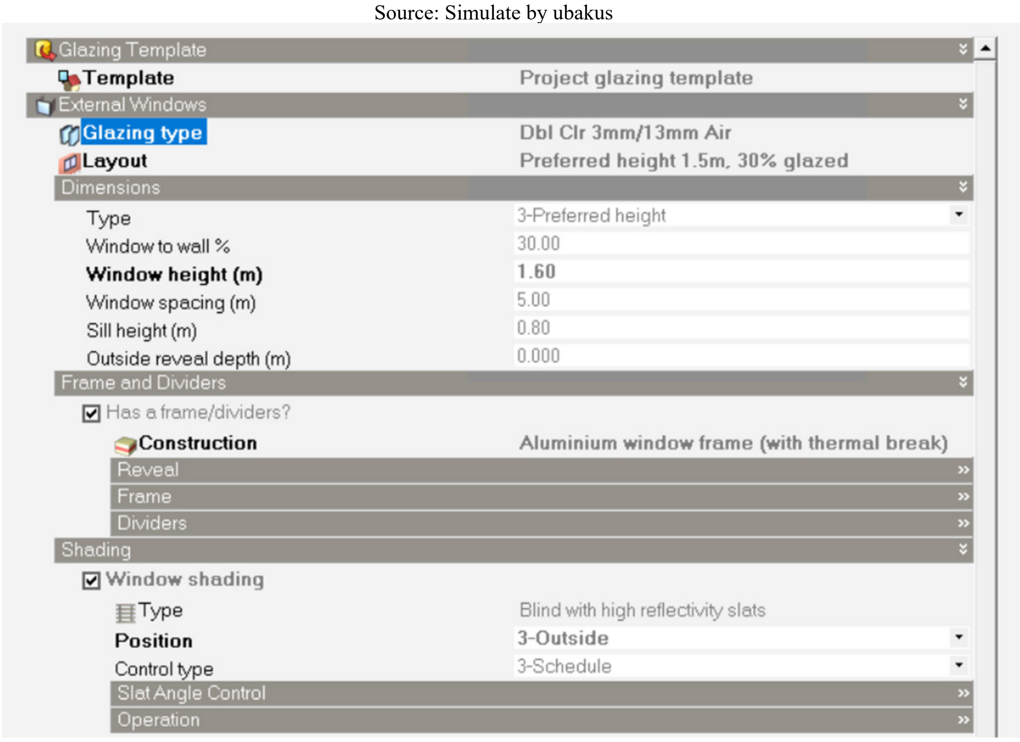


Figure 126: Basic parameters of glass
Source: Simulate by design builder

6.1.2 Simulation results

For cooling, we performed calculations on models with and without shading, compared and analyzed the results (table 8, figure 127) obtained. We found that in the case of shading, the cooling energy consumption from April to September was 26.37KWh/m^2, Significantly lower than without shading (31.9KWh/m^2), and models with shadings in summer required lower design peak cooling load, which means that the rotating shading plays a great role in the project. All rotating shadings will be closed in winter, and the energy consumption for heating was simulated as 59KWh/m^2.

Simulated through software, we could see the electrcity of lighting consumption was 15.49KWh/m^2 and the equipment Consumption was 8.51KWh/m^2 (figure 128).

Cooling System(with shading open Apr-Sep)		
Cooling Energy demand	428	MWh
Peak Sensile Cooling power	1359.63	KW
Cooling System(without shading closed Apr-Sep)		
Cooling Energy demand	517.8	MWh
Peak Sensile Cooling power	1578	KW
Heating System(without shading Oct-Mar)		
Heating Energy demand	961.5	MWh
Peak Sensile Heating power	1029	KW

Table 8: Heating and cooling simulation results
Source: Simulate by design builder

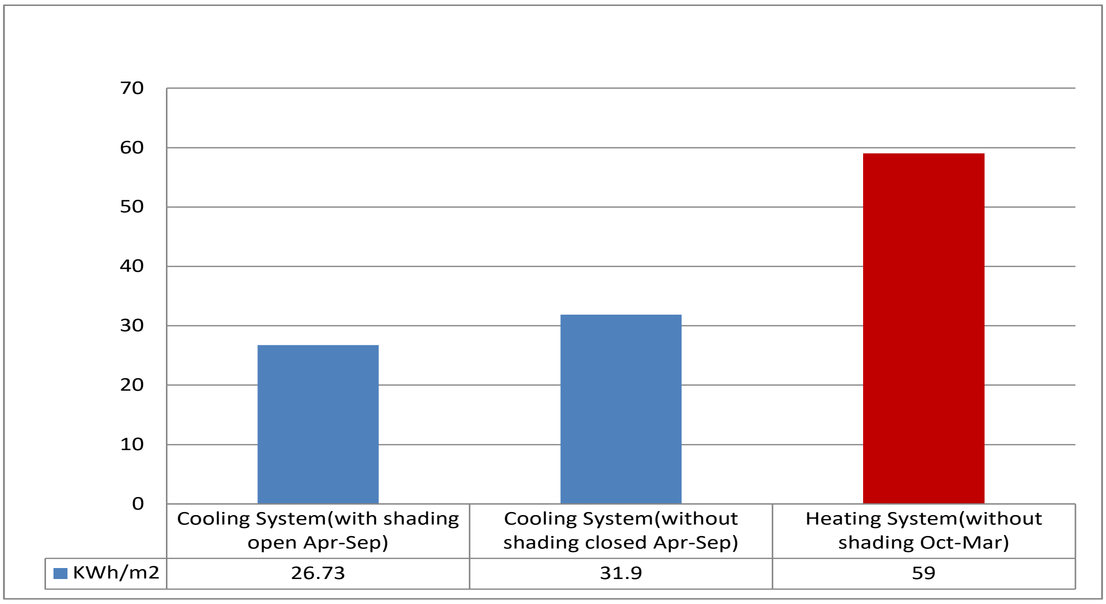


Figure 127: Heating and cooling simulation results
Source: Simulate by design builder

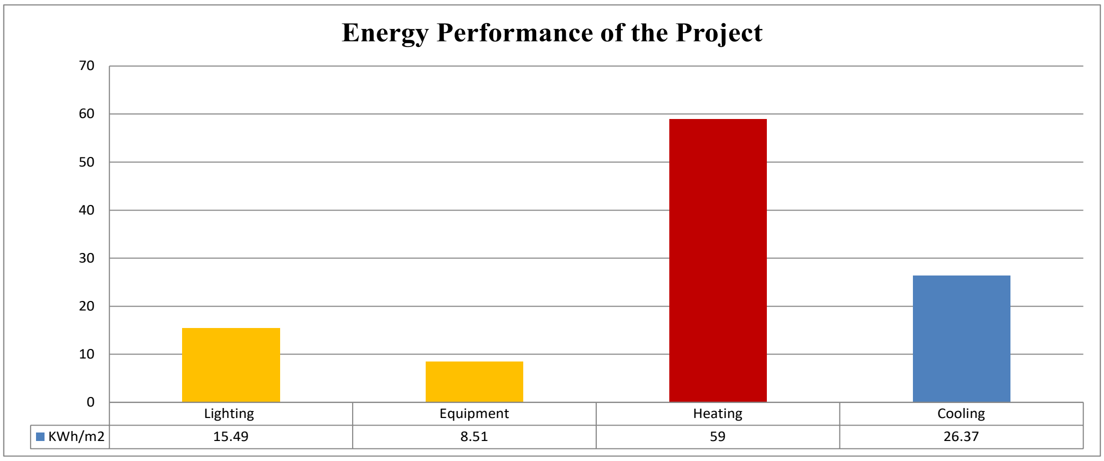


Figure 128: Energy performance of project
Source: Simulate by design builder

6.2 Utilization of Renewable Energy

6.2.1 Ground source heat pumps

We can find that heating and cooling account for a large part of energy consumption (figure 129), so we chose ground source heat pumps as the main energy source for heating and cooling. Ground source heat pumps can transfer energy from low-temperature heat sources to high-temperature heat sources by inputting a small amount of high-grade energy (electric energy).

In winter, the heat in the soil is "taken out", and the temperature is raised and supplied to the room for heating; in summer, the heat in the room is "taken out" and released into the soil, and the underground temperature can be kept balanced all year round. This can maximize the use of natural renewable resources and reduce greenhouse gas emissions compared to other energy sources such as fossils.

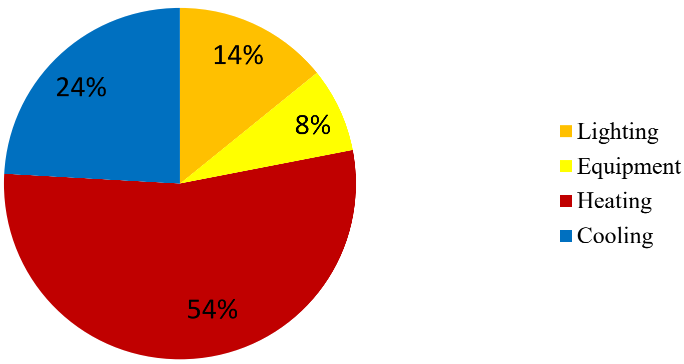


Figure 129: Energy distribution
Source: by author

The VITOCAL 300-G was choosen (figure 130) as the main source of energy for cooling and heating. We calculated the electricity it needed in RETScreen through entering designing heating load (1029.3kW) and cooling load (1359.6kW). The COP of VITOCAL 300-G was 4.6 and it needs 281.3MW for heating, 278.2MW for cooling every year (figure 131).

Vitocal 300-G	Type	BW 301.A21	BW 301.A29	BW 301.A45
Vitocal 300-G	Type	BWS 301.A21	BWS 301.A29	BWS 301.A45
Performance data				
(to EN 14511, B0/W35°C, 5 K spread)				
Rated heating output	kW	21.2	28.8	42.8
COP ε in heating mode		4.7	4.8	4.6
Maximum flow temperature	°C	60	60	60
Refrigerant circuit				
Refrigerant		R410A	R410A	R410A
– Refrigerant charge	kg	4.7	6.2	7.7
– Global warming potential (GWP)		2088	2088	2088
– CO_2 equivalent	t	11.5	13.0	16.1

Figure 130: VITOCAL 300-G heat pump

Source: Viessmann UK, 2023

RETScreen® Heating and Cooling Load Calculation - Ground-Source Heat Pump Project

Site Conditions		Estimate	Notes/Range
Nearest location for weather data		Milano(Milan)/Linate	See Weather Database
Heating design temperature	°C	6.0	-40.0 to 15.0
Cooling design temperature	°C	28.0	10.0 to 40.0
Average summer daily temperature range	°C	9.1	5.0 to 15.0
Cooling humidity level	-	Medium	
Latitude of project location	°N	45.4	-90.0 to 90.0
Mean earth temperature	°C	9.9	Visit NASA satellite data site
Annual earth temperature amplitude	°C	19.6	5.0 to 20.0
Depth of measurement of earth temperature	m	0.0	0.0 to 3.0

Site Conditions		Estimate	Notes/Range
Project name		**Community**	See Online Manual
Project location		**Milan,Italy**	
Available land area	m²	16,229	
Soil type	-	Light soil - damp	
Design heating load	kW	1,029.3	Complete H&CLC sheet
Design cooling load	kW	1,359.6	

System Characteristics		Estimate	Notes/Range
Base Case HVAC System			
Building has air-conditioning?	yes/no	Yes	
Heating fuel type	-	**Natural gas**	
Heating system seasonal efficiency	%	80%	55% to 350%
Air-conditioner seasonal COP	-	2.0	2.4 to 5.0
Ground Heat Exchanger System			
System type	-	Vertical closed-loop	
Design criteria	-	Cooling	
Typical land area required	m²	12,784	
Ground heat exchanger layout	-	Standard	
Total borehole length	m	43,882	
Heat Pump System			
Average heat pump efficiency	-	User-defined	See Product Database
Heat pump manufacturer		Vitocal	
Heat pump model		Vitocal 300-G	
Standard cooling COP	-	4.70	
Standard heating COP	-	4.60	
Total standard heating capacity	kW	896.6	
	million Btu/h	3.059	
Total standard cooling capacity	kW	1,319.0	
	ton (cooling)	375.1	
Supplemental Heating and Heat Rejection System			
Suggested supplemental heating capacity	kW	0.0	
	million Btu/h	0.000	
Suggested supplemental heat rejection	kW	0.0	
	million Btu/h	0.000	

Annual Energy Production		Estimate	Notes/Range
Heating			
Electricity used	MWh	281.3	
Supplemental energy delivered	MWh	0.0	
GSHP heating energy delivered	MWh	**1,008.3**	
	million Btu	3,440.2	
Seasonal heating COP	-	3.6	2.0 to 5.0
Cooling			
Electricity used	MWh	278.2	
GSHP cooling energy delivered	MWh	**1,299.8**	
	million Btu	4,435.0	
Seasonal cooling COP	-	4.7	2.0 to 5.5
Seasonal cooling EER	(Btu/h)/W	15.9	7.0 to 19.0
			Complete Cost Analysis sheet

Figure 131: Calculation of heat pump electricity consumption

Source: Simulate by RETScreen

1.2.2 Solar water collector

Solar water collector is a heating device that converts solar energy into thermal energy, heating water from low temperature to high temperature to meet people's use of hot water in life.

We choose the Sunpad (figure132) as the main source of domestic hot water. As for apartment (figure 133), we have 82 units that require hot water. As for studying space (figure 134), about 144 people studying in the community every day. All restaurants (figure 135) needed to provide about 140 meals a day. Because there is no gymnasium function in the software, we converted it to the number of people in the school who needs to bathe, it's about 200 people. The temperature of the hot water is set at 45 degrees. A total of 139.4 m^2 of area was needed to place the solar water collector through calculation (figure 136). According to calculations (figure 137, 138), the total energy months demand was 204.91MWh, it needed to get the 65% in solar fraction,so the total gross area of solar water collector was about 352.8m^2.

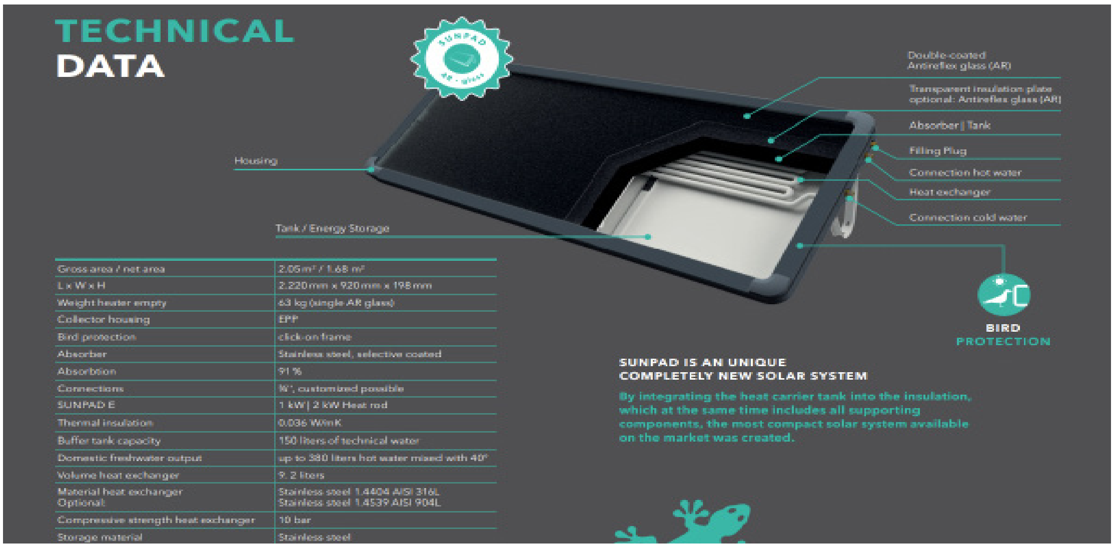


Figure 132: Basic data of Sunpad

Source: SUNPAD Solar. 2022

Water Heating Load Calculation		Estimate	Notes/Range
Application type	-	Service hot water	
System configuration	-	With storage	
Building or load type	-	Apartment	
Number of units	Unit	82	
Rate of occupancy	%	100%	50% to 100%
Estimated hot water use (at ~60 °C)	L/d	11,716	
Hot water use	L/d	11,716	
Desired water temperature	°C	45	
Days per week system is used	d	7	1 to 7
Cold water temperature	-	Auto	
Minimum	°C	9.2	1.0 to 10.0
Maximum	°C	17.0	5.0 to 15.0
Months SWH system in use	month	12.00	
Energy demand for months analysed	MWh	158.88	
	GJ	571.95	

Figure 133: Hot water usage calculation of apartment

Source: Simulate by RETScreen

Water Heating Load Calculation		Estimate	Notes/Range
Application type	-	Service hot water	
System configuration	-	With storage	
Building or load type	-	Office	
Number of units	Person	200	
Rate of occupancy	%	100%	50% to 100%
Estimated hot water use (at ~60 °C)	L/d	760	
Hot water use	L/d	760	
Desired water temperature	°C	45	
Days per week system is used	d	7	1 to 7
Cold water temperature	-	Auto	
Minimum	°C	9.2	1.0 to 10.0
Maximum	°C	17.0	5.0 to 15.0
Months SWH system in use	month	12.00	
Energy demand for months analysed	MWh	10.31	
	GJ	37.10	

Figure 134: Hot water usage calculation of Studying Space

Source: Simulate by RETScreen

Water Heating Load Calculation		Estimate	Notes/Range
Application type	-	Service hot water	
System configuration	-	With storage	
Building or load type	-	Restaurant	
Number of units	Meal/d	140	
Rate of occupancy	%	100%	50% to 100%
Estimated hot water use (at ~60 °C)	L/d	1,274	
Hot water use	L/d	1,274	
Desired water temperature	°C	45	
Days per week system is used	d	7	1 to 7
Cold water temperature	-	Auto	
Minimum	°C	9.2	1.0 to 10.0
Maximum	°C	17.0	5.0 to 15.0
Months SWH system in use	month	12.00	
Energy demand for months analysed	MWh	17.28	
	GJ	62.19	

Figure 135: Hot water usage calculation of Restruant

Source: Simulate by RETScreen

Water Heating Load Calculation		Estimate	Notes/Range
Application type	-	Service hot water	
System configuration	-	With storage	
Building or load type	-	School w/ showers	
Number of units	Student	200	
Rate of occupancy	%	100%	50% to 100%
Estimated hot water use (at ~60 °C)	L/d	1,360	
Hot water use	L/d	1,360	
Desired water temperature	°C	45	
Days per week system is used	d	7	1 to 7
Cold water temperature	-	Auto	
Minimum	°C	9.2	1.0 to 10.0
Maximum	°C	17.0	5.0 to 15.0
Months SWH system in use	month	12.00	
Energy demand for months analysed	MWh	18.44	
	GJ	66.39	

Figure 136: Hot water usage calculation of Sports Centre

Source: Simulate by RETScreen

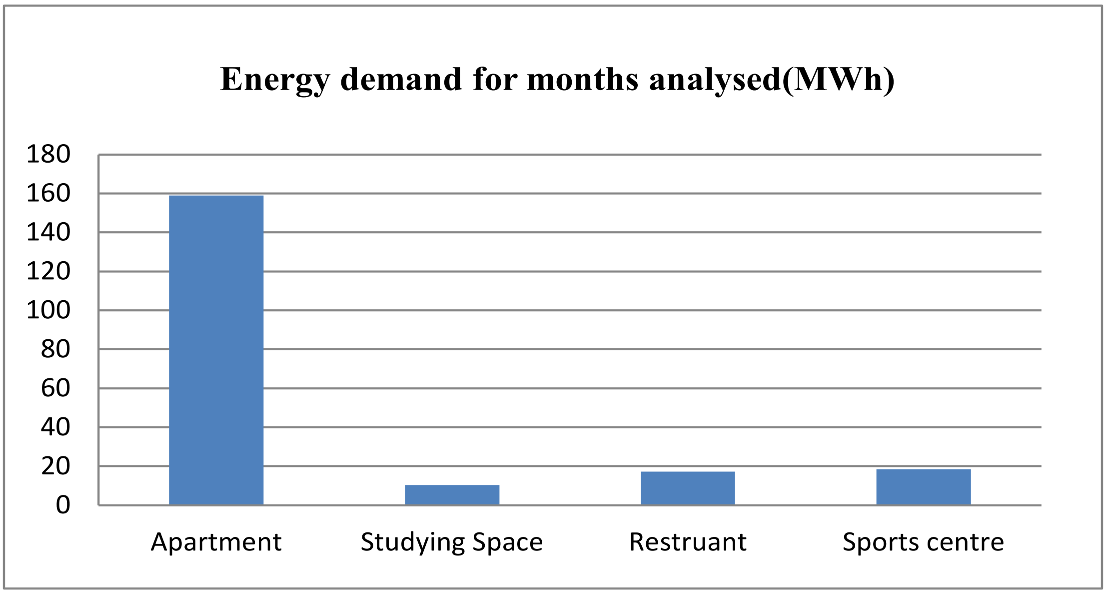


Figure 137: Energy demand for months analysed

Source: Simulate by RETScreen

Water Heating Load Calculation		Estimate	Notes/Range
Application type	-	Service hot water	
System configuration	-	With storage	
Building or load type	-	Apartment	
Number of units	Unit	200	
Rate of occupancy	%	100%	50% to 100%
Estimated hot water use (at ~60 °C)	L/d	26,600	
Hot water use	L/d	15,111	
Desired water temperature	°C	45	
Days per week system is used	d	7	1 to 7
Cold water temperature	-	Auto	
Minimum	°C	9.2	1.0 to 10.0
Maximum	°C	17.0	5.0 to 15.0
Months SWH system in use	month	12.00	
Energy demand for months analysed	MWh	204.91	
	GJ	737.68	
			Return to Energy Model sheet

System Characteristics		Estimate	Notes/Range
Application type		Service hot water (with storage)	
Base Case Water Heating System			
Heating fuel type	-	**Natural gas - m³**	
Water heating system seasonal efficiency	%	91%	50% to 190%
Solar Collector			
Collector type	-	Glazed	See Technical Note 1
Solar water heating collector manufacturer		Austria	See Product Database
Solar water heating collector model		Sunpad	
Gross area of one collector	m²	1.68	1.00 to 5.00
Aperture area of one collector	m²	1.68	1.00 to 5.00
Fr (tau alpha) coefficient	-	0.71	0.50 to 0.90
Fr UL coefficient	(W/m²)/°C	3.96	1.50 to 8.00
Temperature coefficient for Fr UL	(W/(m·°C)²)	0.00	0.000 to 0.010
Suggested number of collectors		80	
Number of collectors		210	
Total gross collector area	m²	352.8	
Storage			
Ratio of storage capacity to coll. area	L/m²	45.9	37.5 to 100.0
Storage capacity	L	16,194	
Balance of System			
Heat exchanger/antifreeze protection	yes/no	No	
Suggested pipe diameter	mm	N/A	8 to 25 or PVC 35 to 50
Pipe diameter	mm	38	8 to 25 or PVC 35 to 50
Pumping power per collector area	W/m²	0	3 to 22, or 0
Piping and solar tank losses	%	1%	1% to 10%
Losses due to snow and/or dirt	%	3%	2% to 10%
Horz. dist. from mech. room to collector	m	5	5 to 20
# of floors from mech. room to collector	-	2	0 to 20

Annual Energy Production (12.00 months analysed)		Estimate	Notes/Range
SWH system capacity	kW_{th}	247	
	MWth	0.247	
Pumping energy (electricity)	MWh	**0.00**	
Specific yield	kWh/m²	379	
System efficiency	%	28%	
Solar fraction	%	65%	
Renewable energy delivered	MWh	**133.74**	
	GJ	481.46	
			Complete Cost Analysis sheet

Figure 138: Total gross area for solar water collector

Source: Simulate by RETScreen

6.2.3 Solar PV

We want the entire project to be powered by solar PV, We covered our roof with 3695 m^2 (figure 139) of solar SPR-MAX3-43 (figure 140) to provide the electricity the building needed.

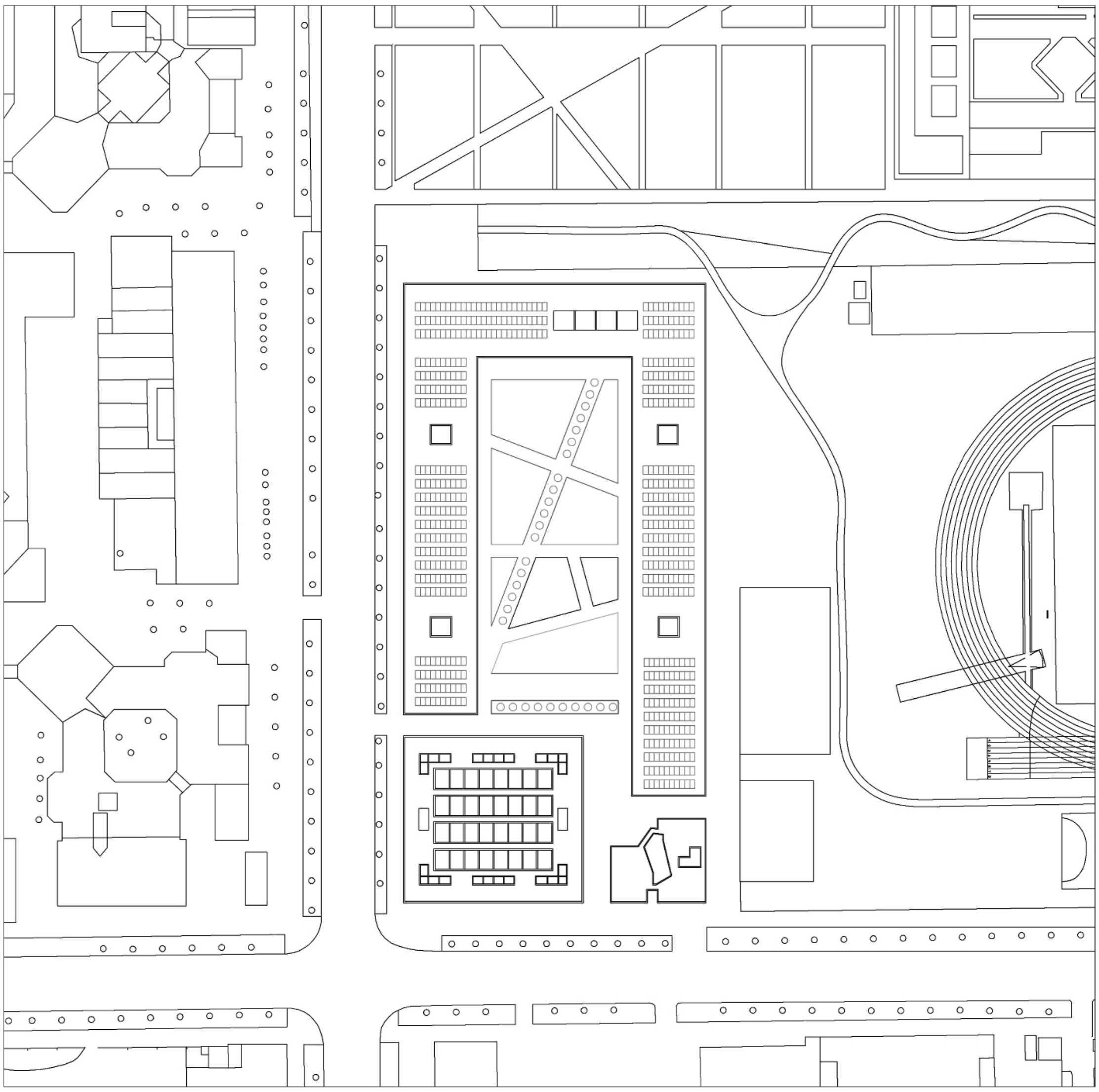


Figure 139: Solar pvs area on roof

Source: by author

Electrical Data	SPR-MAX3-430	SPR-MAX3-425	SPR-MAX3-415
Nominal Power (Pnom) [8]	430 W	425 W	415 W
Power Tolerance	+5/0%	+5/0%	+5/0%
Panel Efficiency	22.7%	22.4%	21.9%
Rated Voltage (Vmpp)	70.4 V	70.0 V	69.2 V
Rated Current (Impp)	6.11 A	6.07 A	6.00 A
Open-Circuit Voltage (Voc) (+/-3%)	81.4 V	81.3 V	81.2 V
Short-Circuit Current (Isc) (+/-3%)	6.57 A	6.57 A	6.55 A
Max. System Voltage	1000 V IEC		
Maximum Series Fuse	20 A		
Power Temp Coef.	– 0.27% / °C		
Voltage Temp Coef.	– 0.236% / °C		
Current Temp Coef.	0.058% / °C		

Figure 140: Basic data of SPR-MAX3-43

Source: SunPower Maxeon, 2019

Site Latitude and PV Array Orientation		Estimate	Notes/Range
Nearest location for weather data		Milano(Milan)/Linate	See Weather Database
Latitude of project location	°N	45.4	-90.0 to 90.0
PV array tracking mode	-	Fixed	
Slope of PV array	°	30.0	0.0 to 90.0
Azimuth of PV array	°	0.0	0.0 to 180.0

Site Conditions		Estimate	Notes/Range
Project name		**Community**	See Online Manual
Project location		**milan, Italy**	
Nearest location for weather data	-	Milano(Milan)/Linate	➡ Complete SR&SL sheet
Latitude of project location	°N	45.4	-90.0 to 90.0
Annual solar radiation (tilted surface)	MWh/m²	1.36	
Annual average temperature	°C	13.1	-20.0 to 30.0

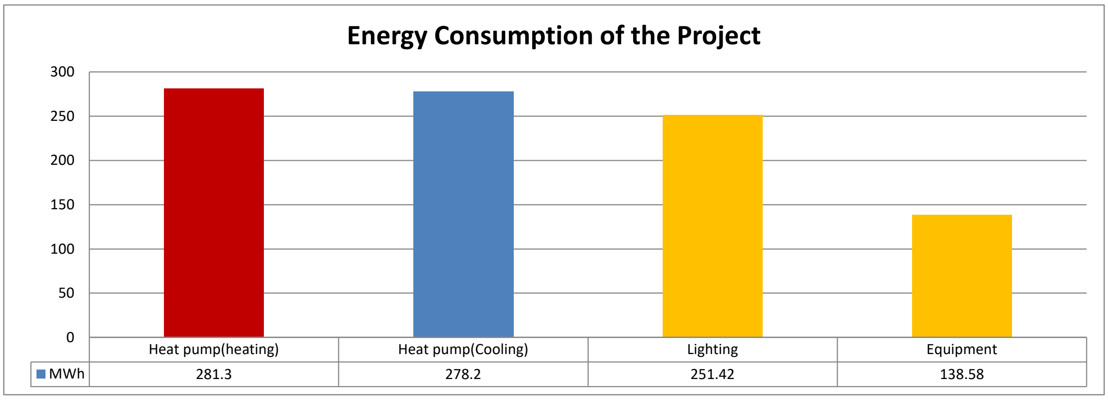
System Characteristics		Estimate	Notes/Range
Application type	-	**On-grid**	
Grid type	-	Central-grid	
PV energy absorption rate	%	100.0%	
PV Array			
PV module type	-	mono-Si	
PV module manufacturer / model #		ABC Inc.	See Product Database
Nominal PV module efficiency	%	23.0%	4.0% to 15.0%
NOCT	°C	45	40 to 55
PV temperature coefficient	% / °C	0.40%	0.10% to 0.50%
Miscellaneous PV array losses	%	5.0%	0.0% to 20.0%
Nominal PV array power	kWp	**850.00**	
PV array area	m²	3,695.7	
Power Conditioning			
Average inverter efficiency	%	90%	80% to 95%
Suggested inverter (DC to AC) capacity	kW (AC)	765.0	
Inverter capacity	kW (AC)	72.0	
Miscellaneous power conditioning losses	%	0%	0% to 10%

Annual Energy Production (12.00 months analysed)		Estimate	Notes/Range
Specific yield	kWh/m²	257.5	
Overall PV system efficiency	%	18.9%	
PV system capacity factor	%	12.8%	
Renewable energy collected	MWh	1,057.447	
Renewable energy delivered	MWh	**951.702**	
	kWh	951,702	
Excess RE available	MWh	**0.000**	
			Complete Cost Analysis sheet

Figure 141: Solar PVs calculation

Source: Simulate by RETScreen

Through calculation in RETScren (figure 141), the electrcity community consumption was 949.5MWh, the electrcity Solar PVs produced was 951.7MWh (figure 142), the electricity provided by solar PVs can be used in the entire project.



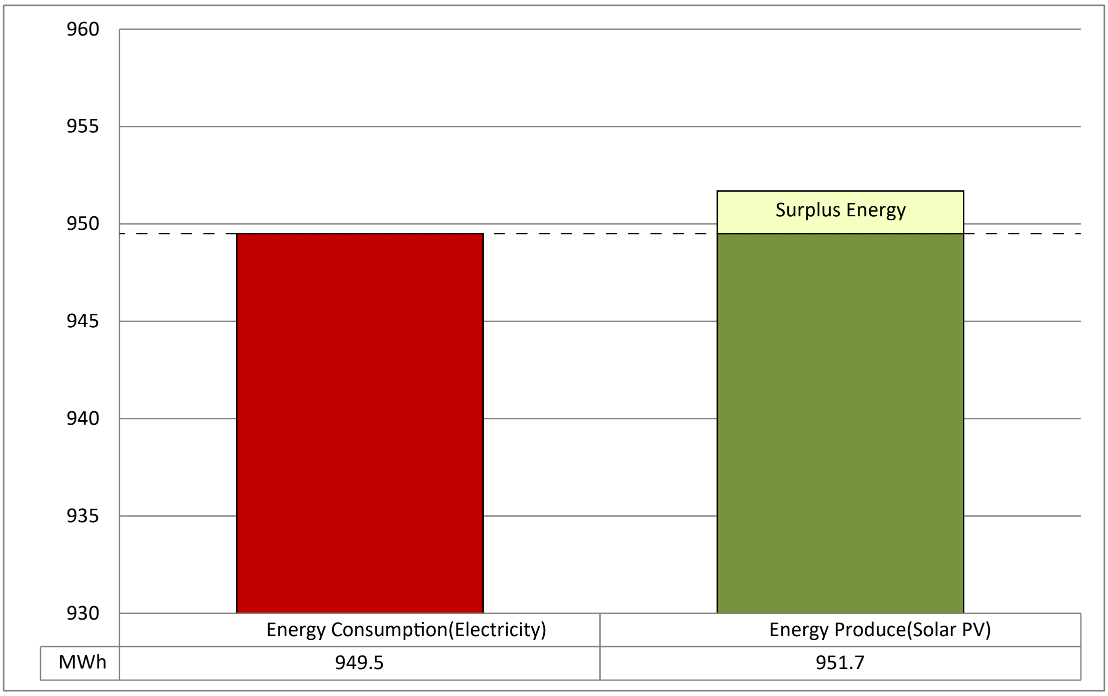


Figure 142: Comparison of energy use and produce
Source: Simulate by RETScreen

6.3 CO_2 Reduction

Software calculations (figure 143) have also been used to derive the amount of carbon dioxide that can be reduced by each system. According to the calculations carried out through RETScreen, the ground source heat pumps, solar PVs and hot water systems can help reduce CO_2 emissions by 240.78 (tons/year) totally (figure 144).

Base Case Electricity System (Baseline)

Fuel type	Fuel mix (%)	CO_2 emission factor (kg/GJ)	CH_4 emission factor (kg/GJ)	N_2O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (t_{CO2}/MWh)
Natural gas	43.0%	56.1	0.0030	0.0010	45.0%	8.0%	0.491
#6 oil	32.0%	77.4	0.0030	0.0020	30.0%		0.937
Solar	18.0%	0.0	0.0000	0.0000	100.0%		0.000
Coal	7.0%	94.6	0.0020	0.0030	35.0%		0.983
Electricity mix	100%	159.7	0.0067	0.0038		3.4%	0.580

GHG Emission Reduction Summary

	Base case GHG emission factor (t_{CO2}/MWh)	Proposed case GHG emission factor (t_{CO2}/MWh)	End-use annual energy delivered (MWh)		Annual GHG emission reduction (t_{CO2})
Heating system	0.254	0.162	1008.3		93.13
Cooling system	0.290	0.124	1299.8		215.50
			Net GHG emission reduction	t_{CO2}/yr	**308.63**

Complete Financial Summary sheet

GHG Emission Reduction Summary

	Base case GHG emission factor (t_{CO2}/MWh)	Proposed case GHG emission factor (t_{CO2}/MWh)	End-use annual energy delivered (MWh)		Annual GHG emission reduction (t_{CO2})
Heating system	0.223	0.000	133.74		29.88
			Net GHG emission reduction	t_{CO2}/yr	**29.88**

Complete Financial Summary sheet

GHG Emission Reduction Summary

	Base case GHG emission factor (t_{CO2}/MWh)	Proposed case GHG emission factor (t_{CO2}/MWh)	End-use annual energy delivered (MWh)		Annual GHG emission reduction (t_{CO2})
Electricity system	0.580	0.000	913.634		529.73
			Net GHG emission reduction	t_{CO2}/yr	**529.73**

Complete Financial Summary sheet

Figure 143: CO_2 emissions reduced in heat pump,solar water collector and solar PVs
Source: Simulate by RETScreen

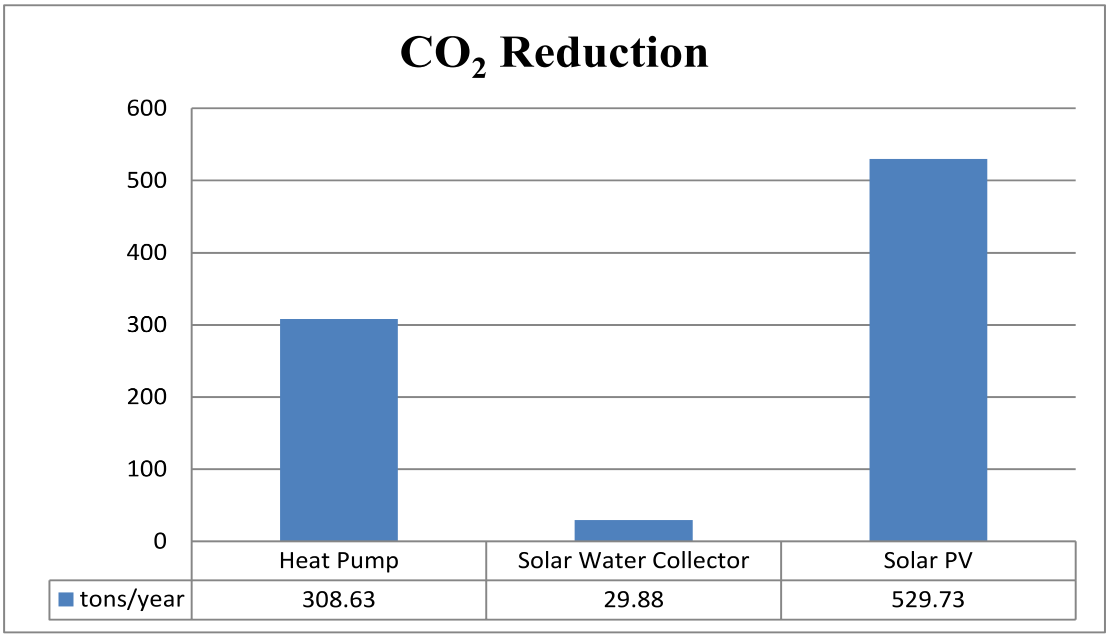


Figure 144: CO_2 emissions reduced in heat pump,solar water collector and solar PVs
Source: by author

7. CONCLUSION

The increasingly urgent issue of global warming demands our immediate attention. The construction sector, responsible for a significant portion of greenhouse gas emissions (38%), must prioritize substantial decarbonization efforts. This is the driving force behind our research on Net Zero Carbon Buildings (NZCBs). Nations worldwide have introduced various carbon reduction policies, such as China's commitment to carbon neutrality, the United States' embrace of a clean energy economy, the European Union's Energy Roadmap 2050, and initiatives like REPowerEU. All of these initiatives have provided valuable guidance for the design of NZCBs.

During the case analysis phase, we studied various measures adopted by different countries to reduce energy consumption in residential buildings in response to climate change, spanning from the early 20th century to the present. These measures encompassed the renovation of existing structures and the construction of new ones.

A recurring theme in all these projects was the incorporation of passive strategies in building design, including layout, shading, and ventilation, to minimize the need for energy-intensive equipment. For instance, the Madrid apartment complex utilized an atrium to enhance cross-ventilation and employed diverse shading techniques to suit the local climate.

Designer Charles David Keeling demonstrated a meticulous approach, considering site topography, wastewater management through runoff, and precise building shading angles using computer-assisted design.

Moreover, renewable energy sources like solar, wind, and geothermal energy were universally employed across these projects, aiming to reduce carbon emissions during building operation. These initiatives underscored a commitment to sustainable practices and climate mitigation.

In architectural design, beyond the imperative of decarbonization, considerations must encompass its harmonious integration with the site, functionality, structural coherence, and aesthetic appeal, among other factors. Consequently, prior to achieving a net-zero carbon building, it is essential to first aspire towards creating a space that seamlessly aligns with its surroundings.

Upon conducting the site analysis, we identified our main target: how to foster a healthier lifestyle for college students. We accomplished this by embracing enclosed architecture, entrance design which link commmunity and city park, and a functional layout that blends sports, culture, and residential spaces. Concurrently, we fostered a strong connection between the community and its surrounding site, invigorating the site's vibrancy.

Incorporating sustainable development strategies into our building design process goes beyond traditional architectural practices. In the initial design phase, we harnessed computer-aided design tools, such as Grasshopper, to analyze solar radiation patterns in the area. This analysis informed our decisions regarding the building's optimal height and block layout. Concurrently, we integrated elements like rainwater management, rotating shading systems, and ecological facades into the architectural design to align with Milan's climate conditions.

When selecting building materials, our focus shifted toward minimizing the use of materials with high greenhouse gas emissions during production, notably concrete and steel. Instead, we employed a more environmentally friendly material and structural approach, guided by simulations conducted on the Ubaku website, ultimately choosing CLT wooden boards.

In our pursuit of achieving zero energy consumption through building energy assessment, we employed Design Builder for comprehensive simulations. These simulations encompassed energy usage both with and without shading during summer, underscoring the essential role of rotating shading systems. Additionally, we calculated the building's annual energy consumption for heating, cooling, lighting, and equipment, all through the utilization of Design Builder.

Upon selecting geothermal heat pumps, solar water heaters, and solar PV as viable renewable energy sources, we harnessed the power of the RETScreen software for precise calculations. This analysis revealed that the heat pump consumed 949.5 MWh of electricity, while the solar PV system generated 951.7 MWh.

This outcome demonstrates that the entire building can sustain its energy demands solely through renewable sources, thereby achieving net-zero carbon emissions. Using REScreen, we quantified the carbon emissions reduction achieved by transitioning from fossil fuels to renewables, resulting in a yearly reduction of 240.78 tons.

While the design outcomes presented in this project are tailored to the specific climate conditions of Milan, it is important to underscore that the design methods, simulation techniques, carbon emission calculations, and sustainability principles employed are universally applicable. These methodologies and insights can serve as valuable reference points and adaptable models for similar endeavors in diverse geographical and climatic contexts.

The focus on sustainable architecture, energy efficiency, and carbon emissions reduction transcends geographical boundaries. By elucidating the interplay between green spaces and architectural design, and by leveraging innovative simulation tools and calculations, this project offers a template for fostering environmentally responsible architectural practices. These practices can be tailored and implemented in various regions, contributing to a global effort to combat climate change and advance the cause of sustainable construction.

By recognizing the universality of these methods and their potential to mitigate the environmental impact of the building sector, this project aspires to inspire and inform similar initiatives worldwide. It underscores the imperative for all communities to embrace sustainable design principles and embark on a path toward carbon neutrality in the pursuit of a more environmentally conscious and resilient future.

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