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Course of Building Engineering

Master's Thesis
REGEN BOSTON energizing urban living

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ABSTRACT

The aim of the project is to create the most innovative, yet practical, multi-unit style housing typologies for urban living of the century on one of two city owned sites. We chose the site that is located at Sargents Wharf, North End in the in the Boston inner Harbor.

The energy performance of the buildings has been one of the core considerations of the project. Passive energy performance improvement strategies like envelope design, orientation, natural ventilation and daylighting have been given first consideration with developing a well-insulated envelope being a close second.

Keeping in view the nature of the building, non-invasive or minimally invasive architectural, structural and technological solutions have been proposed. Additionally the new building has been developed on modern insulation philosophies with air and water tight envelope/insulation solutions and modern materials to make the project as multi-faceted as possible.

ABSTRACT (ITA)

Lo scopo del nostro progetto è stato quello di creare delle tipologie abitative innovative, pratiche e multi-modulari per l'abitare urbano del nostro secolo. Abbiamo scelto il sito che si trova a at Sargent's Wharf, North End, nel porto interno di Boston.

La performance energetica dei fabbricati è stata una delle principali considerazioni del progetto. La considerazione di una performance relativa all'energia passiva ha portato ad altre considerazioni strategiche, riguardanti il design dell'involucro esterno, l'orientazione, la ventilazione e l'illuminazione naturali, aspetti che sono stati sviluppati tenendo sempre presente l'idea di un involucro ben isolato.

Guardando alla natura dell'edificio, che mirava ad essere non invasiva, o comunque meno invasiva possibile, sono state proposte le soluzioni strutturali e tecnologiche. Inoltre il nuovo fabbricato è stato sviluppato sulla base di moderne filosofie di isolamento con acqua e aria inserite nelle soluzioni per l'involucro, e sull'utilizzo di materiali innovativi, in modo da rendere il progetto stesso più sfaccettato possibile.

CONTENTS

CHAPTER 1 URBAN DESIGN

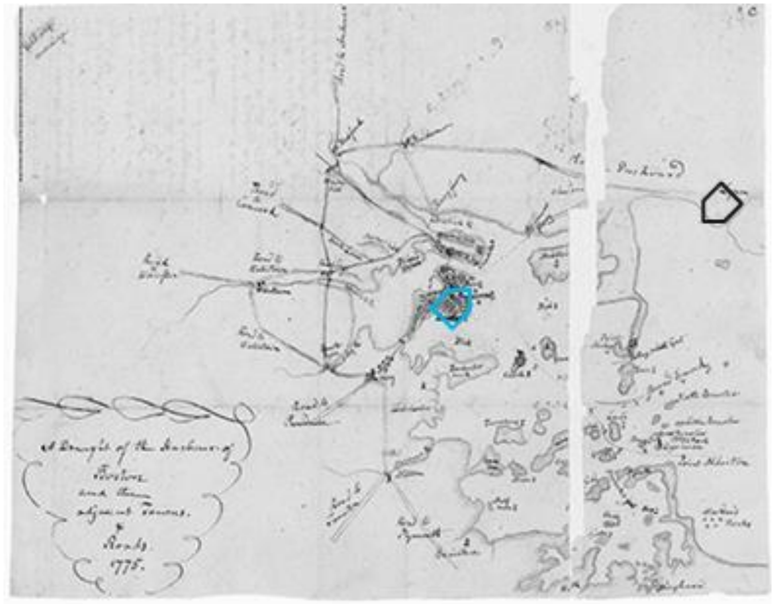
1.1 Urban design; Competition Brief

Title of project is "REGEN BOSTON energizing urban living".

1.1.1 Contest objectives:

In the 21st Century, more people than ever will be living in Cities. Generations are drawn together through the lifestyles a city can provide. In response to growing density in urban areas, cities will renovate and re-purpose existing areas, and new urban centers are ripe to erupt. What new housing typologies will support this love for urban living? If Boston, and other cities, wants to retain their diverse demographic and lasting appeal, there needs to be an enticing solution for housing or, the cities risks losing their greatest asset, residents.

ReGEN Boston seeks innovative housing typologies to responds to Boston's need to house the continuing life-cycles of its residents. The City needs a new round of planning, charged with harnessing growth and extending it to the many neighborhoods, many of which have been overlooked or undervalued.



Belknap, Jeremy. *"Manuscript map of the Boston Harbor, 1775".* Pen and Ink. Massachusetts Historical Society. *https://www.masshist.org/online/massmaps/list.php.* 19 August 2012.

Figure 1-1 : Map of Boston Harbor, 1775

Entrants are challenged to re-imagine traditional housing typologies in order to provide a platform to promote:

- Community living
- Sustained urban life-cycles
- Family urban housing
- Affordability
- Sustainable growth

There are real unfilled opportunities in Boston's housing market and we need creative ideas and proposals for public discussion. This competition will celebrate the 25th anniversary of the Boston Society of Architects 'Boston Visions National Design competition' held in 1988.

1.1.2 Official Competition Regulations:

ReGEN Boston invites designers to create the most innovative, yet practical, multi-unit style housing typologies for urban living of the century on one of two city owned sites. This ideas competition pits the solutions generated for two distinct sites in the Boston Harbor against one another to see which ideas come out on top.

Program Requirements:

- Multi-generational,Housing.(Component1)
  Competitors should develop solutions that improve urban lifestyles in the City for multi-generational users. The idea should create and foster a sense of community between generations, contextualized within the existing and evolving neighborhoods. Entrants should consider how their designs will engage with or ignore the site's existing conditions. While thinking of the urban lifestyle entries should also address connections to water front access, public space, and city infrastructure.
- Public-Space(Component2)
  Entries must consider public space as an integral part of the design. Create an active, engaging and energetic community presence within the design that is universally accessible. Parks, plazas, walking path and unimagined solutions can serve as examples.
- Unique-City-Infrastructure(Component3)
  This component challenges designers to incorporate their design into the larger context of the city's existing infrastructure, while creating a destination tied to the fabric of the community. Designers are asked to develop unique solutions that complement their housing strategy. Think urban farming, hub way stations, transit extensions, and future environmental considerations; to name a few.

Competition entrants are encouraged to consider the following criteria for their entries:

- Reconnect residents with Boston waterfront
- Create a sense of communal inclusion on the site (public program element)
- Housing geared towards all walks of life (students, families, elderly, disabled, etc.)
- A sustainable and affordable housing model to help inform the future of Boston housing

- Innovative methods of creating social connection between residents

1.2 Vision of the Project

Two sites, one goal

A. Site 1:

Hess Site, East Boston

146 Condor Street, Boston, MA

Figure 1-2: Hess Site, East Boston

The Hess site is situated along the Chelsea Creek on the East Boston waterfront. Between mid-1930 and 1979, this site served as a bulk petroleum storage facility. Although the petroleum tanks were decommissioned in 1979, they remained on the site and continued to contaminate the Creek. It wasn't until 1997, when the community began to organize and formed the Chelsea Creek Action Group [CCAG], that a visionary agenda has been established for how this site can served the East Boson neighborhood. The proposed $1.7 million vision to remediate the contaminated site, manage storm water, restore wildlife habitat, and to provide community access to the Chelsea Creek emerged through extensive community involvement, the Neighborhood for Affordable Housing, the Watershed Institute, Mount Auburn Associates, and the Boston Parks and Recreation Department. Today, the oil tanks have been removed and the natural wetlands habitats have begun to return. But, the Boston Redevelopment Authority [BRA] has very different plans for the Hess site. Estimated at $4.5 million, the BRA plans to fill the site with 50,000 cubic yards of fill and dewatering activities in order to prepare the site for development. This would destroy the fragile habitat that has begun to re-emerge. CCAG is not opposed to some development and the BRA holds public review meetings to ensure community concerns are heard, any development on the Hess site will be a delicate balance between the needs of the community, the city, and the environment.

B. Site 2(Chosen site for the project):

Sargents Wharf, North End

1 Eastern Ave, Boston, MA

Figure 1-3: How solar lighting works during night

Sargents Wharf is located in the Boston inner Harbor, on the edge of the North End. This site has always had close ties to the sea. Originally it was encapsulated region surrounded by the Mill Creek, the Harbor, the Charles River, and the Mill Pond. In 1722 the site was densely populated by early merchant dwellings, warehouses and wharves for shipbuilders. During the wave of immigration, Italians vibrantly populated the area. Over the centuries, this neighborhood grew to be characterized by an energetic tie between commerce and residence. Today, the site exists as a money maker, otherwise known as a parking lot. The land, which is currently valued at 6 million dollars, stands as one of the only undeveloped parcels amongst the wharves. Due to its high value, most developments are planned for a small percentage of the city's population: luxury residence.

- Limiting energy consumption

Improved performance of building (residential unit) by limiting losses, installation of renewable energy plants, re-use of gray and rainwater and new efficient waste system are the main strategies for decreasing energy consumption in the area. While at urban design level to use solar street lights and immediate power off-grid applications such as pedestrian lighting, way-finding solutions and advertising signage or be stored in an on-board battery in the unit which can be done by using pavegen slabs for pedestrian pathways.

- Improving connectivity

Increasing parking supply by creating multi-story garages at strategic points, especially on existing parking lots. Managing car mobility in the north end Boston, i.e. classifying the streets with different accessibility (pedestrian, car traffic, limited car traffic for delivery and residents or for a particular time of a day). New pedestrian paths and pedestrian areas will be defined with priority pedestrian access to areas of public use.

- Enhancing commercial activity

Strategies for enhancing commercial activity are realization of protected pedestrian areas, planning the space for urban (open space) events, changing use of some existing spaces to commercial and enhancing the neighborhood business opportunities.

- Enhancing walkability

Strategies for enhancing walkability, development of new trails and pedestrian pathways in north end Boston.

- Prevention of social exclusion

Facilities for young and elderly should be realized (i.e. housing for elderly people as well as families). New cultural and recreational facilities should be provided.

1.3 History:

The North End, often called Boston's "Little Italy," is a one-square-mile waterfront community, bordered by Commercial and Causeway Streets and Atlantic Avenue, located within walking distance of Boston's financial district and Government Center. A highly desirable residential area for professionals who work nearby, the neighborhood also is a major attraction for tourists and Bostonians alike, who come seeking the best in Italian cuisine and to enjoy the decidedly Italian feel of the region. Hanover and Salem Streets, the two main streets of this bustling historic neighborhood, are lined with wonderful restaurants, cafes and shops, selling a variety of delectable edible goods. A trip to Boston would not be complete without including a meal at one of North End's over one hundred fine Italian restaurants.

The North End is a vibrant community that beckons both tourists and residents to enjoy its bounty. The many Genovese, Sicilian, Milanese and Neapolitan immigrants who originally settled here moved onto streets where others from the part of Italy that they called home had settled. In these enclaves, the distinctive dialects, history, and traditions of the regions in Italy from which they came were carefully preserved, and the patron saints of those regions of Italy are celebrated during the summer months in the North End even today. It is a unique treat to witness one of the many festivals celebrating the saints that occur every weekend throughout the summer.

When the first British settlers came to the North End in the early 1600s, the region was a narrow peninsula surrounded on three sides by water. Humble thatched-roof cottages, set amidst gardens and pastures, soon dotted the landscape. Later land was added to the region by filling in Mill Pond with soil from the top of Copp's Hill and Beacon Hill. Subsequent landfill projects have extended the shoreline even more, expanding the North End to a size far greater than in Colonial times.

The first residents of the North End worked at a variety of crafts (e.g., carpentry, shoemaking) from their homes. Their Puritan religion required obedience to a very strict moral code and there were severe punishments for infractions. For example, one man was whipped for kissing his wife in public upon his arrival from a long sea voyage. Two Puritan religious leaders of the period, Increase Mather and his son Cotton Mather are well known for having stirred up fears that ultimately led to the Salem witchcraft trials. The Mathers are buried in the North End's Old North Cemetery on Copp's Hill. The early residents of the North End also included slaves who lived in an area called "New Guinea," after the region of Africa from which they had been brought. Some of them are buried in Old North Cemetery as well.

By the 18th century, many prominent people of British ancestry had settled in the North End, working in the mercantile and shipping industries and building beautiful mansions there. These people helped develop the area in important ways. During this period, for example, Charles Bulfinch, the famous architect, built a beautiful church, since renamed St. Stephen's, which still stands today. The Eliot School, the oldest elementary school in the United States, was founded at this time as well. Later, in 1740, Peter Faneuil donated funds to build Faneuil Hall adjacent to the North End. The building was designed to serve as a town hall and marketplace for Boston. Because some of the meetings held at Faneuil Hall figured prominently in the American Revolution, it is often called the "Cradle of Liberty." Once gutted by fire and rebuilt, Faneuil Hall and Quincy Market continue to be must-see landmarks for tourists to Boston. Another landmark in the North End is the home of Paul Revere, one of the participants in the Boston Tea Party, who is most famous for his ride from Boston to Lexington and Concord to warn the Patriot leaders that the British were coming.

At the end of the war, many of the wealthy residents of the North End, those who remained loyal to Britain, left the area, either returning to England, or moving to eastern Canada, or to other parts of Boston or the suburbs. Within a few decades, the region went into decline as wave after wave of poor immigrants - Irish, Jews, Portuguese, and Italians - crowded into the North End. By 1800, the large mansions had become run down and were replaced by tenements and lodging houses to serve as residents for the newcomers. In addition, warehouses and dockyards were built in the area for shipping which had become the major industry of the region and the quality of life in the region changed as sailors, who needed to unwind after lengthy periods at sea, also flooded in. Prostitution, drunkenness, gambling, and crime were rampant in the area. As one observer wrote in 1872: “North End was once the most important part of the town, containing not only the largest warehouses and public buildings, but the most aristocratic quarter for dwelling-houses. But this was a long time ago. A large part of the North End proper has been abandoned by all residents except the poorest and most vicious classes."

The first Irish immigrants came to the North End in the 1840s. Their numbers increased rapidly after 1847, which was the year of the potato famine in Ireland, and finally peaked around 1880. The Irish residents of the North End experienced severe job discrimination, which kept them in extreme poverty, with living conditions that promoted the rapid spread of illness and very high mortality rates. Large families lived in single-room apartments. The most fortunate found jobs as laborers working on the railroads, as maintenance workers, in construction, in factories, or as domestics.

Around mid-century, Jewish immigrants, forced by hardships in Eastern Europe arrived, joining the Irish in the North End. The new arrivals were supported by relatives and acquaintances that helped them out until they could get on their feet. Many of these immigrants were skilled tailors working in the clothing industries. Others worked as peddlers, buying small items that people needed for day-to-day life on credit and selling them at a small profit. These peddlers often had to spend many days on the road away from their family and friends. Those who were successful acquired real estate and/or opened their own shops. But by the 1920s most of the Jewish residents of the North End had moved to other areas of Boston or the suburbs.

The first Italians arrived in the North End in the 1860s, forced by unbearable conditions in the homeland and their numbers grew in the 1880s and 1890s. Most were unskilled laborers. Although many of the first Italian immigrants worked as vendors of fruits and vegetables, later many found work in commercial fishing, in shipping, in construction (e.g., building subways), and as peddlers and shopkeepers, selling the food, clothing, and services needed by other residents of the North End. Like the Jewish immigrants to the

North End, they sought help from family members and acquaintances from the same regions of Italy who had already established themselves in the area. Over time, this resulted in enclaves of residents living together on streets segregated by the region of Italy - Sicily, Milan, Naples, and Genoa - from which they had come and preserving its language and customs as well. Over the next decades, the Italian population of the North End increased and other immigrant groups moved elsewhere. By 1900, Italians had firmly established themselves in the North End, and by 1930, the North End was almost one hundred percent Italian.

The Italian population in the North End has gotten smaller in recent years with sky-rocketing property values that have forced many of the less affluent residents to move elsewhere. Increasingly, the residents of the North End are young professionals attracted to the area by its proximity to their downtown offices, by the North End's narrow streets and brick buildings, by its safety and sense of community, as well as by its decidedly European ambience. Although Italians presently make up less than half of the population of the North End, its old world Italian flavor is preserved the region's language, music, cuisine, and customs.

City evolution and growth along history:

The history of Boston plays a central role in American history. In 1630, Puritan colonists from England founded the town, which quickly became the political, commercial, financial, religious and educational center of the New England region. The American Revolution erupted in Boston, as the British retaliated harshly for the Boston Tea Party and the patriots fought back. They besieged the British in the city, with a famous battle at Bunker Hill and won the Siege of Boston, forcing the British to evacuate the city. However, the combination of American and British blockades of the town and port during the conflict seriously damaged the economy, and the population fell by two thirds in the 1770s.

The city recovered after 1800, re-establishing its role as the transportation hub for the New England region with its network of railroads, and even more important, the intellectual, educational and medical center of the nation. Along with New York, Boston was the financial center of the United States in the 19th century, and was especially important in funding railroads nationwide. In the Civil War era, it was the base for many anti-slavery activities. In the 19th century the city was dominated by elite known as the Boston Brahmins. They faced the political challenge coming from Catholic immigrants. The Irish Catholics, typified by the Kennedy Family, took political control of the city by 1900.

The industrial foundation of the region, financed by Boston, reached its peak around 1950; thereafter thousands of textile mills and other factories were closed down and the city went into decline. By the 21st century the city's economy had recovered and was centered on education, medicine, and high technology—notably biotechnology, while the many surrounding towns became residential suburbs.

Prehistorical area:

The Shawmut Peninsula was originally connected to the mainland to its south by a narrow isthmus, Boston Neck, and surrounded by Boston Harbor and the Back Bay, an estuary of the Charles River. Several prehistoric Native American archaeological sites, including the Boylston Street Fishweir, excavated during construction of buildings and subways in the city, have shown that the peninsula was inhabited as early as 7,500 years before present.

Boston had taken an active role in the protests against the Stamp Act of 1765. Its merchants avoided the customs duties which angered London officials and led to a crackdown on smuggling. Governor Thomas Pownall (1757 to 1760) tried to be conciliatory, but his replacement Governor Francis Bernard (1760–69) was a hard-liner who wanted to stamp out the opposition voices that were growing louder and louder in town meetings and pamphlets. Historian Pauline Maier says that his letters to London greatly influenced officials there, but they "distorted" reality. "His misguided conviction that the 'faction' had espoused violence as its primary method of opposition, for example, kept him from recognizing the radicals' peace-keeping efforts....Equally dangerous, Bernard's elaborate accounts were sometimes built on insubstantial evidence." Warden argues that Bernard was careful not to explicitly ask London for troops, but his exaggerated accounts strongly suggested they were needed. In the fall of 1767 he warned about a possible insurrection in Boston any day, and his exaggerated report of one disturbance in 1768, "certainly had given Lord Hillsboro the impression that troops were the only way to enforce obedience in the town." Warden notes that other key British officials in Boston wrote London with the "same strain of hysteria." Four thousand British Army troops arrived in Boston in October 1768 as a massive show of force; tensions escalated.

Figure 1-4: Boston in October 1768

A map showing Boston and vicinity, including Bunker Hill, Dorchester Heights, and troop disposition of Gen.Artemas Ward during the Siege of Boston. From "Marshall's Life of Washington" (1806).

By the late 1760s Americans focused on their rights as Englishmen, especially the principle of "No Taxation without Representation," as articulated by John Rowe,James Otis, Samuel Adams and other Boston firebrands. Boston played the primary role in sparking both the American Revolution and the ensuing American Revolutionary War. The Boston Massacre came on March 5, 1770, when British soldiers fired into unarmed demonstrators outside the British custom house, resulting in the deaths of five civilians and dramatically escalating tensions. Parliament, meanwhile, insisted on its right to tax the Americans and finally came up with a small tax on tea. Up and down the 13 colonies, Americans prevented merchants from selling the tea, but a shipment arrived in Boston Harbor. On December 16, 1773, 30–60 local Sons of Liberty, disguised as Indians, dumped 342 chests of tea in the harbor in the Boston Tea Party. The Sons of Liberty decided to take action in order to defy Britain's new tax on tea, but the British government retaliated with a series of harsh laws, closing down the Port of Boston and stripping Massachusetts of its self-government. The other colonies rallied in solidarity behind Massachusetts, setting up the First Continental Congress, and arming and training their militia units. The British sent more troops to Boston, and made its commander General Thomas Gage the governor. When Gage discovered the Patriots had set up a shadow government based in the town of Concord, he sent troops to break it up. Paul Revere, William Dawes, and Dr. Samuel Prescott made their famous midnight rides to alert the Minutemen in the surrounding towns, who fought the resulting Battle of Lexington and Concord in April 1775. It was the first battle of the American Revolution.

Figure 1-5: A plan of the TOWN of Boston, 1775

Militia units across New England rallied to the defense of Boston, and Congress sent in General George Washington to take command. The British were trapped in the city, and suffered very heavy losses in their victory at the Battle of Bunker Hill. Washington brought in artillery and forced the British out as the patriots took full control of Boston. The American victory on March 17, 1776, is celebrated as Evacuation Day. The city has preserved and celebrated its revolutionary past, from the harboring of the USS Constitution to the many famous sites along the Freedom Trail.

1.4 Geographic expansion:

Figure 1-6: 1880 census map showing landfill and annexations up until that year

The City of Boston has expanded in two ways - through landfill and through annexation of neighboring municipalities.

Between 1630 and 1890, the city tripled its physical size by land reclamation, specifically by filling in marshes and mud flats and by filling gaps between wharves along the waterfront, a process Walter Muir Whitehill called "cutting down the hills to fill the coves." The most intense reclamation efforts were in the 19th century. Beginning in 1807, the crown of Beacon Hill was used to fill in a 50-acre (20 ha) mill pond that later became the Bulfinch Triangle (just south of today's North Station area). The present-day State House sits atop this shortened Beacon Hill. Reclamation projects in the middle of the century created significant parts of the areas now known as the South End, West End, Financial District, and Chinatown. After The Great Boston Fire of 1872, building rubble was used as landfill along the downtown waterfront.

The most dramatic reclamation project was the filling in of the Back Bay in the mid to late 19th century. Almost six hundred acres (240 hectares) of brackish Charles River marshlands west of the Boston Common were filled in with gravel brought in by rail from the hills of Needham Heights. Boston also grew by annexing the adjacent communities of East Boston, Roxbury, Dorchester, West Roxbury(including Jamaica

Plain and Roslindale), South Boston, Brighton, Allston, Hyde Park, and Charlestown, some of which were also augmented by landfill reclamation.

Several proposals to regionalize municipal government failed due to concerns about loss of local control, corruption, and Irish immigration, including:

- 1896 - "County of Boston" proposal in the state legislature
- 1910 - "Real Boston" proposal by Edward Filene to create a regional advisory board
- 1912 - "Greater Boston" proposal by Daniel J. Kiley that would have enlarged the City of Boston to include all 32 municipalities within 10 miles
- 1919 - Annexation proposal by Boston mayor Andrew Peters

The state government has regionalized some functions in Eastern Massachusetts, including the Massachusetts Bay Transportation Authority (public transit), the Massachusetts Water Resources Authority (water and sewer), and the Metropolitan District Commission (parks, later folded into the state-wide Department of Conservation and Recreation).

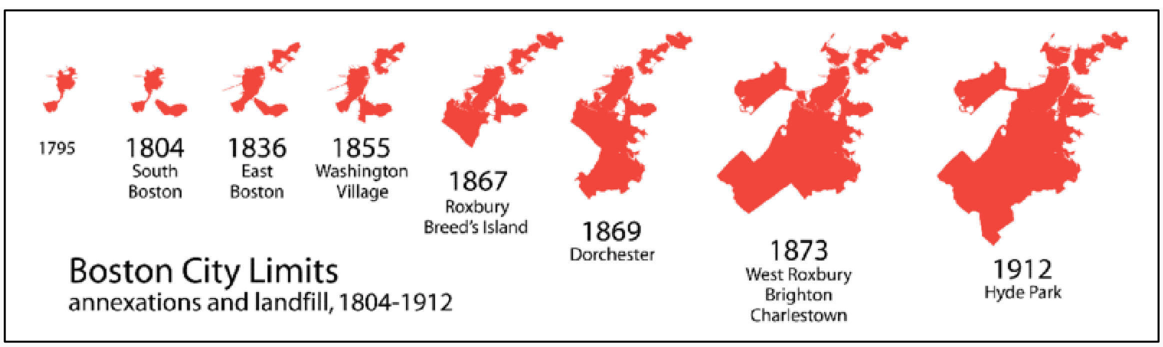


Figure 1-7: Several proposals to regionalize municipal government, Annexations and Landfill, 1804-1912. (Some dates approximate, due to time lag between approval and completion.)

Timeline of annexations, secessions, and related developments (incomplete):

- 1705 - Hamlet of Muddy River split off to incorporate as Brookline
- 1804 - First part of Dorchester by act of the state legislature[68]
- 1851 - West Roxbury (including Jamaica Plain and Roslindale) is split off from Roxbury as an independent municipality.
- 1855 - Washington Village, part of South Boston, by act of the state legislature[68]
- 1868 - Roxbury
- 1870 - Last part of Dorchester
- 1873 - Brookline-Boston annexation debate of 1873 (Brookline was not annexed)
- 1874 - West Roxbury, including Jamaica Plain and Roslindale (approved by voters in 1873)[68]
- 1874 - Town of Brighton (including Allston) (approved by voters in 1873)[68]
- 1874 - Charlestown (approved by voters in 1873)[68]
- 1912 - Hyde Park[69]
- 1986 - Vote to create Mandela from parts of Roxbury, Dorchester, and the South End passes locally but fails city-wide.

Timeline of land reclamation (incomplete):

- 1857 - Filling of the Back Bay begins
- 1882 - Present-day Back Bay fill complete
- 1890 - Charles River landfill reaches Kenmore Square, formerly the western end of the Back Bay mill pond
- 1900 - Back Bay Fens fill complete

1.5 Climate:

A brief study of weather and climate is shown although a detailed study of weather and climate will be shown in the next chapters.

Boston has a continental climate with some maritime influence, and using the −3 °C (coldest month (January) isotherm, the city lies within the transition zone from a humid subtropical climate (Köppen Cfa) to a humid continental climate (Köppen Dfa), although the suburbs north and west of the city are significantly colder in winter and solidly fall under the latter categorization. Summers are typically warm to hot, rainy, and humid, while winters oscillate between periods of cold rain and snow, with cold temperatures. Spring and fall are usually mild, with varying conditions dependent on wind direction and jet stream positioning. Prevailing wind patterns that blow offshore minimize the influence of the Atlantic Ocean.

The hottest month is July, with a mean temperature of 23.0 °C. The coldest month is January, with a mean of 1.7 °C. Periods exceeding 32 °C in summer and below freezing in winter are not uncommon but rarely extended, with about 13 and 25 days per year seeing each, respectively and the most recent sub-18 °C reading occurring on January 24, 2011.Several decades may pass between 38 °C readings, with the most recent such occurrence July 22, 2011. The city's average window for freezing temperatures is November 9 through April 5.

Official temperature records have ranged from −28 °C on February 9, 1934, up to 40 °C on July 4, 1911; the record cold daily maximum is −17 °C on December 30, 1917, while, conversely, the record warm daily minimum is 28 °C on August 2, 1975. Boston's coastal location on the North Atlantic moderates its temperature, but makes the city very prone to Nor'easter weather systems that can produce much snow and rain. The city averages 1,110 mm of precipitation a year with 111 cm of snowfall per season. Snowfall increases dramatically as one goes inland away from the city (especially north and west of the city) away from the moderating influence of the ocean.

Most snowfall occurs from December through March, as most years see no measurable snow in April and November, and snow is rare in May and October. There is also high year-to-year variability in snowfall, for instance the winter of 2011−12 saw only 23.6 cm of accumulating snow, but the previous winter, the corresponding figure was 2.06 m. Fog is fairly common, particularly in spring and early summer and the occasional tropical storm or hurricane can threaten the region, especially in late summer and early autumn. Due to its situation along the North Atlantic

The city is often subjected to sea breezes especially in the late spring, when water temperatures are still quite cold and temperatures at the coast can be more than 11 °C colder than a few miles inland. Thunderstorms occur from May to September, that is occasionally severe with large hail, damaging winds and heavy downpours. Although downtown Boston has never been struck by a violent tornado, the city itself has experienced many tornado warnings while damaging storms are more common to areas north, west, and northwest of the city.

1.6 Economy:

A global city, Boston is placed among the top 30 most economically powerful cities in the world. Encompassing $363 billion, the Greater Boston metropolitan area has the sixth-largest economy in the country and 12th-largest in the world.

Boston's colleges and universities have a significant effect on the regional economy since it attracts more than 350,000 college students from around the world who contribute more than $4.8 billion annually to the city's economy.
The area's schools are major employers and attract industries to the city and surrounding region. The city is home to a number of technology companies and is a hub for biotechnology, with the Milken Institute rating Boston as the top life sciences cluster in the country. Boston receives the highest absolute amount of annual funding from the National Institutes of Health of all cities in the United States.
The city is also considered highly innovative for a variety of reasons that include the presence of academia, access to venture capital and the presence of many high-tech companies.

Tourism comprises a large part of Boston's economy, with 21.2 million domestic and international visitors spending $8.3 billion in 2011. Because of Boston's status as a state capital and the regional home of federal agencies, law and government are another major component of the city's economy. The city is a major seaport along the United States' East Coast and the oldest continuously operated industrial and fishing port in the Western Hemisphere.

Other important industries are financial services, especially mutual funds and insurance. Boston-based Fidelity Investments helped popularize the mutual fund in the

1980s and has made Boston one of the top financial cities in the United States. The city is home to the headquarters of Santander Bank, and Boston is a center for venture capital firms.

State Street Corporation which specializes in asset management and custody services is based in the city.

Several major companies headquartered within Boston or nearby—especially along Route 128, the center of the region's high-tech industry. In 2006 Boston and its metropolitan area ranked as the fourth-largest cyber city in the United States with 191,700 high-tech jobs.

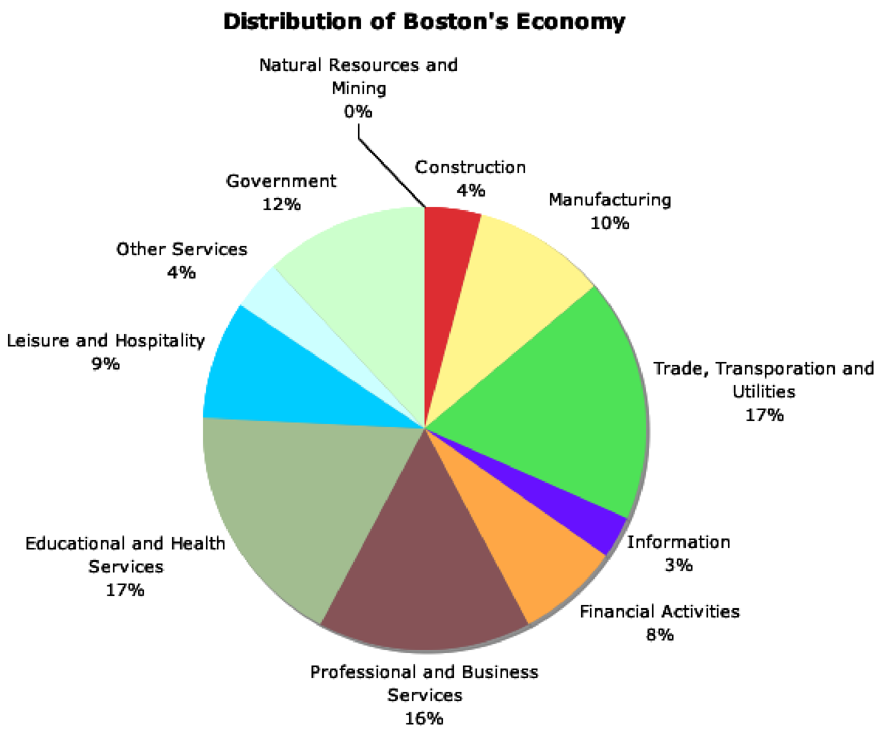


Figure 1-8: Distribution of Boston's Economy

1.7 Function, Suitability and feasibility:

Based on the carried out analysis, it was quite interesting to start thinking of energizing urban living and to start conducting conclusions on the previously collected data and go into deep details of the site and see what are the edges of the site from all perspectives and hence to start implementing the theoretical theories to produce a good project that gives a push to the city with taking into considerations the urban tissue and the morphology of the city

1.8 Geography:

Boston is the capital and largest city of the Commonwealth of Massachusetts in the United States. Boston also serves as county seat of Suffolk County. The largest city in New England, the city proper, covering 124 km^2, had an estimated population of 645,966 in 2014, making it the 24th largest city in the United States. The city is the anchor of a substantially larger metropolitan area called Greater Boston, home to 4.5 million people and the tenth-largest metropolitan area in the country. Greater Boston as a commuting region is home to 7.6 million people, making it the sixth-largest Combined Statistical Area in the United States.

One of the oldest cities in the United States, Boston was founded on the Shawmut Peninsula in 1630 by Puritan colonists from England. It was the scene of several key events of the American Revolution, Upon American independence from Great Britain, the city continued to be an important port and manufacturing hub, as well as a center for education and culture Through land reclamation and municipal annexation, Boston has expanded beyond the original peninsula.

Its rich history helps attract many tourists, with Faneuil Hall alone attracting over 20 million visitors Boston's many "firsts" include the United States' first public school, Boston Latin School (1635),

The area's many colleges and universities make Boston an international center of higher education and medicine, and the city is considered to be a world leader in innovation for a variety of reasons.

It has one of the highest costs of living in the United States, though it remains high on world livability rankings.

Geographically Boston can be divided into several zones was formed all over the history through different circumstances some of these areas are new and some are historical depending on the age of developing them.

These zones are as shown in the following map can be divided into:

- North end
- Downtown
- Government Center
- West End
- Bacon Hill
- Boston Public garden
- Back bay
- Seaport District

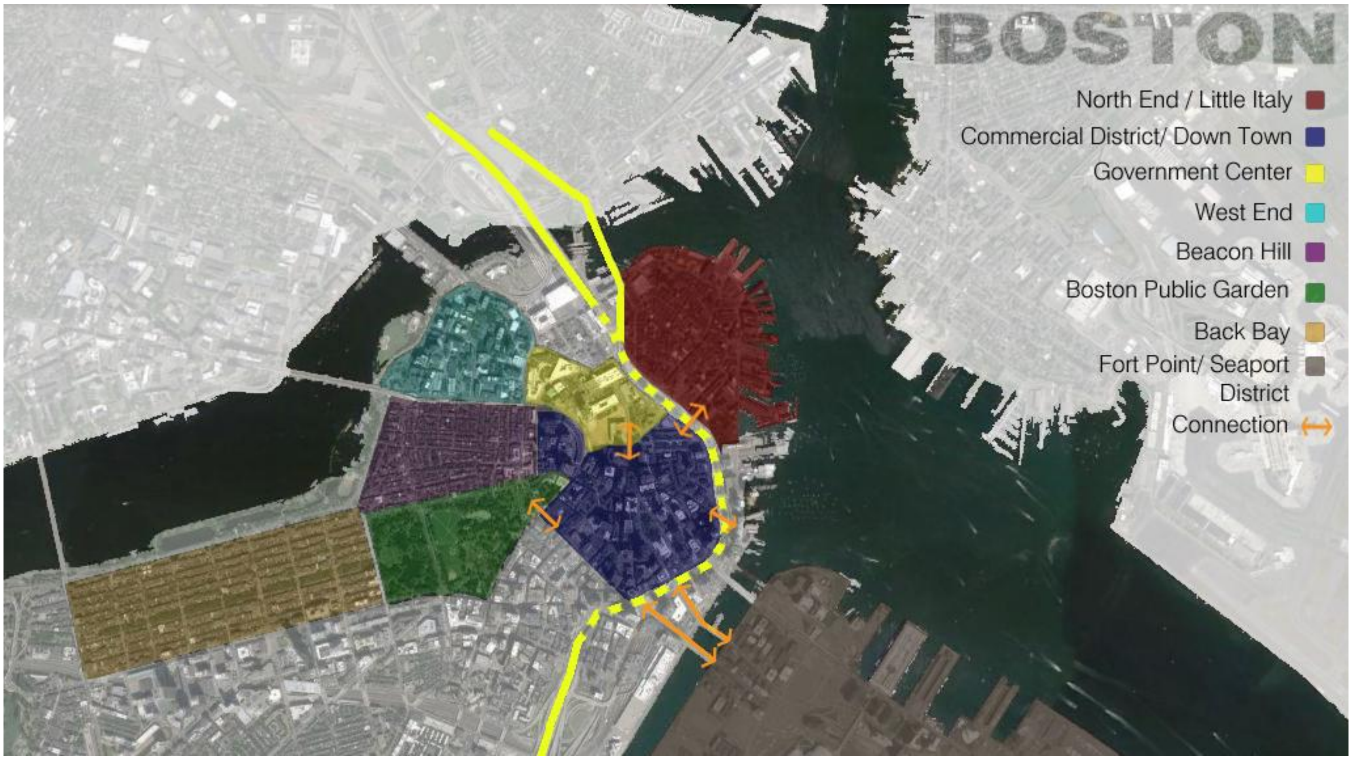


Figure 1-9: North end map

Since the project lies in north-end Boston, the following map shows the site and its relation with the surroundings together with the relation of the site with the waterfront and the harbor walk which is one of the main important projects in Boston, detailed analysis and maps will be showed in the following pages.

Figure 1-10: Boston city scale map

Site No. 2:

Among the two sites which had a common background regarding the location, morphology, transportation etc. , it was very important to start choosing a site to start working on and based on that , the competition brief and the requirements were really well studied in order to reach the main aim of the project.

based on the carried out analysis it was observed that the second site could be better from the terms of urban living especially that it is very well connected to the city historical center in a very critical location full of borders which always helps in a better design, together with the observed governmental efforts to enhance the city center and to connect north end

Boston with financial area especially that Boston is considered as the most walkable stat in the united states.

Merging the American citizen's trends with the requirements of the project, it was clearly observed that something not easy needs to be designed (Something that changes way of living)

In the following pages it will be introduced the analysis carried out on the site and how it was concluded to design the so called "**Regenerate Boston"**

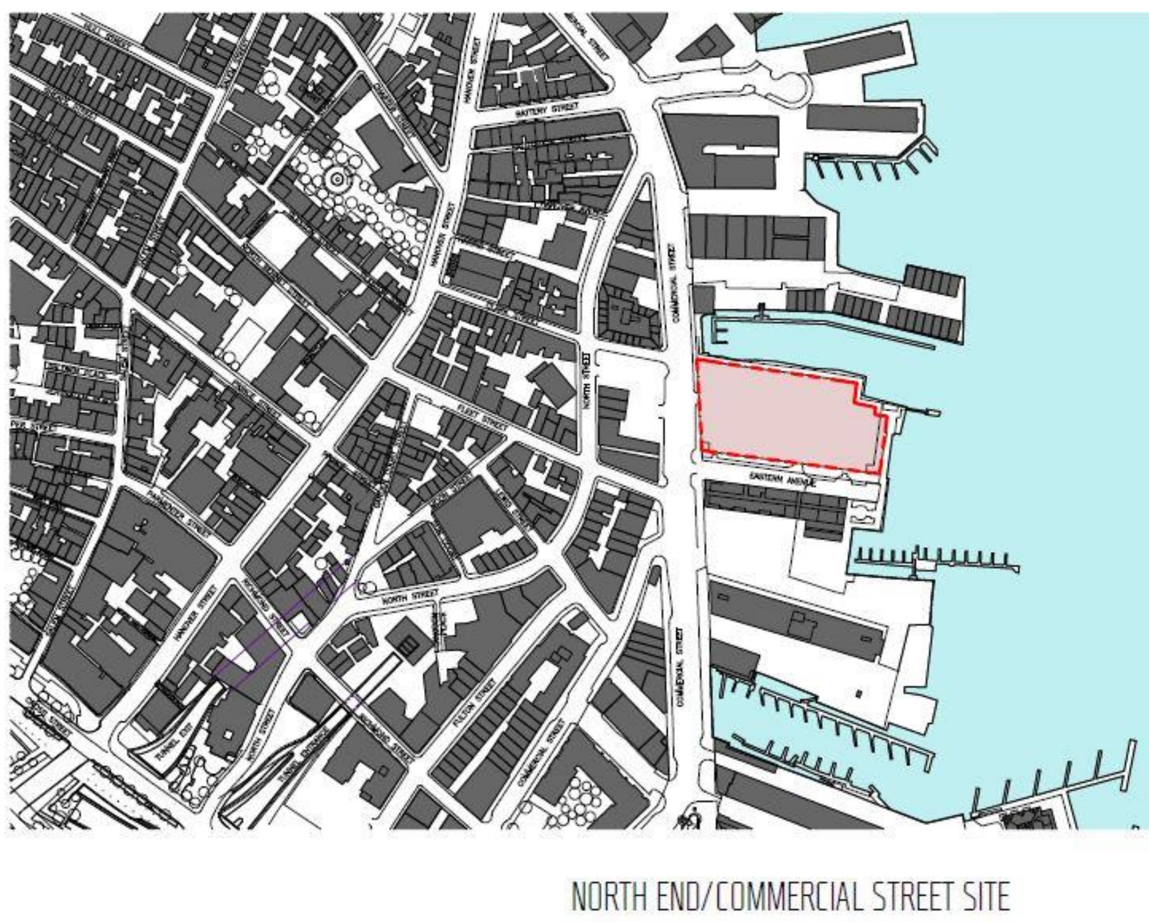


Figure 1-11: Boston city scale map

1.9 Site Analysis:

To start designing the project, doing very detailed analysis was a must to maintain accurate data to provide well designed project that matches with the urban tissue and provides applicable solutions for the city problems.

One of the main aspects that guided the design of the project was sustainability and how to depend the most on renewable energy to achieve community needs, and hence the analysis started by doing the shadow analysis for all north end Boston where the site lies and where we are focusing all our analysis on since it is strongly connected to the financial district (downtown of Boston)

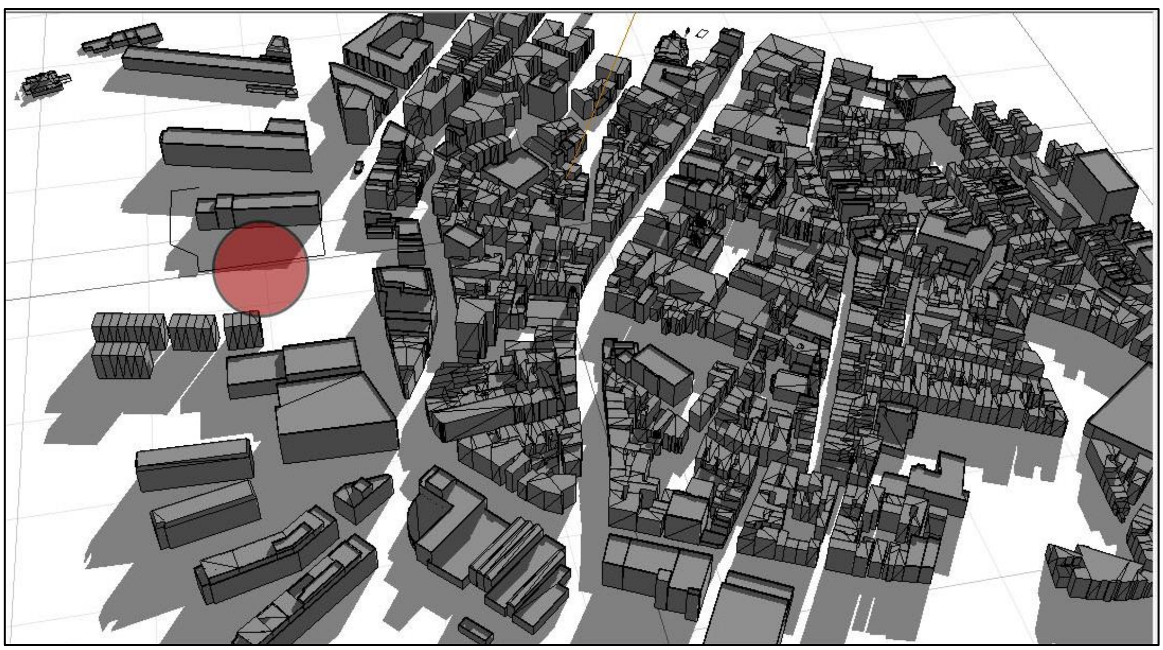


Figure 1-12: shadow analysis on 1st Jan at 2pm

The previously shown map shows the shadow analysis of north end Boston on the first of January which presents the minimum angle of inclination of the sun, to study the effect of the buildings on each other's and on the streets which relatively affects the solar gains of these elements.

The following map shows the shadow analysis of north end Boston in first of June at 2pm which presents the sun maximum verticality and hence the shadow becomes preferable and creates higher levels of comfort zones .

Figure 1-13: shadow analysis on 1st June at 2pm

- **Conclusion**:

It was clear from the analysis that the two main streets which are (Hanover and Salem streets) are having a very good thermal exposure in winter and good shadow in summer which led us to start analyzing them on a smaller scale on Ecotect software so that we could get exact values of solar exposure

The following figure shows the solar access analysis of the two above mentioned streets and the connections between them

Figure 1-14: winter solar access analysis

1.10 North-end Boston land use:

An analysis was carried out to know exactly what is the functions of the surroundings to be able to understand the category of the zone that we are working in , and hence the function assignment could be done.

The figure below shows the distribution of functions on land blocks based on the color and it is clear that most of the North end Boston is residential and it was also clear that the commercial or retails is of very low portions

- **Conclusion:**

By studying the relationship between parking lots and the residential domination it was found that north-end Boston is facing a bit problem since people who are heading to financial district usually park their cars in North-end Boston and sometimes they walk or take the easiest way of transportation which will be explained in the following pages to reach financial district.

Based on the previous conclusion, it became important to study the morphology of North-end Boston from the perspective of entrances and the relation between the streets and tunnels.

Figure 1-15: North end land-use map

1.11 Transportation system:

First map shows the various transportation systems in North-end Boston and its relation to the site. It is clear from the map that north-end Boston is well connected to each other's through a network of buses which passes through the waterfront that also connects the main train station with the underground lines, from underground, passengers could access the financial district easily. Also from the noticeable points that was clear from the map, is the pedestrian paths which connects from the main train station to the financial district through north-end which is considered as a promising project to increase the walkability in Boston since Boston is considered as the most walk able city in the united states The ferry path is a method of transportation that moves people between harbors and it was very close to the site which is considered as a good edge to the site The second map shows the and the tunnels exits and entrances which shows the complexity of the tunnel system under north-end Boston which will be showed separately in another separate map

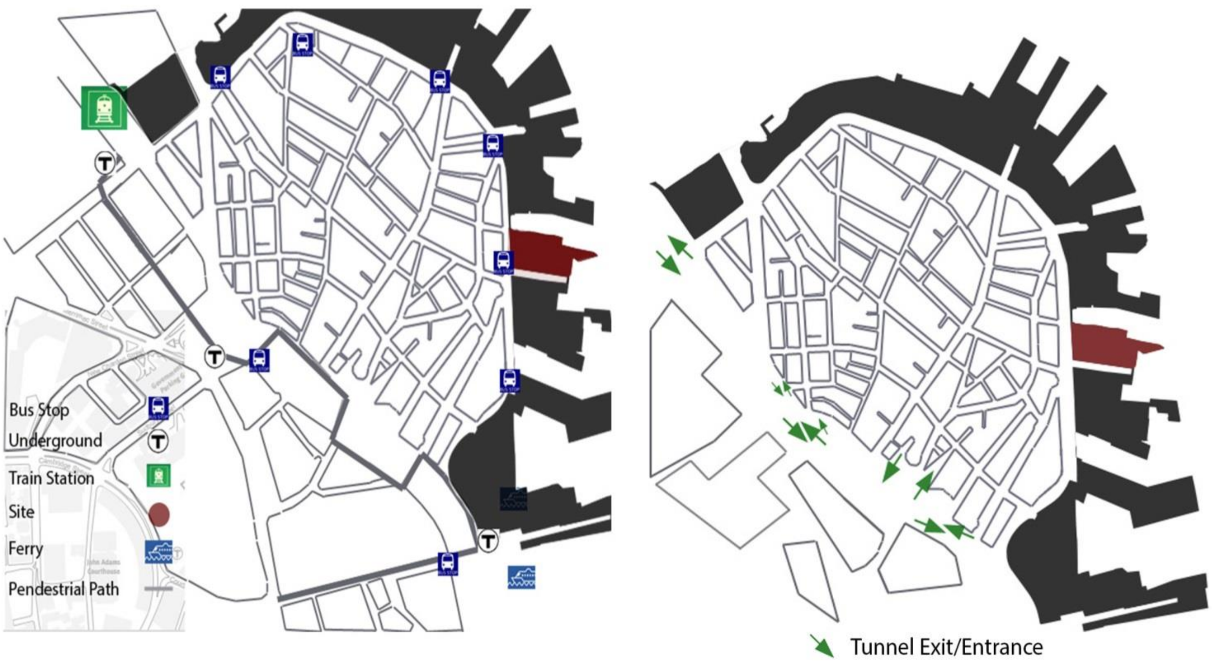


Figure 1-16: North end transportation map and North end tunnels exits

1.12 Underground Tunnels:

The following map shows the network of tunnels passing under north-end generally and under the site specifically and it is obvious that these tunnels are working as a tool against north-end since it is working on separating it totally as it takes passengers from out of north end to south Boston without passing by north-end

That's why it was important to study the relation between the tunnel exits/entrances with the waterfront and to collect the data regarding these routes and how to improve them to attract people to visit the project.

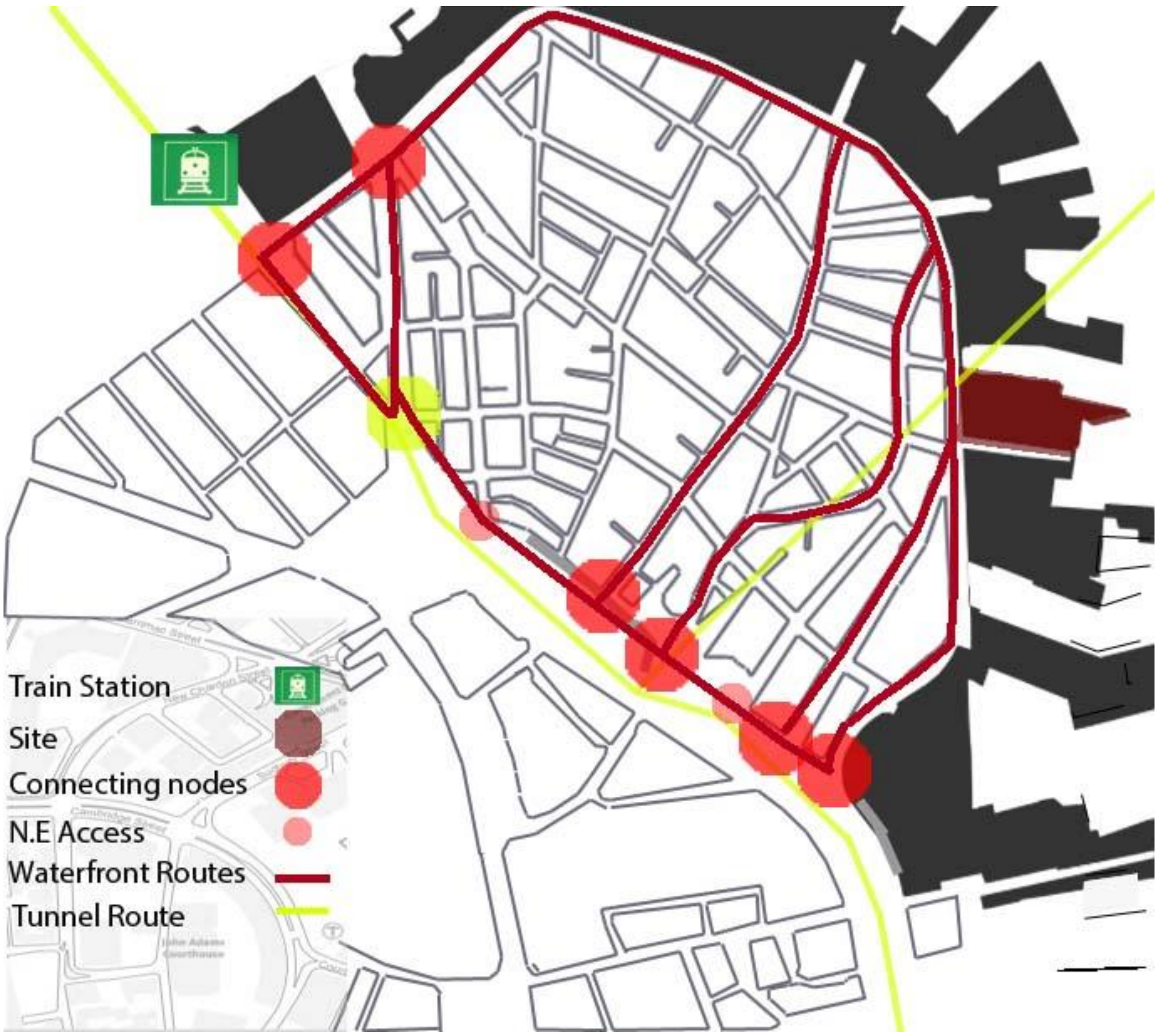


Figure 1-17: North end tunnels system

1.13 Streets Hierarchy:

Going from the scale of north-end to the scale of the site, it was important to study the relationship between the streets and their situation and how to work on the transformation of these streets into walkable streets taking into considerations the massive difference in culture which appears mainly in the use of cars and the parking problem.

The following map shows the Hierarchy between the various streets in north-end and their connections so that it helps developing the project It is clear from the topography of streets is that there is two main streets which are Hanover street and Salem street, where both of them is working as an artery for the waterfront, and the connection between both streets will be explained in details in the following pages.

Figure 1-18: North end streets hierarchy map

1.14 North-end green spaces

The following map shows the different green spaces in north-end and its relation to the site

Figure 1-19: north end Green spaces map

1.15 North-end Blocks area:

The following map shows the square meter area of the blocks in north-end to give a better understanding of the scale of the city and the scale of the blocks compared to the site putting into considerations the massive area of the site

Figure 1-20: North end blocks area and store front map

1.15.1 Hanover Street

It is one of the main elements on which the design of the project was based on The street is one of the oldest in Boston, and was originally an Indian path, allowing access to the shore, prior to the first European settlement. In the 17th century, the street was called Orange Tree Lane. In 1708, the street was renamed after the British House of Hanover, heirs to the throne under the Act of Settlement 1701.

Figure 1-21: Street view of Hanover Street

In 1824, North Street and the former Middle Street became part of Hanover. In the 1960s a large section of the street was demolished to make way for the construction of Government Center. Hanover Street is now home to many businesses, cafes, churches, and Italian restaurants.

It is planned for Hanover street to be transformed into a walk able street with changing the street section by removing totally the vehicles entry in this street and transforming the routes in the historical center to provide a direct sustainable artery to the waterfront generally and the site specifically and changing the pavement of the street to give the feeling of the pedestrian friendly.

1.15.2 Salem Street:

Salem Street is the secondary street parallel to Hanover and connected to it through perpendicular short streets parallel to each other and it was planned to form the closed loop of sustainable walk able streets in north-end Boston by following the same previously mentioned procedures in Hanover Street.

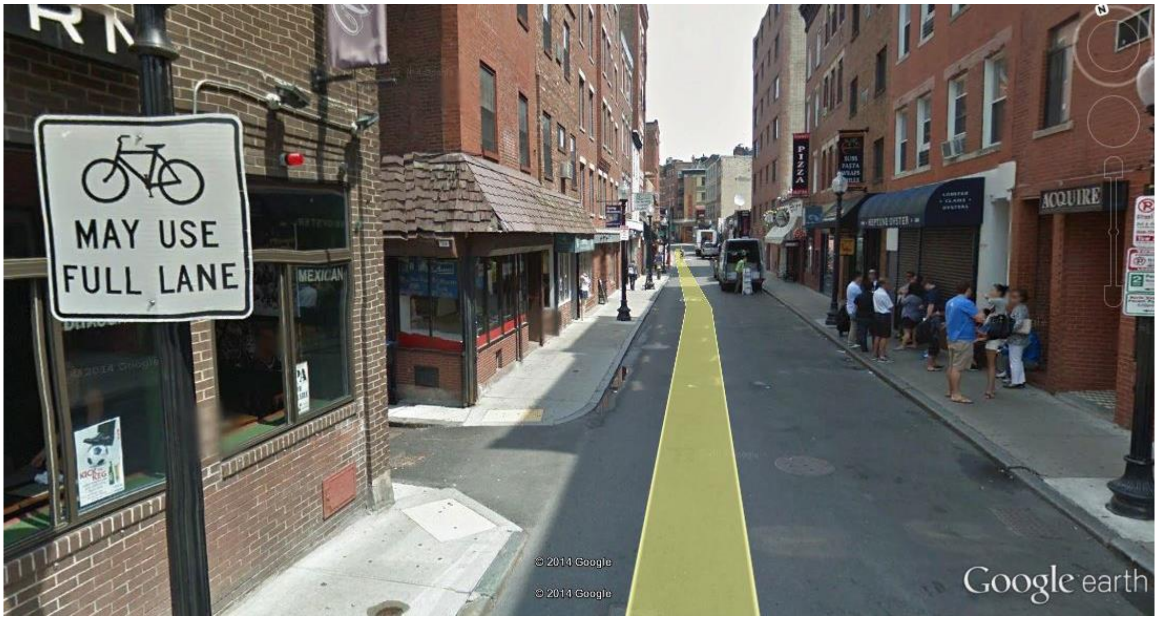


Figure 1-22: Street view of Salem street

1.15.3 Harbor walk

The Harbor Walk has a changing character as it winds through the city's waterfront neighborhoods and downtown district, stretching from Chelsea Creek to the Neponset River, through East Boston, Charlestown, North End, Downtown, South Boston and Dorchester, Part of the richness of the Harbor Walk is its variety, reflecting the various activities and urban texture of adjacent land. The Harbor Walk's design guidelines allow for the expression of diversity and a variety of active and passive uses.

The Harbor Walk is designed to connect the public to a clean and restored Boston Harbor. The Harbor Walk links the water's edge to the city's open space system. Along some areas of the waterfront, the Harbor Walk extends into maritime industrial areas. In these areas the Harbor Walk may be a series of observation points, rather than a linear path, where the public has the opportunity to view at close range the exciting operations of a working industrial port. At certain locations and times, there are limitations to public access in order to protect public safety and industry operations.

The Harbor Walk also connects to new and existing networks of inland trails, which will link the Harbor Walk to established parkways and open space networks, including the Emerald Necklace system, the Charles River Esplanade, and the Rose Kennedy Greenway. In the future, the South Bay Harbor Trail will offer Boston residents a new and exciting way to access the Boston Harbor on foot or bicycle. The trail will extend from the Ruggles MBTA station and winds its way through Lower Roxbury, the South End, and Chinatown to reach the Harbor Walk at the Fort Point Channel. Harbor Walk is a long term ongoing project since parts of this project is ongoing and another is intended and the rest is to be linked with the Harbor Walk

There is a strong relationship between the site and the Harbor Walk since it is passing on its borders together with having an important node exactly before the site which could be developed to form a very strong attraction point on the waterfront

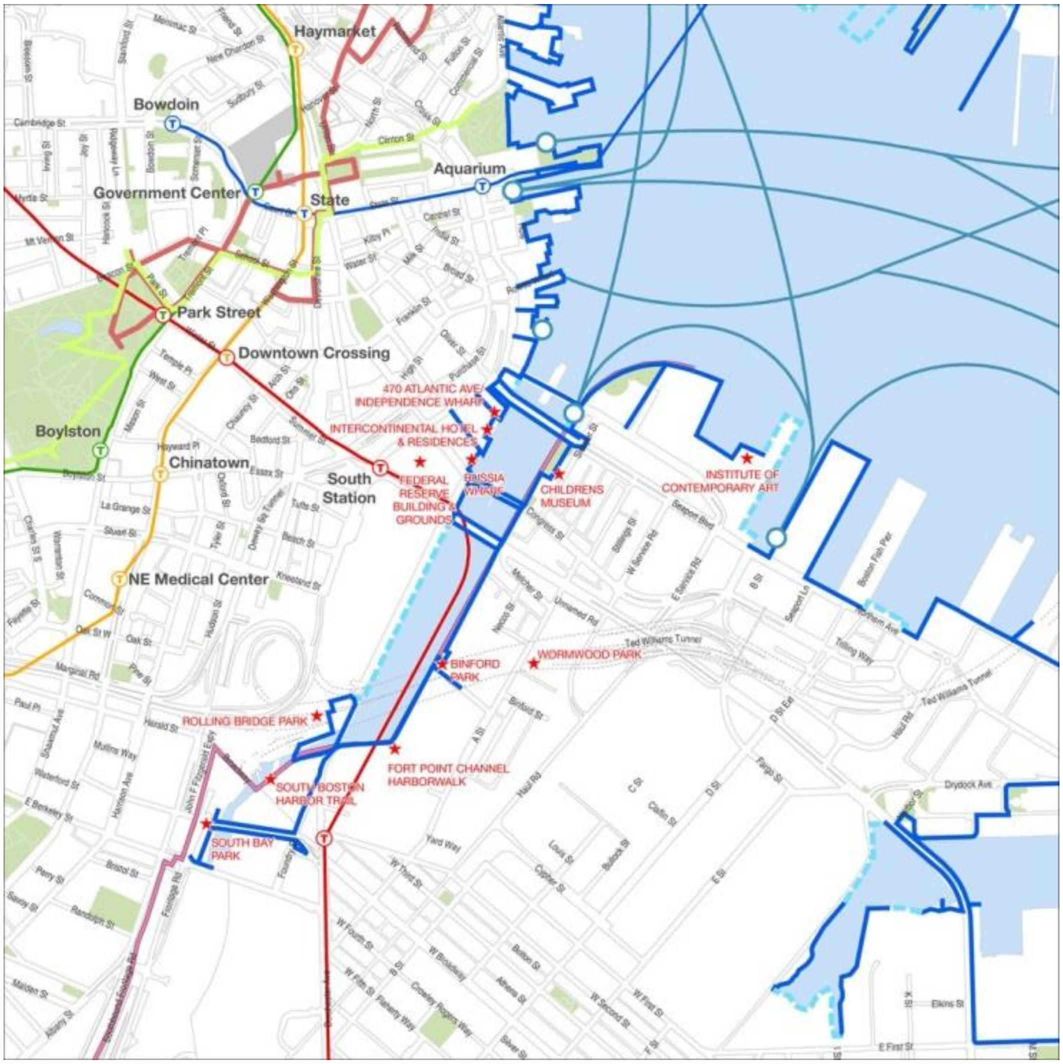


Figure 1-23: map shows the Harbor Walk going with the waterfront all over Boston

Conclusion

Strong connection needs to be created between downtown, waterfront and north-end historical city center , this connection aims for achieving the design goals through energizing urban living generally and giving another dimension of the sustainable public space specifically.

1.16 SWOT analysis:

SWOT analysis was done in several main branches so that it gets specific data, the branches are

- Accessibility, transportation and location
- Morphology and Land use
- Social and community
- Climate
- Cultural heritage and future planning

On two separate scales SWOT analysis was done, on north-end scale, to evaluate the site from a larger scale so that the data is related to north-end Boston and its connection to the financial district. On the site scale to evaluate the site as a site, so that minor data provides wider image and better project is then designed.

Strengths	Weaknesses
Accesibility,transportation and location _Calm urban context despite complicated transportation infrastructure (Tunnels) _Car free sustainable streets _Strong transportation network _Nearness to downtown,considered as an attracting community _Waterfront vicinity **Morphology and land use** _Organic urban grid _Green spaces (10%) of whole land _Existence of well working wharfs over waterfront _Locality as residential district _Public potentials of hanover street _Harbor walk (recreational activities, moderation of climate, connection) **Social and community** _Age diversity (Old and young city) _Retired people attractive Sustainable community _So called-Small Italy (Italian majority among inhabitants) _Diversity of inhabitants _High density (10526 pop./Km^2) **Climate** _High solar gains (hanover street) (summer/winter) _High compactness **Cultural Heritage and future planning** _Historical identity _Leadership in Sustainable approach to district compared to US _Presence of several tours(Historical tour-wine tasting tour-photo tour) _Sustainable future planning (BRA organisation)	**Accesibility,transportation and location** _Lack of pedestrian connection between green spaces_Insufficient parking areas _Not pedestrian friendly + not bicycle friendly _Disconnected from downtown _Insufficient parking aeas **Morphology and land use** _No visual connection to water _Visual and physical disconnected waterfront0 _Parking placed in north end not serving Downtown _Not well defined commercial street + not pedestrian friendly _High land cost _Lack of public spaces _Not well defined harbor walk (functions, meeting points, attractions and connections) _A lot of open parking lots _Not well defined gate to waterfront from the cross street **Social and community** _Non affordable available residential units
Opportunities	**Threats**
Accesibility,transportation and location _Use of street networks to access waterfront _Pedestrian connection to downtown **Morphology and land use** _Availability of water visual connected spots _Presence of huge open parking areas **Social and community** _Upcoming residential demand **Climate** _Positive solar analysis of hanover street (summer/winter)	**Accesibility,transportation and location** _Overcrowded waterfront **Morphology and land use** _Some unconsolidated earth **Social and community** _Adamant behavior of residents _Retired people attractive city (80% of retired are not leaving) _Increasing housing demand (employees and graduates need to live near downtown) _Growing the work opportunities in downtown together daily parking behavior **Climate** _Rising sea level _Climatic catastrophes

Figure 1-24: North end scale SWOT

Strengths	Waterfront (moderating the temperature-visual connection) Indirect solar gain from water Wind sheltered site Directly allocated on Harbor walk Easy access by means of transportation Accessibility(Direct access to commercial street-direct connection to cross street)	Non pedestrian friendly neighborhood Away from compacted urban context Existing out of urban context Airport in neighborhood (noise-pollution) High cost in coherence with land price
Opportunities	Free land in front of site Direct solar gain all over the year Collective hub on harbor walk near to the site Connection with hanover street via two link roads (clark st.-fleet st.) Vicinity to (Christoph Columbus park and Langone park)	Flood (0.60 m rise in sea level within 20 years) Climatic catastrophes Parking functionality distribution Confrontation of strong wind 30km/h from North West (Hurricanes)

Figure 1-25: Site scale SWOT

1.17 Goals and objectives

Based on the general and SWOT analysis carried out on both scales, a better understanding vision was created which helped in the development of an applicable solution for the project.
This vision leads to goals and objectives:

- Introducing new sustainable culture in Bostonians culture
- Provide the maximum possible amount of residential affordable units on the land size
- Create new attracting pole on the site to reconnect north-end inhabitants
- Keep cultural heritage

1.18 Actions and strategies

To achieve the goals and objectives, some actions and strategies were followed as:

- Changing the street section of Salem street and Hanover street into pedestrian friendly streets
- Contributing in solving the housing problem through providing residential low cost units for various types of customers
- Better definition of the waterfront which is not well defined in North-end Boston through creating new attracting nodes in the project
- Proposing new well studied spaces for the construction of multi storey parkings instead of the ones cancelled due the transformation of the Hanover and Salem streets
- Creating a new connecting hub (Regenerate Boston) ta attract people living in North-end Boston
- Connecting the water front with the city center through pedestrian friendly path in the north-end zone
- Creating a new node on the harbor walk as a public space so that it provides more security and potential

- Keeping the cultural heritage in the historical Boston by designing the new residential complex on the same architectural morphology of the city
- Introducing the sustainability concept in new buildings by providing the first nearly zero energy building in the neighborhood

1.19 Green strategies adopted on the basis of Analysis:

Solar Street light: Why we choose solar energy as power generation for the street light:

1. The sun is a direct source of energy. Using renewable energy technologies, we can convert that solar energy into electricity
2. All solar lights are “wireless”. They are not “hooked up” to external sources of power.
3. Solar lights produce no pollution and cause no harmful environmental effects.
4. Solar lighting is sometimes preferred for applications where the need is temporary (fairs, mining sites, Olympics, introduction of real estate developments, etc.).
5. Solar lights are immune to black outs.
6. Solar-powered outdoor lighting is virtually maintenance-free, since the batteries require no water or other regular service.
7. Solar lights provide enhanced security in poorly-lit remote areas where access to grid power is challenging, such as parks and large parking lots.
8. Solar lights work at night.
9. Solar lights work even after cloudy days. During daylight, even when overcast, the solar panels’ “solar generators” charge long-life batteries, which store the energy until needed, up to 5 days for Sol systems

1.19.1 Pathway and Trail Lighting:

Figure 1-26: Pathway and Trail Lighting

Recommended: Greenway® Solar Path Lighting:

GreenWay® is the reliable, affordable solution for pedestrian-scale outdoor solar lighting. This commercial LED lighting system features a low profile aesthetic design with single PV module, lockable hidden battery enclosure and invisible mounting hardware powder coated in your color choice. It is ideally suited for pathways, walkways, trails and remote locations that have no access to conventional power. GreenWay® solar lights are configured to your requirements to run throughout the night or to save energy with dimming when full light is not required.

Features:

- Choice of luminaire and light pattern including IDA Dark-Sky approved - Type V and TypeII
- Maintenance free gel cell batteries provide five nights of back-up power
- EternO® 4 control module is TÜV listed to UL 60950-1:2007 and CSA C22.2.60950-1:2007
- FivePlus™ Warranty includes 10 years on electronics, wiring, fixtures and 20 years on mounting hardware and solar panels

How solar street lighting works:

Solar-powered lighting consists of a solar panel or photovoltaic cell that collects the sun's energy during the day and stores it in a rechargeable gel cell battery. The intelligent controller senses when there is no longer any energy from the sun and automatically turns the LED light on using a portion of the stored energy in the rechargeable battery.

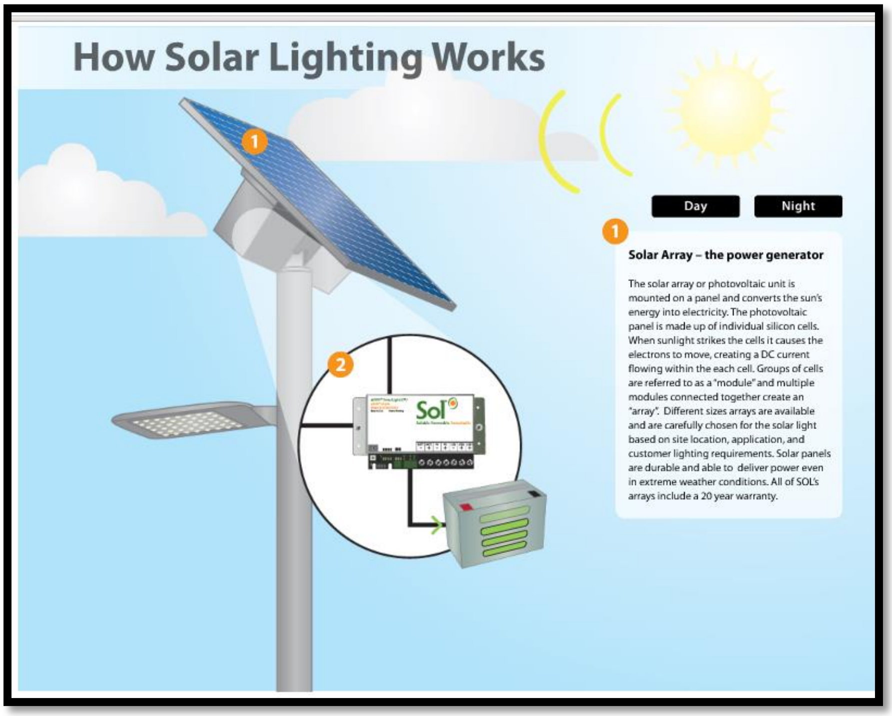


Figure 1-27: How solar lighting works during the day

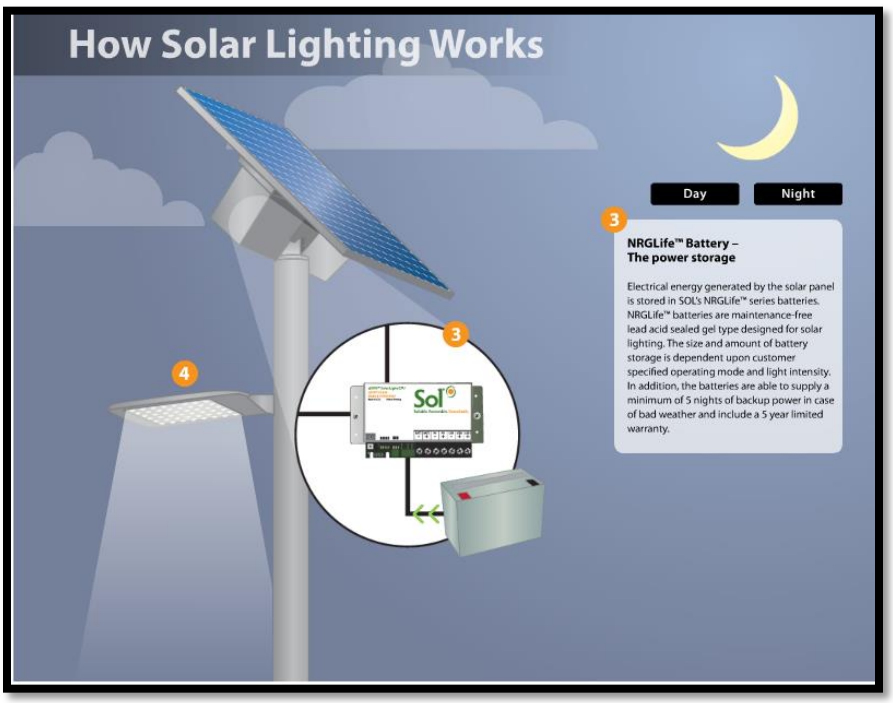


Figure 1-28: How solar lighting works during night

LED lights, alternative in case of some situation when solar energy is not available:

Light Emitting Diodes (LEDs) are a solid-state light source that has unique properties that make it ideal for efficient and solar powered lighting applications. Although most people think of LEDs as indicator lighting, one type of LEDs is specifically designed for general illumination applications.

As the technology has become more robust, reliable and efficient, LED lighting is becoming more commonplace in everyday life. LEDs for illumination, when properly integrated into a light fixture, or luminaire, should achieve over 80 lumens per watt of efficiency (7x more efficient than a light bulb) and a life of over 60,000 hours (> 12 years). The technology means that in more and more applications the light source lasts as long as the light fixture!

Sol exclusively uses LEDs as the source for illumination in our street, parking lot and area lighting systems. The reason for using LED lies in the basic physics of the device. LEDs:

• Emit light in a controlled directional way,

• Emit light efficiently and

• Have extremely long life when properly engineered into a luminaire

Although LEDs are not right for every lighting challenge, in solar lighting LEDs provide excellent efficacy (light efficiency measured in lumens/Watt) and allow the use of precision optics to direct light in precise, repeatable patterns to maximize pole spacing.

LED lighting is a diverse field; it spans traffic lights, to televisions to light bulbs. The types of LEDs used in each application are unique, so Sol only selects high-flux LED lighting for illumination. Use of 5mm style or high brightness LEDs for electronics will result in lower light output and unattractive color shifting. Our approach is to select the highest quality LEDs, follow the guidelines of the International Illuminating Engineers Society (IES), test our luminaires to the LM-79 standards and purchase the actual LED from leading suppliers. [More on LM-79 testing standards for LEDs

As with any new technology, features and benefits of LEDs need to be weighted. For instance, bluish-white LEDs are more efficient than warm-white LEDs, but most people find warm white LED lighting more appealing. In outdoor lighting, opinions are mixed so Sol has selected an "outdoor-white" color temperature of about 5000K to furnish high color rendering (colors appear to be their true color) and deliver a white light that is a fair balance between less efficient warm colors and very cold blue. In the end, factors like CCT (correlated color temperature); efficacy, CRI (color rendering index), etc. should all be considered

1.19.2 Converting energy from footsteps into electricity:

Figure 1-29: Pavegen tiles

Every time someone walks over a Pavegen tile, renewable energy is harvested from the footstep. The technology converts the kinetic energy to electricity which can be stored and used for a variety of applications.

Usage of pavegen tiles:

The energy harvested by the Pavegen tile can immediately power off-grid applications such as:

- Pedestrian lighting,
- Way-finding solutions
- advertising signage or be stored in a battery

The technology is best suited to high-footfall urban environments. The Pavegen technology offers the first tangible way for people to engage with renewable energy generation and to provide live data on footfall wherever the tiles are.

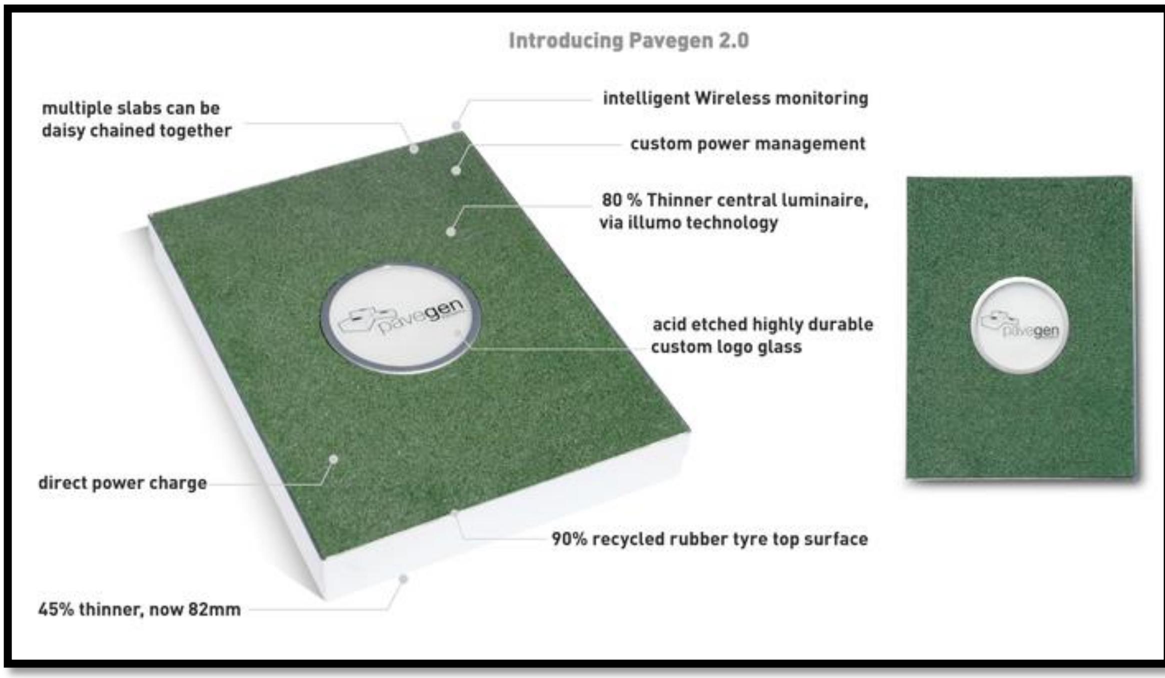


Figure 1-30: Specifications of pavegen tile

Pavegen uses what it calls a hybrid black box technology to convert the energy of a footstep into electricity, which is either stored in a battery or fed directly to devices. A typical tile is made of recycled polymer, with the top surface made from recycled truck tires. A foot stomp that depresses a single tile by five millimeters produces between one and seven watts. These tiles generate electricity with a hybrid solution of mechanisms that include the piezoelectric effect (an electric charge produced when pressure is exerted on crystals such as quartz) and induction, which uses copper coils and magnets. The marathon runners generated 4.7 kilowatt-hours of energy, enough to power a five-watt LED bulb for 940 hours, or 40 days. “We came together for Paris Marathon to highlight how technology is really going to change the way people think about energy,” says Joe Hart, senior vice president of Segment & Solution Marketing at Schneider Electric.

Materials:

The top surface of the flooring unit is made from 100% recycled rubber and the base of the slab is constructed from over 80% recycled materials. The system can be simply retrofitted in place of existing flooring systems as well as specified for new developments.

Durability:

The Pavegen tiles are designed to withstand harsh outdoor locations with high footfall. The slabs are waterproof to allow them to operate efficiently in both internal and external environments.

Due to the innovative and unique nature of the product, it is ensured that producers carry out a substantial amount of testing for both the indoor and outdoor environment.(so do pavegen tiles producers)

- Dead load 3KN/m2
- Live load 7KN/m2 – Test taken from BS6399 for dynamic loading
- Traffic simulation to 40,000,000 footstep cycles, repeated every 3 seconds.

Restriction of Hazardous Substances Directive (RoHS) 2002/95/EC:

Pavegen uses manufacturers that are RoHS compliant to the RoHS Directive

Series Manufacture:

All manufacturers of Pavegen components are ISO9001 compliant and certification documents are available on request to Pavegen Systems Ltd. UK.

1.20 Case study:

Energy-Harvesting Street Tiles Generate Power from Pavement Pounder: Power for the people takes on a whole new meaning, as the largest installation of Pavegen energy-harvesting tiles to date produces 4.7 kilowatt-hours of energy during the Paris marathon, enough to power a laptop for more than two days

PARIS—On April 7, 2013, Kenya's Peter some won the 37th Paris Marathon with a time of 2:05:38. A surprise winner some missed the event record by only 27 seconds, thus depriving him of a place in running history. He need not have worried; unknown to him and thousands of fellow marathoners, they were all nonetheless part of a historic event. As they ran across the Avenue des Champs Élysées and thumped their feet on 176 special tiles laid on a 25-meter stretch, the athletes generated electricity.

Interventions:

Use of paintings on all harbor walk to make it interesting for the people to walk and to do jogging. The motivation is taken from an exhibition which was done on water front harbor walk, while in our project we will use it as permanent paintings.

Motivation taken:

Flash Forward Festival Photography Exhibitions on Harbor walk:

1.21 Concept Map:

Figure 1-31: Concept plan Map

CHAPTER 2 ARCHITECTURAL DESIGN

The main Aim of this chapter is to show the design process of a residential complex in north end Boston-Masachetues United states, the design process passed through several scales starting from the wide scale which was studying and analyzing the zone potentials and the surrounding functions and the feasibility of designing a residential complex on such a critical piece of land on the seafront with many potentials and drawbacks which would be described in the following pages.

The narrow scale was the architectonic scale by which the design principles were applied on on the project to attain the required function.

In the following pages, the sequence was used as showing the location of the site and its boundaries followed by the competition design requirements and finally the design intervention will be shown passing by different analysis and studies on the site and the project.

Before we started to approach our design analysis were done on a larger scale in order to understand the existing zone with all its potentials and constraints. This analysis was the motive for us to approach out final design.

2.1 Location:

Following figure shows the site boundaries, the commercial street, waterfront and the street connections to the existing blocks.

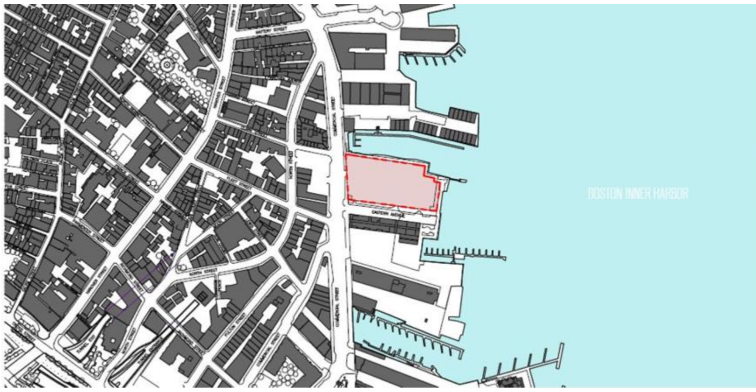


Figure 2-1: Top view of the site.

2.2 Aim of project:

The main aim is to develop low cost residential units with providing a public space to generate a new hub of specific functions to collect people living in the new building with users of public space putting

The main objectives were to design a project which is well defined and suitably organized tackling critical problems which are:

- The existing function of the site is parking with a huge parking problems in the surrounding area
- The site is on waterfront with expected rise in water level of 0.6 m in the next 100 years which is considerable rise
- According to the analysis which will be showed that Boston community is so called as a variable community due to the massive overlap between retirements and students

The new building should provide the maximum possible number of units considering providing the required variety of units’ models to satisfy different categories of clients.

2.3 Analysis:

- From 2000 to 2010 more than 20000 units were completed for housing ,6100 of these units were affordable
- More than 10000 new dorm beds were to free up apartments for neighborhood families
- By 2020 the demand on the residential units is raised to be 29000 units
- Share of the workers living in Boston was raised from 34% to 39% since year 2000
- Colleges in Massachusetts is working as a magnet for 20 – 34 aged students which represented more than 70000 students since year 2000
- 80 % of the retirees stays in Boston
- Since 2010, thirteen thousands retired which means that their jobs would be opened but their houses won't be available.
- The community in Boston can be classified as follows :
  - 40%-50% (workers)
  - 20% retirees
  - 30% families
  - 10% families
- Middle class people who are in Boston are lower than in all US are losing share, since all built projects where out of reach
- The government planned to develop the reachable housing to 12000 unit
- Only 20% of built units is affordable
- 20 % of Bostonians spend half their income on housing
- In lottery, 1500 applicants for each 25 units

2.3.1 Decision based on analysis:

Based on these analysis and information carried out, it was concluded that the Bostonian community is a diverse community and the project carried out should be one of the solutions of the housing problems in Boston with a variety in units to target all portions in society and hence it was decided to follow the following division to satisfy the customer needs.

- 50% of units should be targeting workers
- 35% of units should be targeting families
- 15% of units should be targeting retirees

Based on the carried out analysis it was observed that most of the ongoing and planned projects are targeting the university students in the form of dormitories, that's why it was decided to focus more on the portion of residents were the problem exists.

2.4 Architectural Concept/Vision:

While developing architectural concept the major factors in our minds were to integrate the whole building with surroundings (i.e. urban fabric, transportation system, view, Culture, Economy, Density and Volumes) and with its own systems (i.e. Envelope design, sustainable solutions, Technological design, Energy efficient design, Structural system) .

2.4.1 ReGEN Boston:

Sargents Wharf is located in the Boston inner Harbor, on the edge of the North End. This site has always had close ties to the sea. Originally it was encapsulated region surrounded by the Mill Creek, the Harbor, the Charles River, and the Mill Pond. In 1722 the site was densely populated by early merchant dwellings, warehouses and wharves for shipbuilders. During the wave of immigration, Italians vibrantly populated the area. Over the centuries, this neighborhood grew to be characterized by an energetic tie between commerce and residence. Today, the site exists as a money maker, otherwise known as a parking lot. The land, which is currently valued at 6 million dollars, stands as one of the only undeveloped parcels amongst the wharves. Due to its high value, most developments are planned for a small percentage of the city's population, luxury residence.

Our Aim was to develop a housing that can have integration of site not only with urban fabric of the north end of city but also an affordable residence that will have geometric alignment with the city transportation network as well as perfect view. That is why we named our project as Regeneration Boston.

2.4.2 Concussion:

We were going to develop a building system that is very new and has got sustainable approach, and it was to be integrated with the surrounding and hence we respected, imitated and regenerated all at the same time.

Figure 2-2: South Amsterdam, Netherlands an example

2.4.3 Body of water:

Water has also been a central and sacred feature of human settlement, and in history we always find it a most important site for living if we have some water body in the surrounding. Water can not only be called important for living usage but now a day for promoting sports and views it has become strong architectural element.

In our project it was most important consideration while defining the shape and orientation of the volume itself because it is difficult to imagine another element so central and so vital both to basic life and to a diverse range of aesthetic and recreational pleasure. The use of water in the built environment is thousands of years old and is interwoven throughout its long history with symbolism and religious rites as well as with sensual delight.

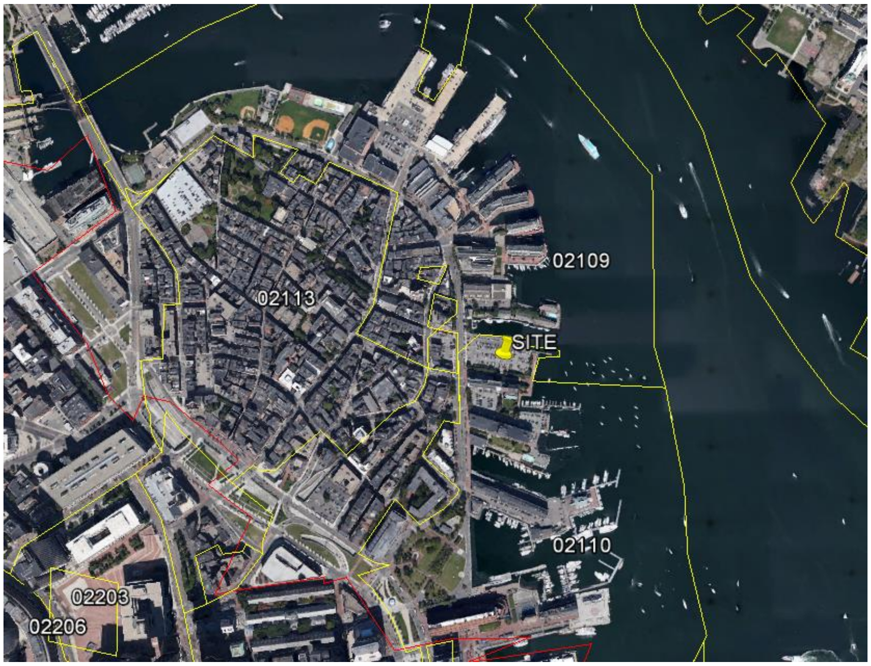


Figure 2-3: North end Boston and water channel

Figure 2-4: Manarola, Italy, an example

2.4.4 Intersection:

Different relations exist between public spaces and introduced functions, they work in synergy, enabling or disabling each other from evolving and blossom. Very different (positive or negative) faces of urban life can coexist within relatively small physical limits.

Understanding these parameters gives us an opportunity to access multilayered existence of urban life in designing the new, redeveloped and revived community in respect with the past of the place. All elements need to be observed in their complexity, the sense of place, weather and climate, density, geography and topography, culture and history and so on. Although all of previous examples are very different and represent different, sometimes contrasting societies, cultures and environments, they all have the purpose of enabling us to predict reaction to any action in our own circumstances.

2.4.5 Culture:

Many consider Boston a highly cultured city, perhaps as a result of its intellectual reputation.

The culture of Boston, Massachusetts, shares many roots with greater New England, including a dialect of the Eastern New England accent popularly known as Boston English. The city has its own unique slang, which has existed for many years. Boston was, and is still, a major destination of Irish immigrants. Irish Americans are a major influence on Boston's politics and religious institutions and consequently on the rest of Massachusetts. The city is also been inspired by Italian culture. Hence all these cultures have great impact on Architecture of our site. So while designing and developing our project we were very much concerned to integrate that system with our system.

2.4.6 Imposing the shape:

Natural context is determining the shape of the settlement. Or in other words: the shape of a town is a reaction to natural forces in its environment. In our project as the weather is very harsh (which has been already discussed in urban design part) so the north end of Boston is very compact. It lead us to make our building in shape that is very compact so that in long period of winter we should not have high energy loads, and later while doing energy analysis we came out with the result that it worked.

Figure 2-5: Bird's eye view of north end Boston

2.5 Design objectives

1-Providing an open enclosed space that could act as a link between the two contradicting use of the surrounding of the site, represented by the central part of two blocks of housing.

2-Axis of volume was defined in order to have direct connectivity with the waterfront and the same axis was leading towards the other end of north end Boston neighborhood. Also the basis of this axis was sun path so that we can enter the winter sun as much as possible.

3- Maintaining the visual connectivity form inside the open space to the waterfront. And to fulfill this objective we developed offsets that will work as balconies for the adjacent flats.

4- Connecting to the open spaces of urban context surrounding the site through integrating with the open space provided.

5- Defining the relation between the new construction at site and already existing urban fabric and volumes.

6-Articulating the relation between the skyline of the new addition and the existing building

7-Integrating the landscape materials of the new addition open space with the old historical pavement of the surrounding.

8-Designing the openings in a way to have natural ventilation during summer and mid-season and at the same time a compact volume in order to avoid energy loss. For this purpose we provided sunspace and window locations were proposed in a way to have cross ventellation.at the same time we tried to develop stack effect and for that we used stair case area and the warm used air was to be collected from the corridors adjacent stair cases.

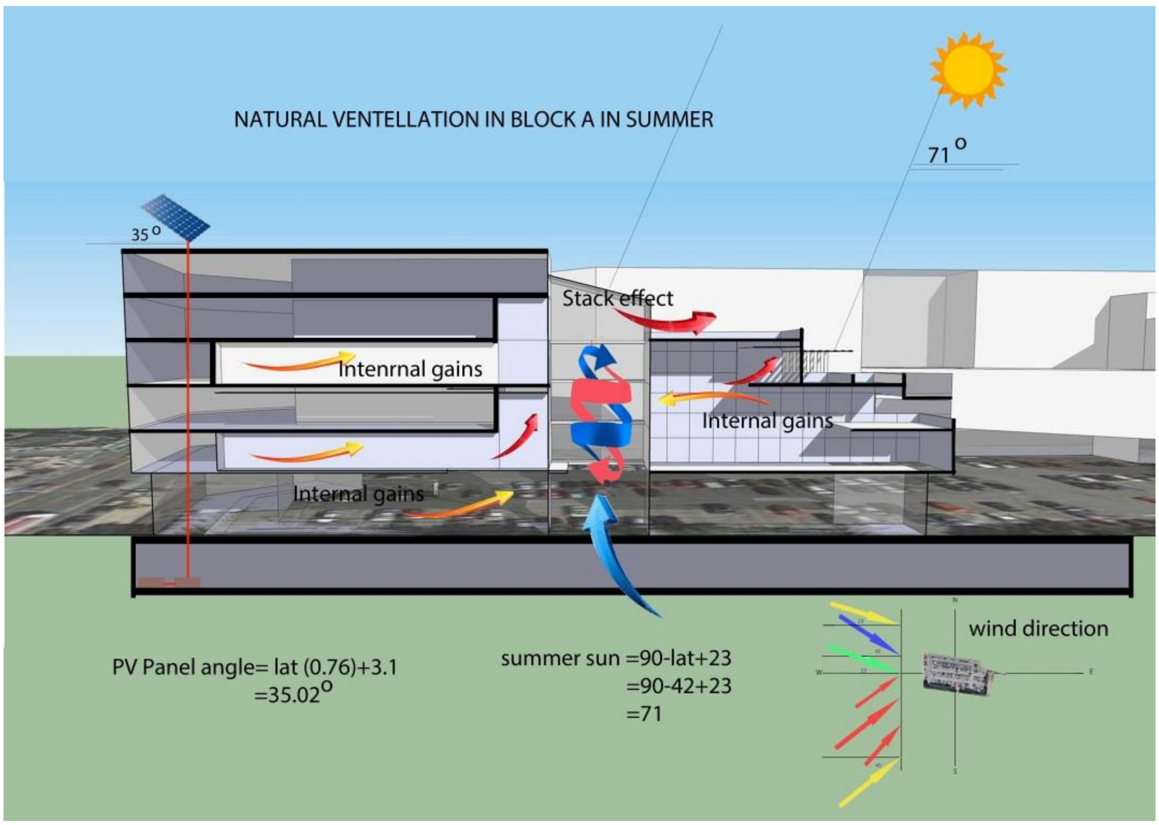


Figure 2-6: schematic showing the objectives regarding ventilation

2.6 Consideration of Passive design Techniques:

SITE PLANNING

- **Site Design**

Site design and site planning have a large impact on how solar passive home will be. The sun is the main source of heat in all homes. By looking at how houses receive sunlight, site planning can help optimize how much solar energy is available to heat a house and how much heat must be removed with air conditioning

- **Orientation**

The orientation of a building can be determined by the climatic factors (wind and sun) as well as by the view, noise and requirements of privacy which may, override the climatic considerations. The orientation of a building is affected by the amount of solar radiation falling on different sites at different times. Both solar radiation and air temperature act together to produce the heat experienced by a body or surface. This is expressed as the sol-air temperature, which takes into account the air temperature, the solar (short-wave) radiation absorbed by the surface, and the long wave radiant heat exchanged with the environment.

- **Building Form**

As a general rule, the optimum shape for a building is that which has the minimum heat gain in summer and the minimum heat loss in winter. Based on calculations in different environmental simulations, a square building is not the optimal shape anywhere, although it is more efficient in both summer and winter than shapes elongated in a north-south direction. The most satisfactory shape is one in which the building is elongated in some general east-west direction.

Optimum orientation would reduce sun light to a minimum during the hottest periods, while allowing some heat gain during the cool months.

In hot and regions, however, the heat stress in summer is so severe that a compact, inward-looking building with an interior courtyard may often be a better scheme. This shape minimizes the solar radiation impact on the outside walls and provides a cool area within the building. As the height of the courtyard is usually greater than any of its dimensions on plan there is always adequate shading. In addition to the importance of the building shape in minimizing unwanted heat gain, the building elements themselves can provide shade through overhangs, shading devices, balconies, etc

- **Lot Orientation**

As planners map out lots and roads, they should carefully consider the relationship between buildings and the sun. They plan roads to allow houses to take advantage of great views, or to work around hillsides and other landscape features. Site planning must also consider how road design, lot lines, and orientation will influence the way that houses face the sun.

Lot lines and roads should be situated to minimize home exposure to east and west. These orientations provide the greatest solar heat gains. Subdivisions should be planned so that the longer sides of the houses face north or south. Single-family homes tend to have longer fronts and backs and narrower sides, so lots facing north or south are preferred. Streets should be positioned in an east-west direction. The Florida Solar Energy Center estimates that proper orientation can result in substantial savings of heating and cooling costs, depending on specific site conditions and house designs. Highly efficient houses, especially those with good windows, are less dependent on orientation and shading to manage solar gain.

- Shading is not nearly as important when windows with a low solar heat gain coefficient (i.e., SHGC of 0.35 or less) are used. Using a low-solar-gain low-emissivity coating results in great energy cost reductions for all conditions, even with no shading. This is because the glazing itself provides the necessary control of solar radiation, so these additional measures become less important in terms of energy use. The Efficient Windows Collaborative Web site provides a description of the interactions between window performance and shading.

- Lot orientation is especially important if a home includes solar heating or electric generation systems. Inexpensive tools can help assess how much solar energy will be blocked by obstacles on a particular site.
- In addition to helping manage the sun and providing a marketing advantage, proper street design can reduce the environmental impacts of runoff, encourage walking and bicycling, and discourage speeding by through-traffic.
- Subdivision planning can also help homes to gain cooling benefits from the wind. Houses and other buildings that are tightly packed may create a wake in the wind that is four to five times the buildings' eave height.
- Curved streets and staggered lots can assist in preventing wind disturbance. Trees can help to keep breezes cool. Taking advantage of breezes will reduce cooling costs. Wind conditions at any individual site may differ considerably from regional averages. Local geography such as ocean beaches, lakes, fields, golf courses, parks, and malls can influence local breezes.

2.7 Conclusion based on Urban and Architectural Design:

The result of urban and architectural design should be Multi-generational and affordable Housing and developing solutions that improve urban lifestyles in the City for multi-generational users. The idea should create and foster a sense of community between generations, contextualized within the existing and evolving neighborhoods. Consideration will be how our design will engage with or ignore the site’s existing conditions. While thinking of the urban lifestyle we would also address connections to water front access, public space, and city infrastructure.

NOTE:

Refer to the Architectural Drawings from Page No. 196 onwards.

CHAPTER 3 TECHNOLOGICAL DESIGN

3.1 General Climate of boston city; An Introduction:

Massachusetts's Shawmut Peninsula, upon which Boston is located, lies at the mouths of the Charles and Mystic rivers. The rivers flow into Boston's inner harbor and then into Boston Harbor itself. This harbor is part of Massachusetts Bay and leads ultimately to the North Atlantic Ocean. Boston's Harbor Islands are located in the inner harbor. Shawmut was originally a hilly peninsula that was separated almost entirely from the mainland by marshy swamps. Over the years, Boston's hills were leveled to fill in the back bay marshes; nonetheless, Boston's terrain remains rolling today.

The city lies within the transition zone from a humid subtropical climate(A humid subtropical climate (Köppen climate classification Cfa or Cwa) is a zone of subtropical climatecharacterized by hot, humid summers and generally mild to cool winters.) to a humid continental climate (A humid continental climate ,is a climatic region typified by large seasonal temperature differences, with warm to hot (and often humid) summers and cold (sometimes severely cold) winters.).

Fog and humidity are by-products of Boston's proximity to water. Rain is frequent throughout the spring and summer, while snow falls regularly throughout the winter, making Boston one of the nation's wettest cities. Atlantic Ocean breezes keep Boston's climate relatively mild compared to other cities in the northeastern United States. Those same Atlantic breezes, however, help rank Boston among the country's windiest cities and occasionally blow into full-fledged storms called "nor'easters."

- Area: 48 square miles (2000)
- Elevation: 15 to 29 feet above sea level
- Average Temperatures: January, 29.3° F; July, 73.9° F; annual average, 51.6° F
- Average Annual Precipitation: 42.53 inches of rain; 42.6 inches of snow

Climate is composed of atmosphere which depends on parameters as
Parameters of the atmosphere:

- Air temperature
- Air pressure
- Wind
- Precipitation
- Humidity
- Clouds
- Sunshine

The above parameters regarding our site has been described in detailed in the following discussion. First we need to check that which factors affect these parameters.
In refrence to urban and architecture design the main factors with refrence to temperature, precipitation and prvailing winds are important , which has been described below with parameters.

3.1.1 Temperature:

If we look at average the , from 1996 to 2012 the temperature varies between -7^{o}C to 29^{o}C.
While ignoring average value the real situation gives us data as max. temp = 37^{o}C in the month of july and min. as -22^{o}C in december and january.
The factors which influence temperture are:

- latitude (as latitude increases ,the average yearly temperature decreases)
- Nearness to centres of large landmasses
- Nearness to large bodies of water
- Location relative to large mountain ranges
- Elevation
- Ocean currents

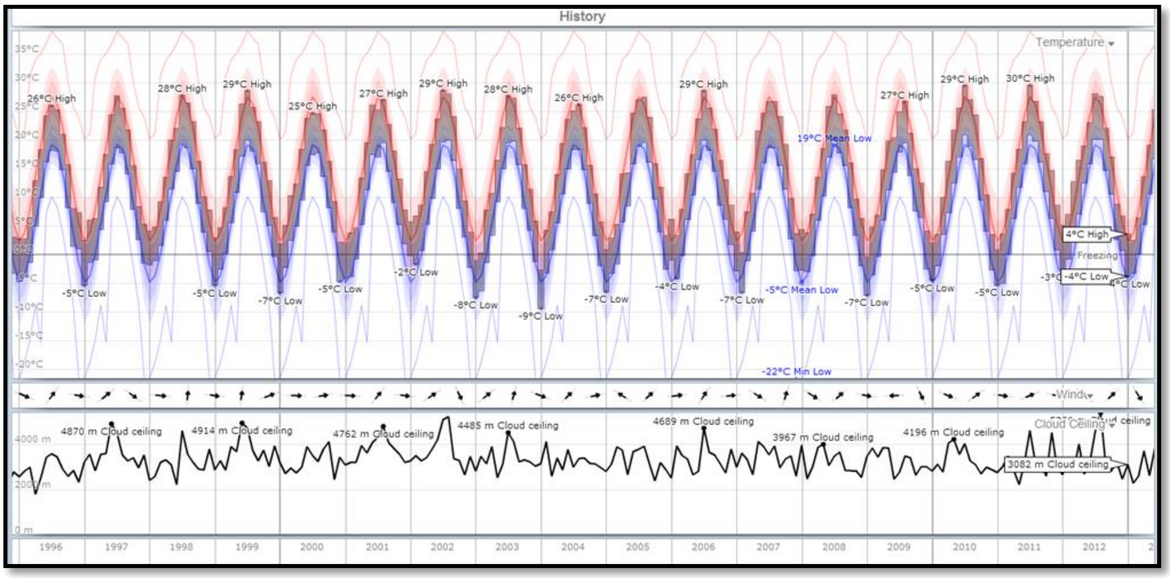


Figure 3-1: Historical climate data from 1996 to 2012

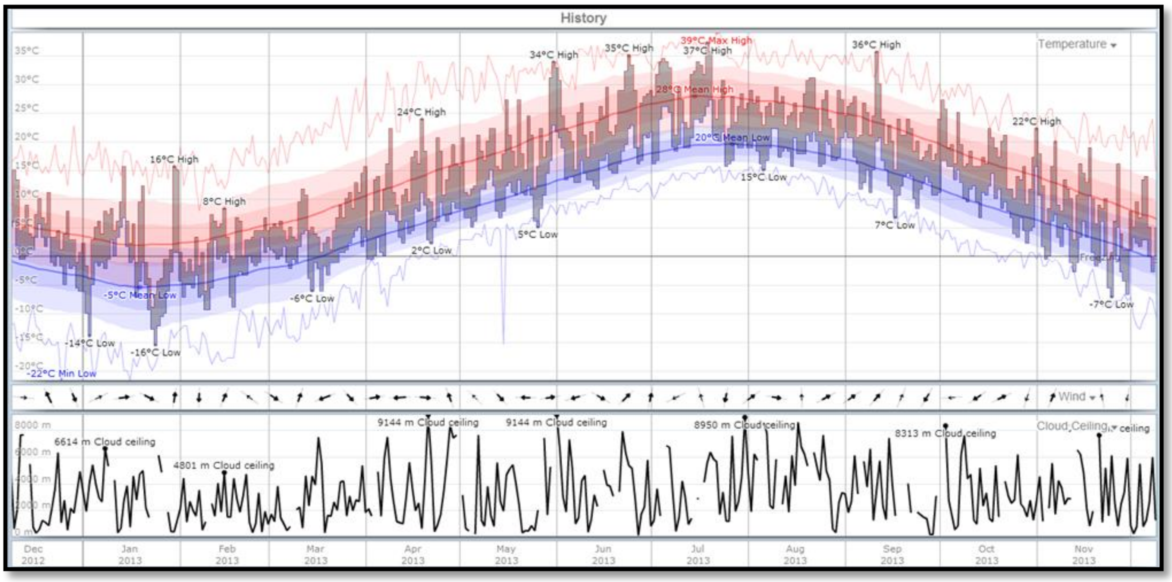


Figure 3-2: Climate data for the whole year of 2013

3.1.2 Snow Depth, Wind Speed and Precipitation:

From the graph given below we can easily access that snow depth can be ±10cm.wind speed sometimes approaches hurricane, storm or even more than that as happened in 2012. Precipitation rate can be 1.9mm/h.

The factors which influence precipitation are:

- Prevailing wind direction
- latitude (as latitude increases ,the average yearly temperature decreases)
- Nearness to centres of large landmasses
- Nearness to large bodies of water
- Location relative to large mountain ranges
- Elevation

Table 1 Load conditions based on wind speed

Wind Speed	Description	Land Conditions
< 1 km/h **< 1 mph** **< 1 knot** **< 0.3 m/s**	Calm (Beaufort #0)	Smoke rises vertically
1.1 – 5.5 km/h **1.2 1 – 3 mph** **1.3 1 – 3 knot** **1.4 0.3 – 1.5 m/s**	Light air (Beaufort #1)	Smoke drift indicates direction; leaves are still
5.6 – 11 km/h **4 – 7 mph** **4 – 6 knot** **1.6 – 3.4 m/s**	Light breeze (Beaufort #2)	Leaves rustle; wind felt on skin
12 – 19 km/h **8 – 12 mph** **7 – 10 knot** **3.5 – 5.4 m/s**	Gentle breeze (Beaufort #3)	Leaves and small twigs moving; light flags extended
20 – 28 km/h	Moderate breeze	Small branches move; dust and

13 – 17 mph **11 – 16 knot** **5.5 – 7.9 m/s –**	(Beaufort #4)	loose paper rises
29 – 38 km/h **18 – 24 mph** **17 – 21 knot** **8 – 10.7 m/s**	Fresh breeze (Beaufort #5)	Moderate sized branches move; small trees sway
39 – 49 km/h **25 – 30 mph** **2 – 27 knot** **10.8–13.8 m/s**	Strong breeze (Beaufort #6)	Large branches move; umbrella hard to use
50 – 61 km/h **31 – 38 mph** **28 – 33 knot** **13.9 – 17.1 m/s**	High wind (Beaufort #7)	Whole tree moves; hard to walk against the wind
62 – 74 km/h **39 – 46 mph** **34 – 40 knot** **17.2–20.7 m/s**	Gale (Beaufort #8)	Twigs break from tree; extremely difficult to walk in wind
75 – 88 km/h **47 – 54 mph** **41 – 47 knot** **20.8–24.4 m/s**	Strong gale (Beaufort #9)	Branches break from tree; small trees blow over
89 – 102 km/h **55 – 63 mph** **48 – 55 knot** **24.5–28.4 m/s**	Storm (Beaufort #10)	Trees broken or uprooted; structural damage imminent
103–117 km/h **64 – 73 mph** **56 – 63 knot** **28.5–32.6 m/s**	Violent storm (Beaufort #11)	Widespread vegetation and structural damage

≥ 118 km/h **≥ 74 mph** **≥ 64 knot** **≥ 32.7 m/s**	Hurricane force (Beaufort #12)	Severe widespread vegetation and structural damage

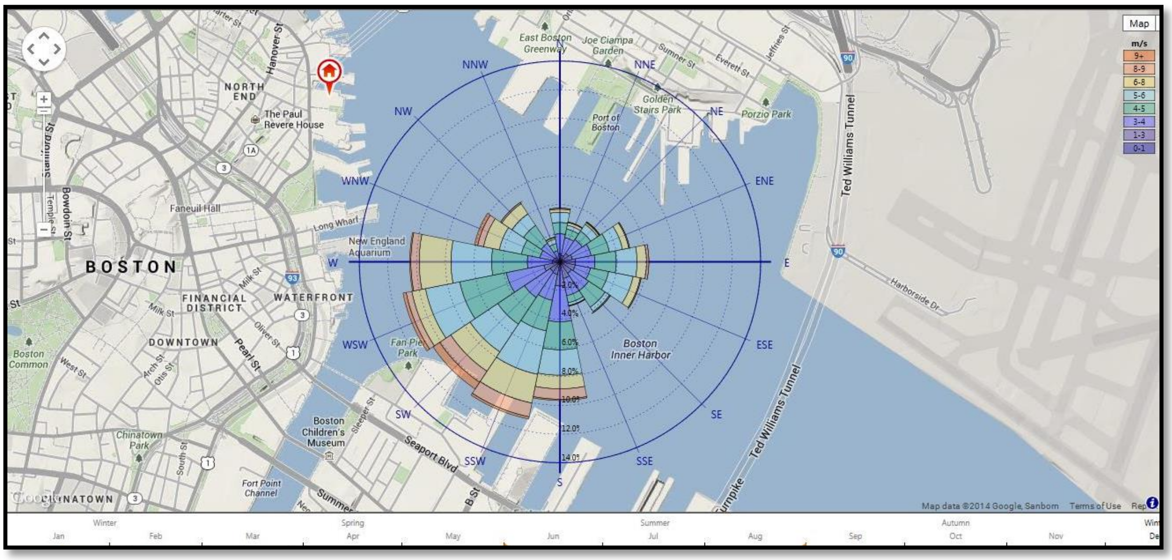


Figure 3-3: summer Wind Rose Diagram for north end Boston

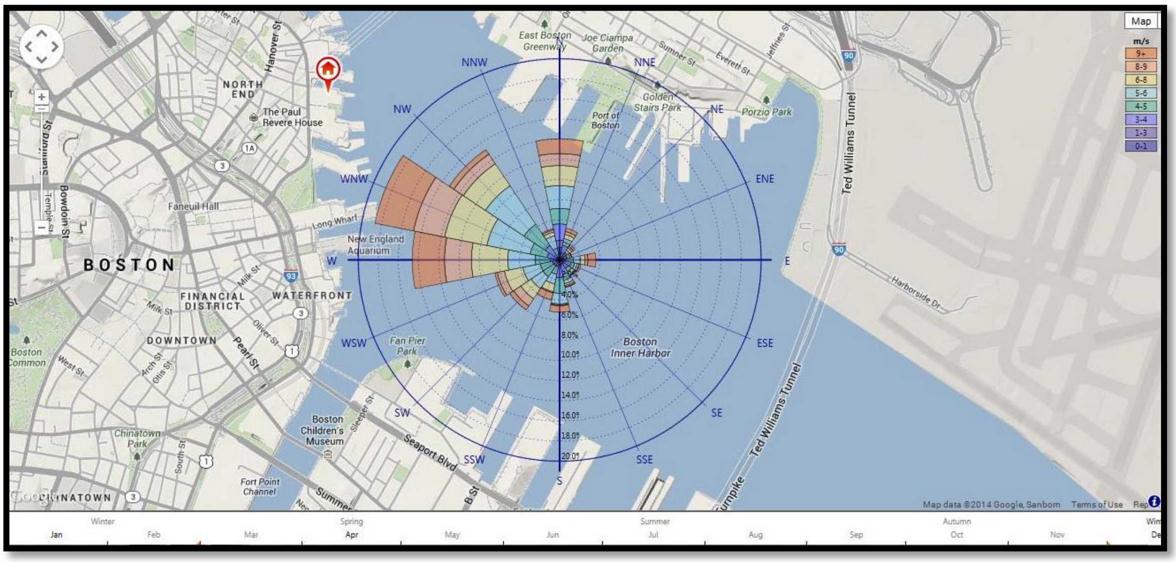


Figure 3-4: Winter Wind Rose Diagram for north end Boston

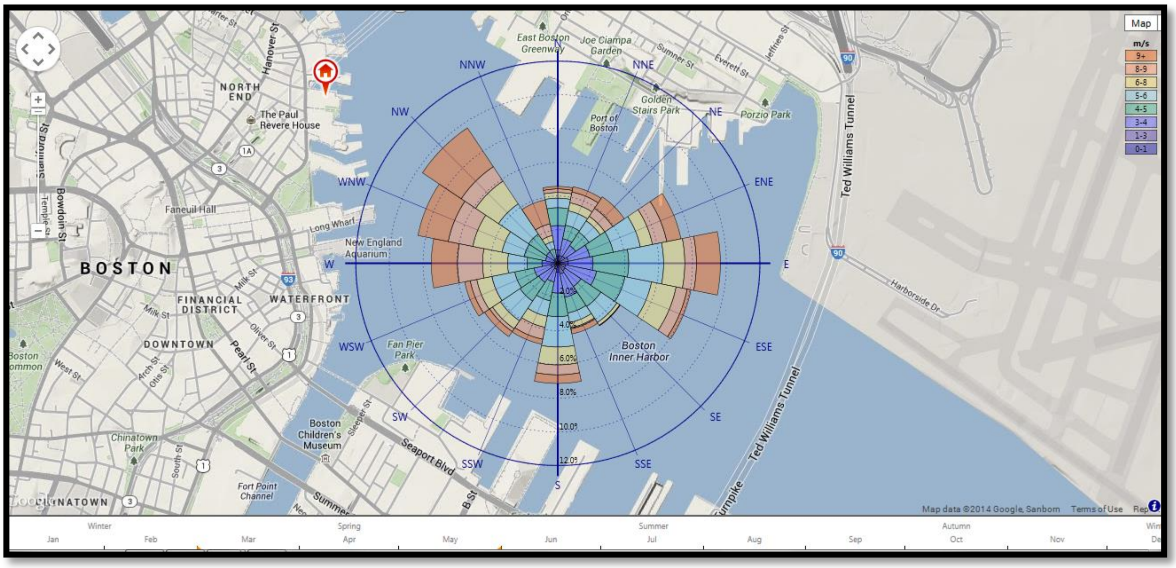


Figure 3-5: Spring Wind Rose Diagram, North End Boston

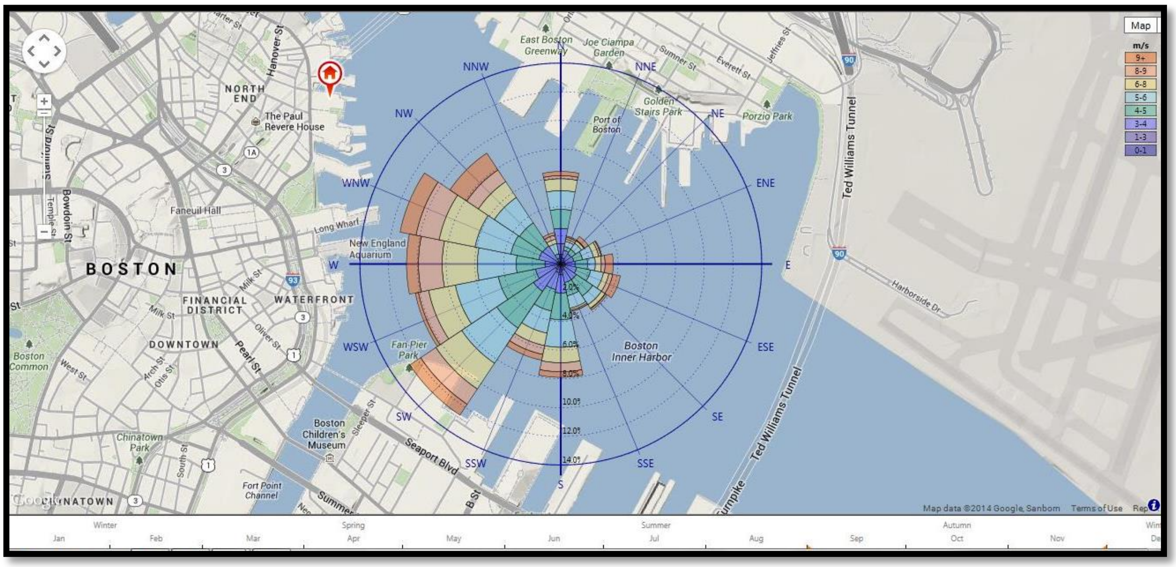


Figure 3-6: autumn wind rose diagram for North End Boston

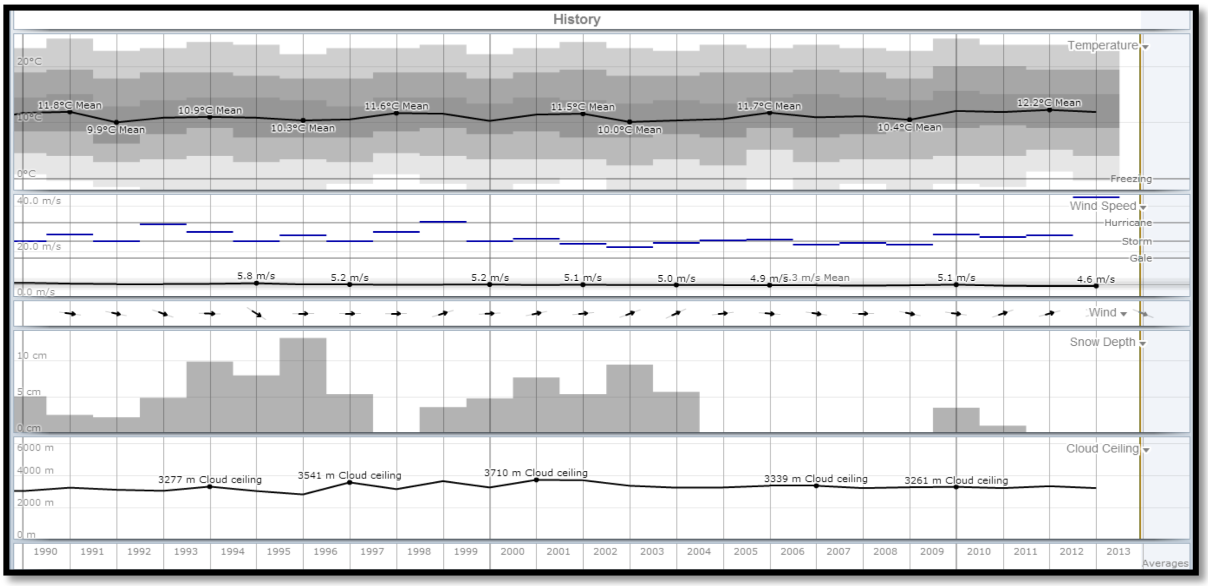


Figure 3-7: Historical data about Snow Depth, Wind Speed and Precipitation

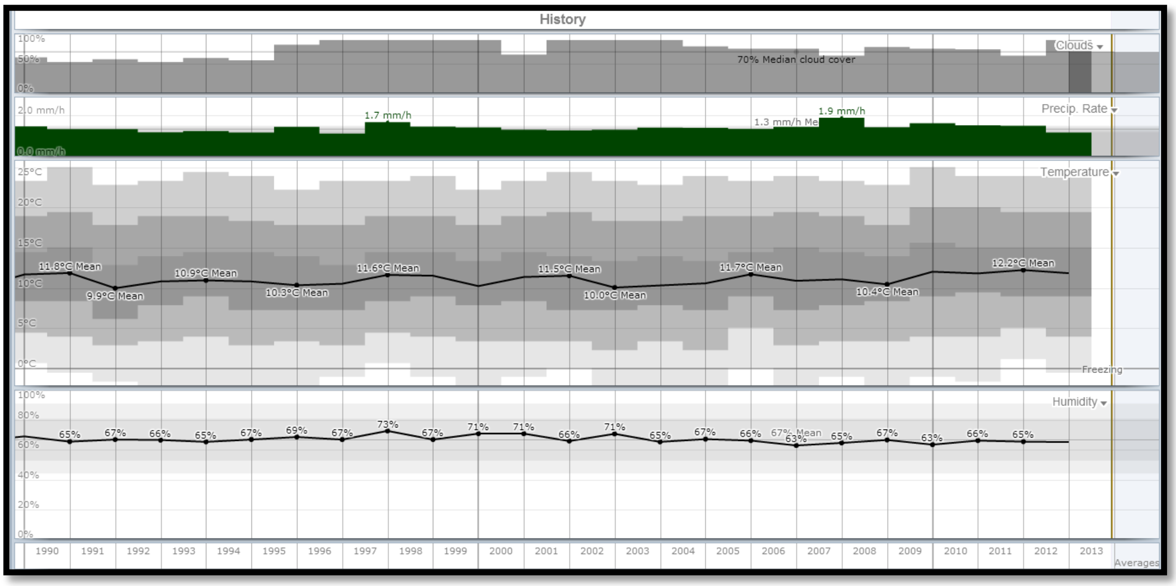


Figure 3-8: Historical data about Temperature, Humidity and Precipitation

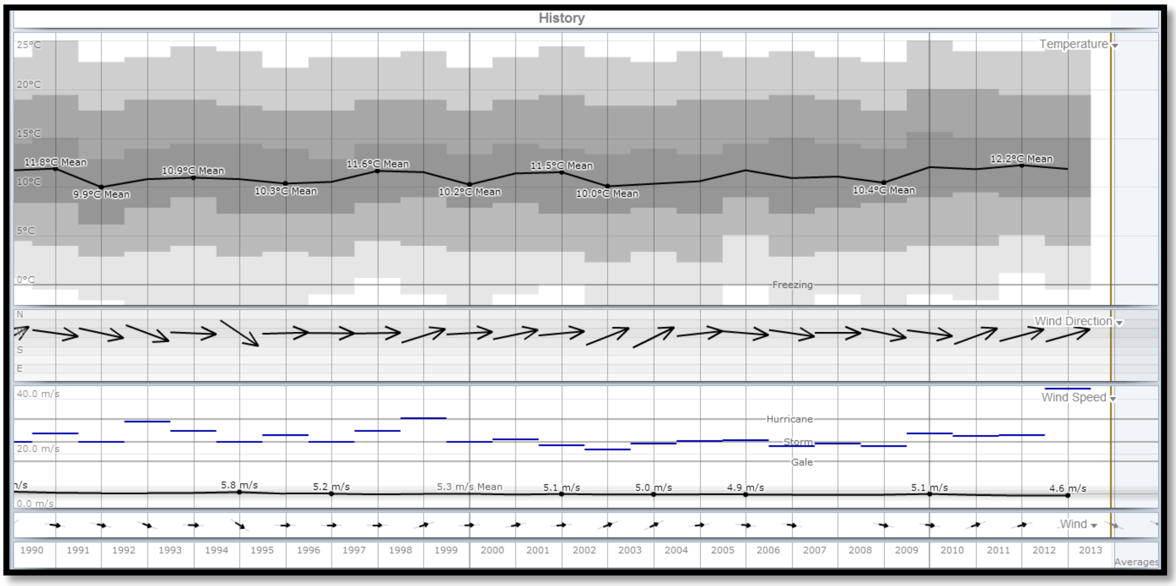


Figure 3-9: Historical data about Wind direction, Wind Speed and Temperature

Following is the psychometric chart taken by Ecotect software showing the comfort zone of Boston in winter with activity level as sedentary. It is clear from the the temperature can be between 15.5^{0}C to 19.5^{0}C and the relative humidity between 30% to 90%.

3.2 "Rising Water, Rising Worries":

The Globe reports on a new study showing the North End / Waterfront and much of Boston is likely to feel the worst of sea level rise as local tide levels "are rising three to four times faster than the global average." Boston's sea levels are forecasted to rise by 2 to 6 feet by the end of this century, increasing potential harm and flooding during storms in the coming decades.

Harbor walk flooding is already common at the New England Aquarium that has moved its electrical systems to higher floors and elevated its outside areas. From the Globe article:

"As we get further along with climate change, buildings in the city like the aquarium are going to have to look at anywhere water can penetrate," said Bud Ris, its chief executive. "People are going to have to think about whether they need sandbags or automatic devices to close off their buildings during storms or high tides. They're also going to have to think about drainage and how to divert water."

The new study used tide gauge data to show that the region's waters have risen between 2 millimeters and 3.7 millimeters per year over the past two decades, compared with the global average of 0.6 millimeters to 1 millimeter per year.

The following is excerpted from an interactive graphic developed by UMass Boston, showing that a 2.5 foot sea level rise and a storm with a 5 foot surge would largely flood most of the waterfront and periphery of the North End as well as low lying areas in Back Bay, South End East Boston and the Seaport area.

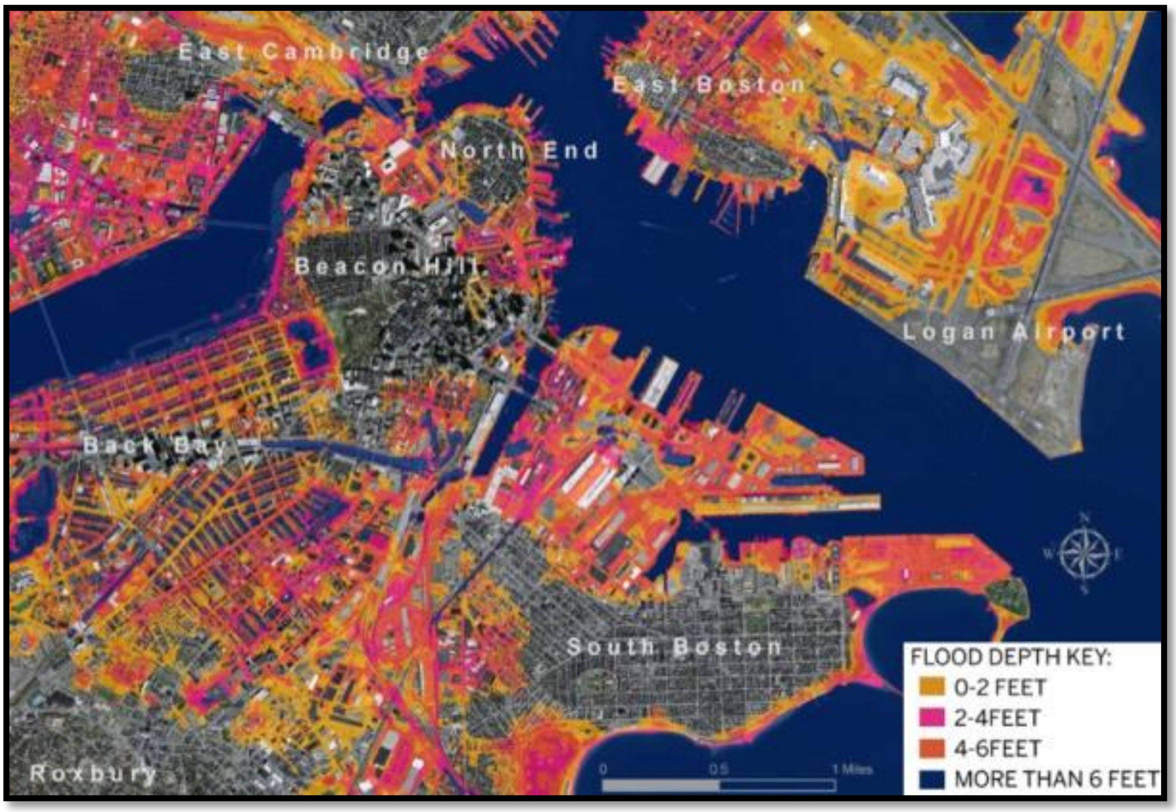


Figure 3-10: Boston Flooding with 2.5 Feet Sea Rise & 5 Foot Storm Surge (Globe Graphic – UMass Boston, Dr. Ellen M. Douglas)

This report describes the typical weather at the Logan International Airport (Boston, Massachusetts, United States) weather station over the course of an average May 14. It is based on the historical records from 1974 to 2012. Earlier records are either unavailable or unreliable.

Boston, Massachusetts has a humid continental climate with hot summers and no dry season. The area within 25 miles of this station is covered by forests (51%), oceans and seas (26%), and built-up areas (21%).

Following is the Highest and lowest temperature all over year:

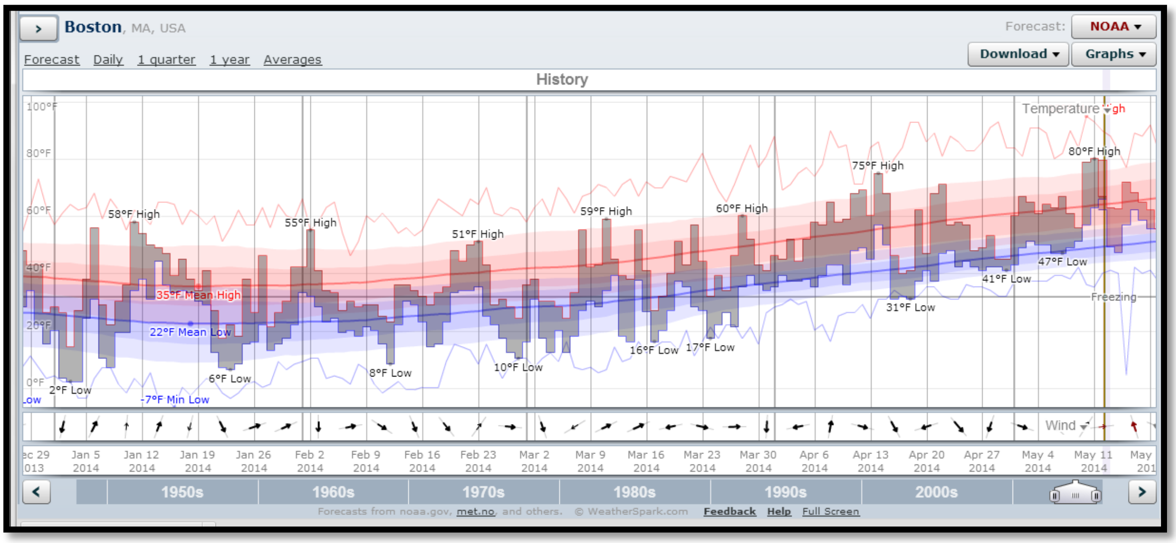


Figure 3-11: Highest and lowest temperature range all over the year,2014

The temperature typically varies from 52°F to 62°F and is rarely below 45°F or above 75°F.

3.3 Comfort zones

Buildings are only energy-effective when their occupants are comfortable. Thermal comfort is difficult to measure because it is highly subjective. It depends on the air temperature, humidity, radiant temperature, air speeds, activity rates, and clothing levels In the location of Boston-Massachusetts (Lat.42.4-Long.-71.0) near Logan International Airport comfort zones where extracted from Weather tool in existing environmental conditions and after applying several heating and cooling strategies as study for the best suitable strategy for designing a sustainable building.

Following graphs shows the comfort zone all without implementing any strategies all over the year, in summer and in winter.

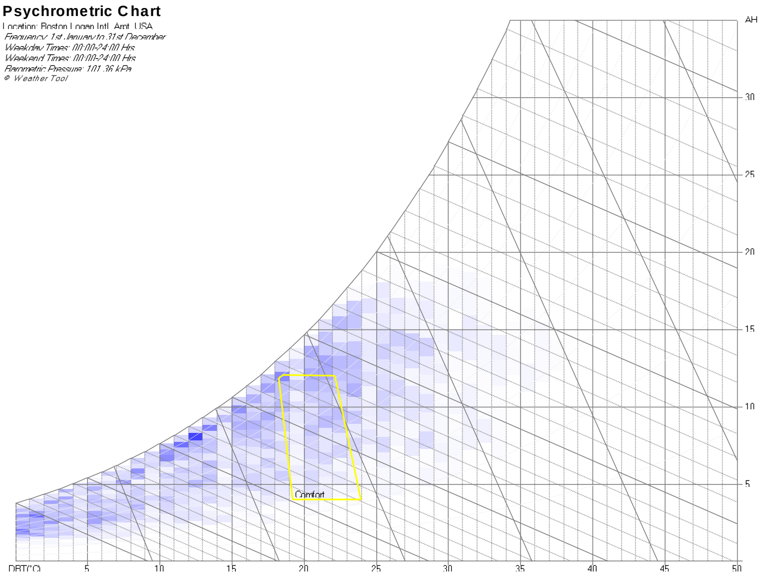


Figure 3-12: comfort zone all over the year

Following is the psychometric chart taken by Ecotect software showing the comfort zone of Boston in summer with activity level as sedentary. It is clear from the temperature can be between 23.5^{0}C to 28^{0}C and the relative humidity between 20% to 70%.

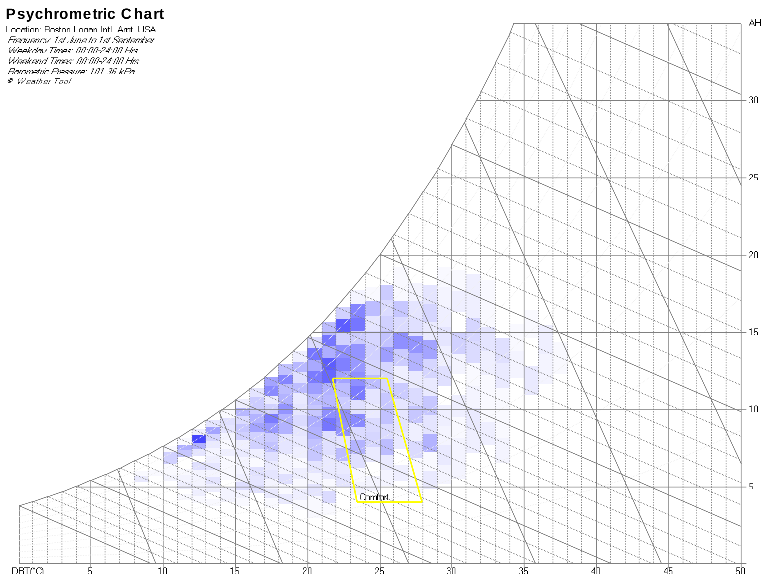


Figure 3-13: comfort zone over summer

Following graph shows the comfort zone in winter ranging between 16°c to 20°c with a relative humidity 40% to 90% which shows need of heating with dehumidification since it is going away from the existing environmental conditions.

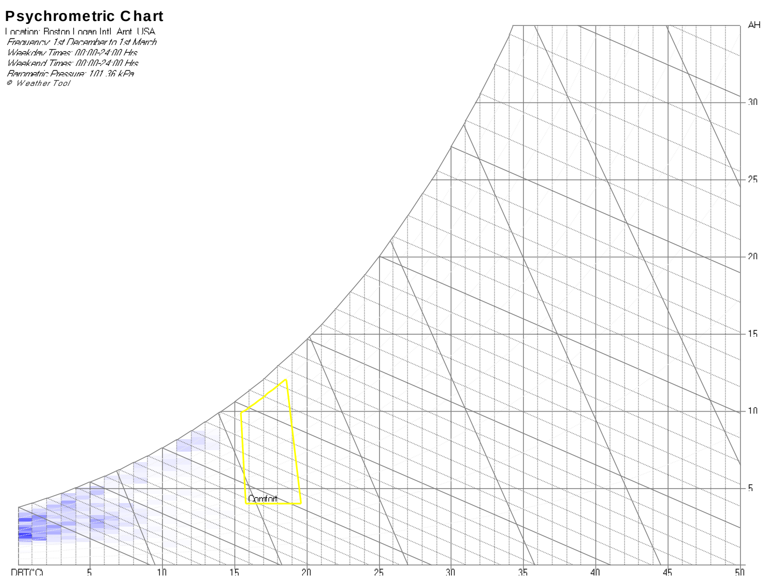


Figure 3-14: comfort zone over winter

3.3.1 Passive solar heating:

In passive solar building design, windows, walls, and floors are made to collect, store, and distribute solar energy in the form of heat in the winter and reject solar heat in the summer. This is called passive solar design or climatic design because, unlike active solar heating systems, it doesn't involve the use of mechanical and electrical devices; following graph shows the effect of using passive solar heating in winter season on the comfort zone considering the glazing ratio 20%.

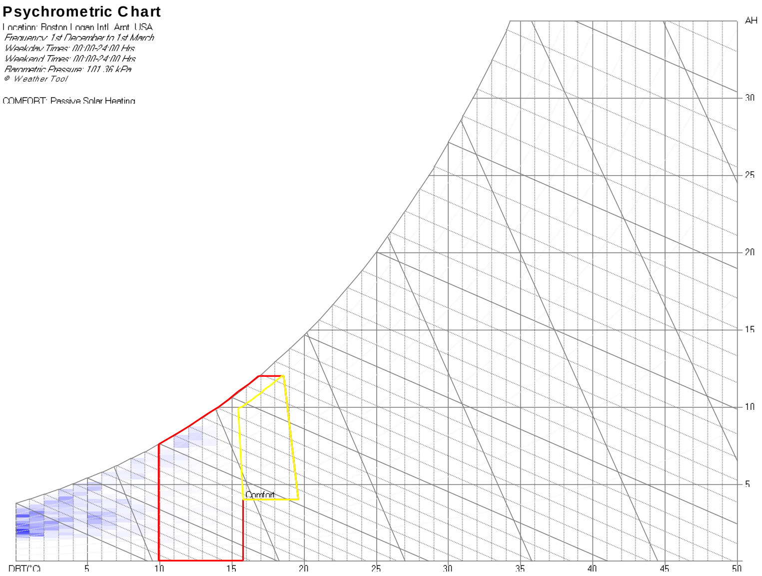


Figure 3-15: passive solar heating 20% glazing-winter season

By increasing the glazing ratio from 20% to 40% it is obvious that the comfort zone increased since the solar gain is increased as thermal energy is allowed to be inside the building, the following graph shows the effect of passive solar heating with 40% glazing ratio

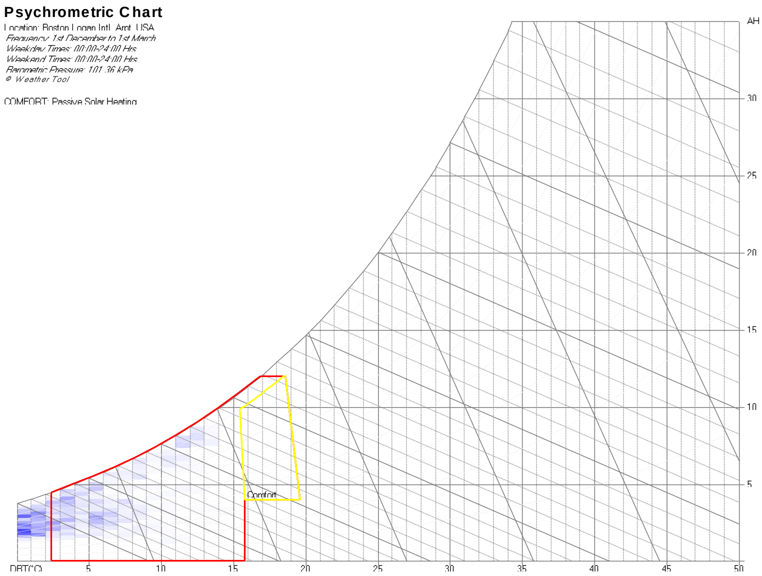


Figure 3-16: passive solar heating 40% glazing-winter season

3.3.2 Thermal mass:

Using thermal mass in the building shows widening of the comfort zone on the psychometric chart from the right and the left showing the advantage of using it as a cooling strategy in summer and heating strategy in winter

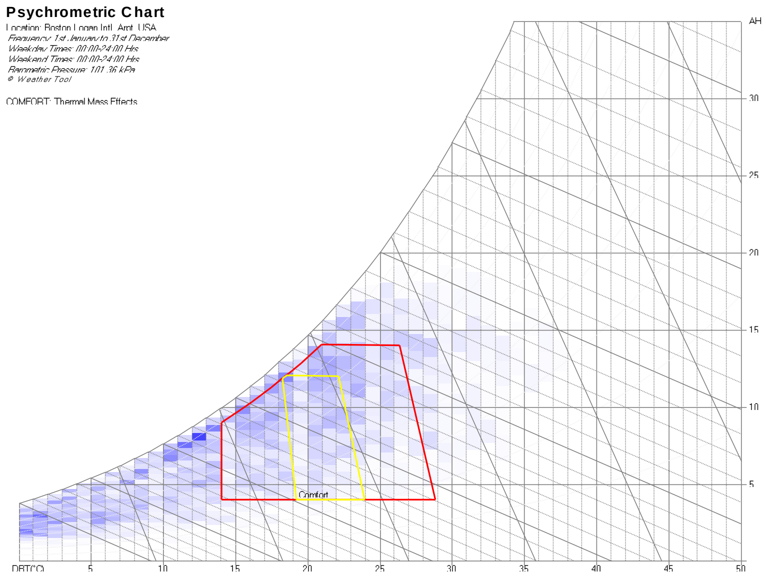


Figure 3-17: Thermal mass effect in all year

3.3.3 Thermal mass+ Night ventilation:

It describes the application of a thermal mass with letting air inside the building whether by natural ventilation or mechanical fans and it shows drastic change in the comfort zone as the graph below shows the effect of applying a thermal mass with night air ventilation

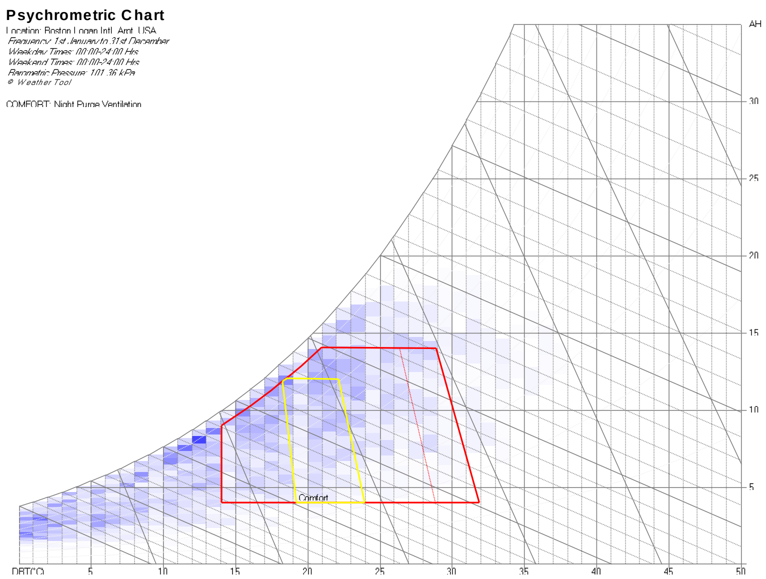


Figure 3-18: Thermal mass effect +night ventilation during all year

3.3.4 Natural ventilation:

Natural ventilation brings fresh air inside the building besides having cooling effect on the human body. This affects rate of sweat evaporation producing sensation of cooling. This design strategy can have favorable results especially in summer; the following graph shows the effect of natural ventilation is summer season

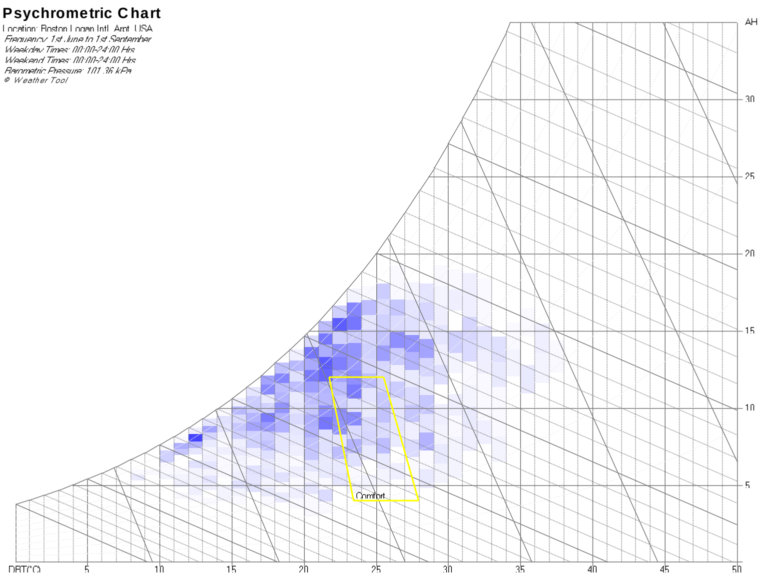


Figure 3-19: Natural ventilation (summer season)

3.3.5 Direct evaporative cooling:

Evaporative cooling takes place when water is changed from liquid water to gas, thus cooling the air by adding humidity. Evaporative cooling phenomenon is usually good cooling Strategy for hot dry climates, but it can be utilized where applicable in achieving the comfort Conditions.

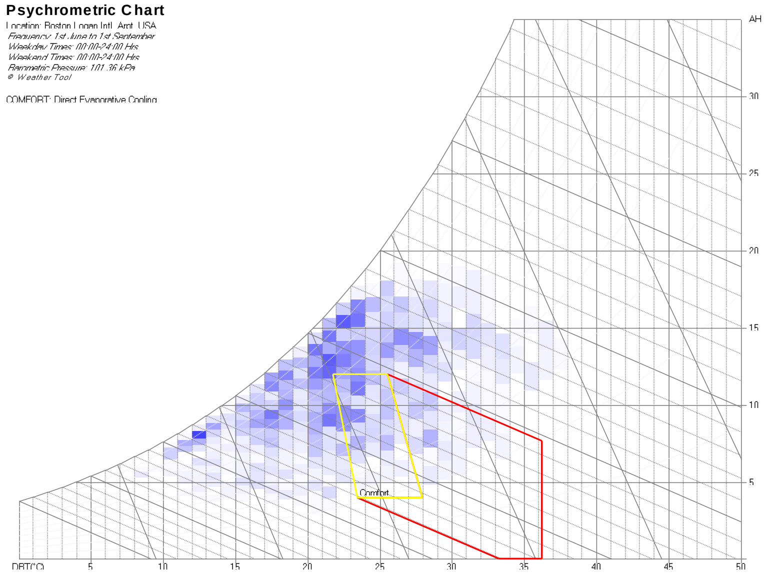


Figure 3-20: Direct evaporative cooling (summer season)

3.3.6 Indirect evaporative cooling:

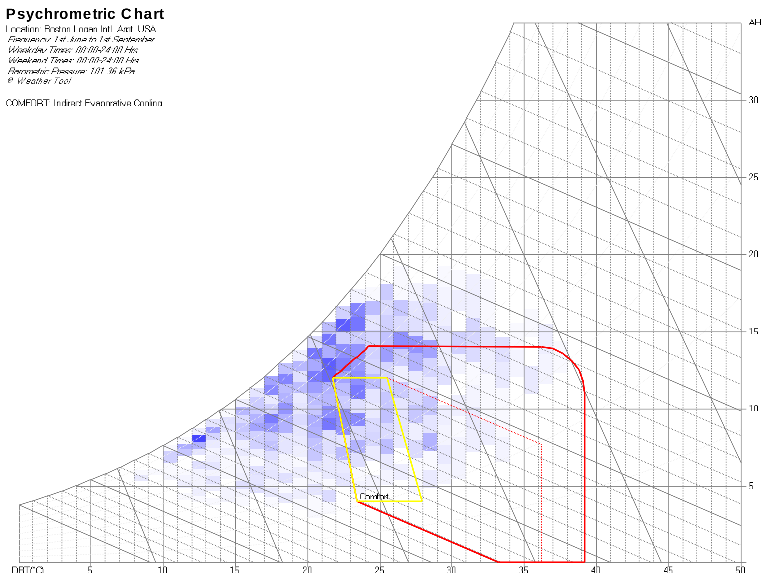


Figure 3-21: Indirect evaporative cooling (summer season)

3.3.7 Multiple techniques (winter):

Following graph shows effect of multiple strategies in winter on the comfort zone for Boston.

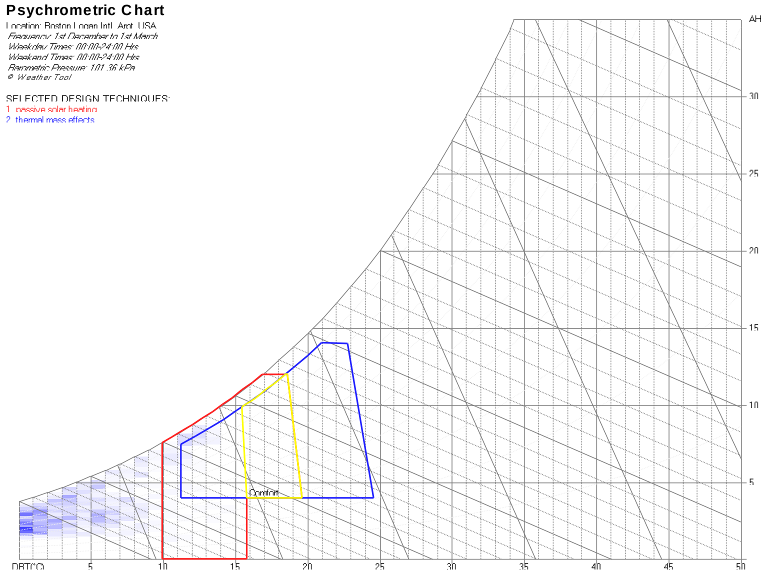


Figure 3-22: Multiple techniques (winter)

3.3.8 Multiple techniques (summer)

Following graph shows effect of multiple strategies on the comfort zone for Boston in summer.

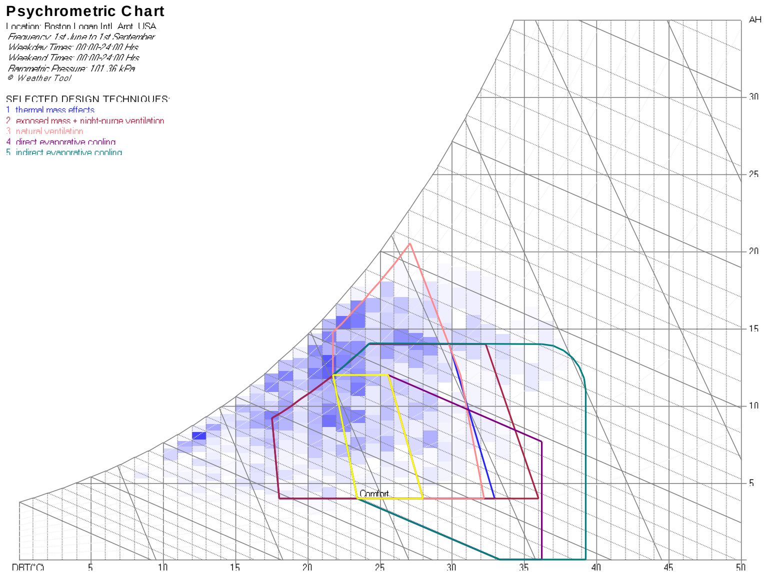


Figure 3-23: Multiple techniques (summer)

3.4 Shadding Analysis (shape and orientation) :

Before we even think about Energy Star appliances, recycled-content products, or whiz-bang technologies, the first thing anyone building a building needs to do is position the structure for maximum benefit. It is, perhaps, the most important decision we make.

The right site orientation is where energy savings begin. In addition to beneficial daylight, a properly sited house will avoid solar heat gain and require less mechanical cooling in the summer. It may also take advantage of the prevailing breezes for free cooling. “East west [orientation] is best,” says architect Ed Binkley, of Ed Binkley Design in Oviedo, Fla.

The north side provides the best light, southern exposure is easy to control with shading, and the east and west should have less glass.

The form and especially the window openings in the façade were decided based on a detailed shadow analysis. A number of volumes were checked in the initial stages of the project and thus multiple window solutions were also vetted. The first step was to carry a site shadow analysis.

The software used for the shadow analysis and orientation decisions was Ecotect. The sun path and shadow range throughout the day was explored for all the four seasons and the results have been given below.

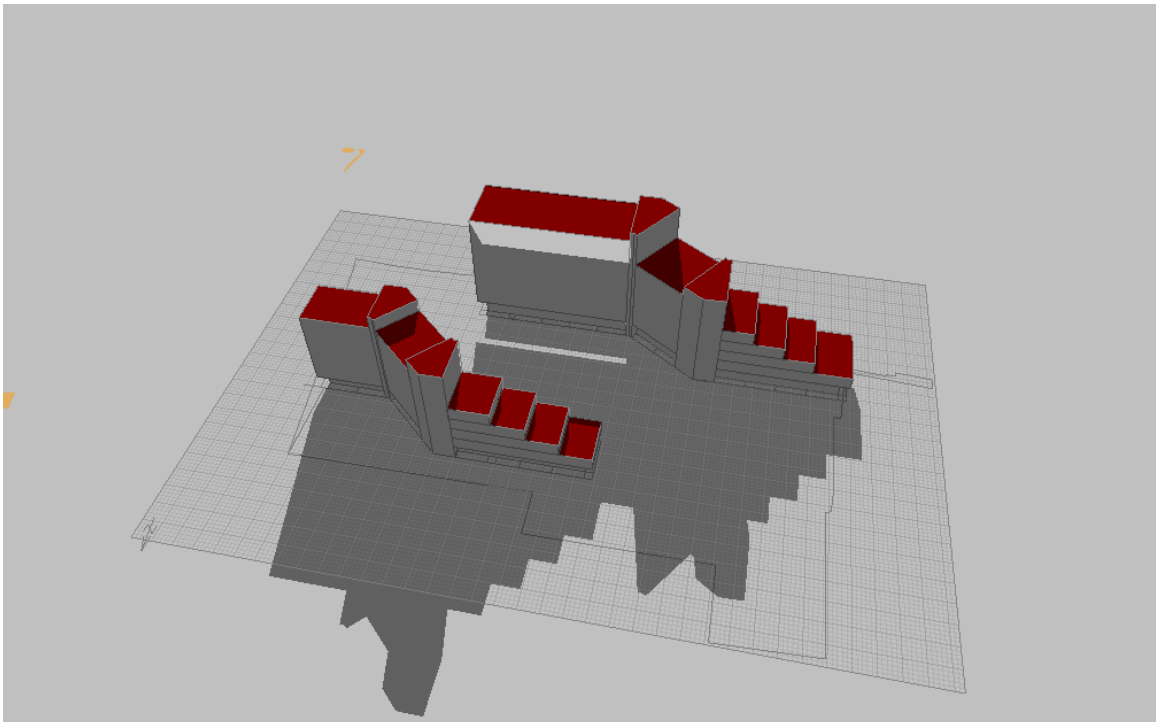


Figure 3-24: Shadow Analysis (daily sun path) at 13:45 for 22nd December

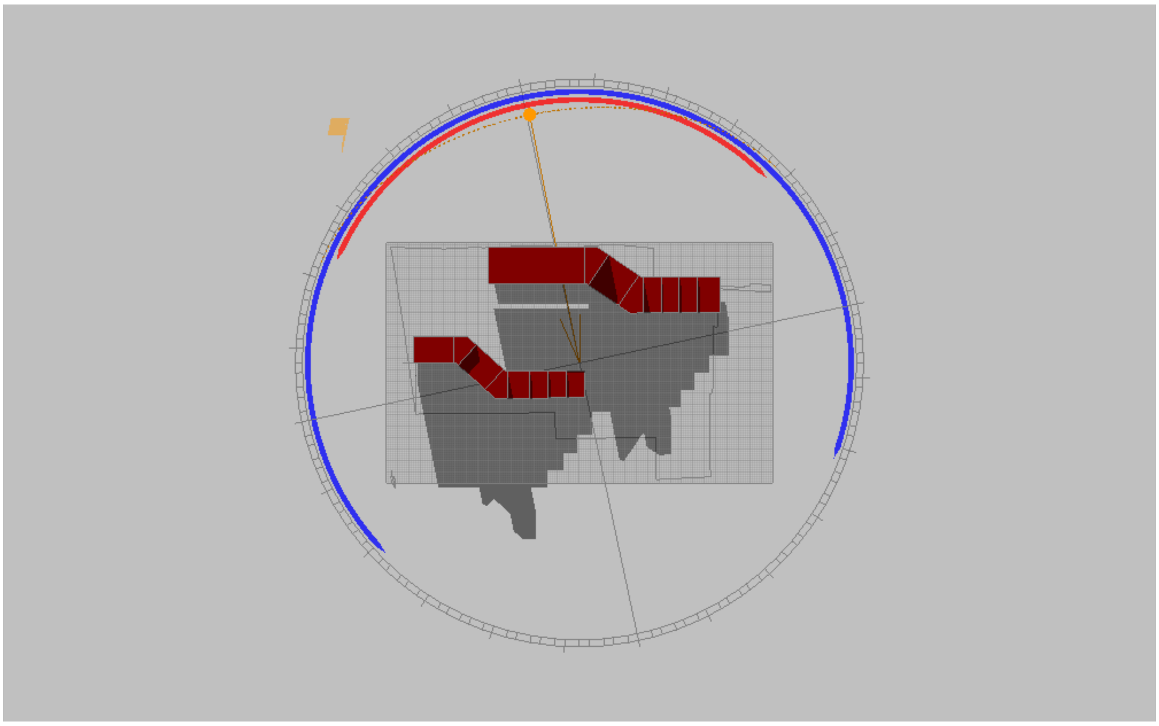


Figure 3-25: Shadow Analysis (daily sun path) at 13:45 for 22nd December (Top view)

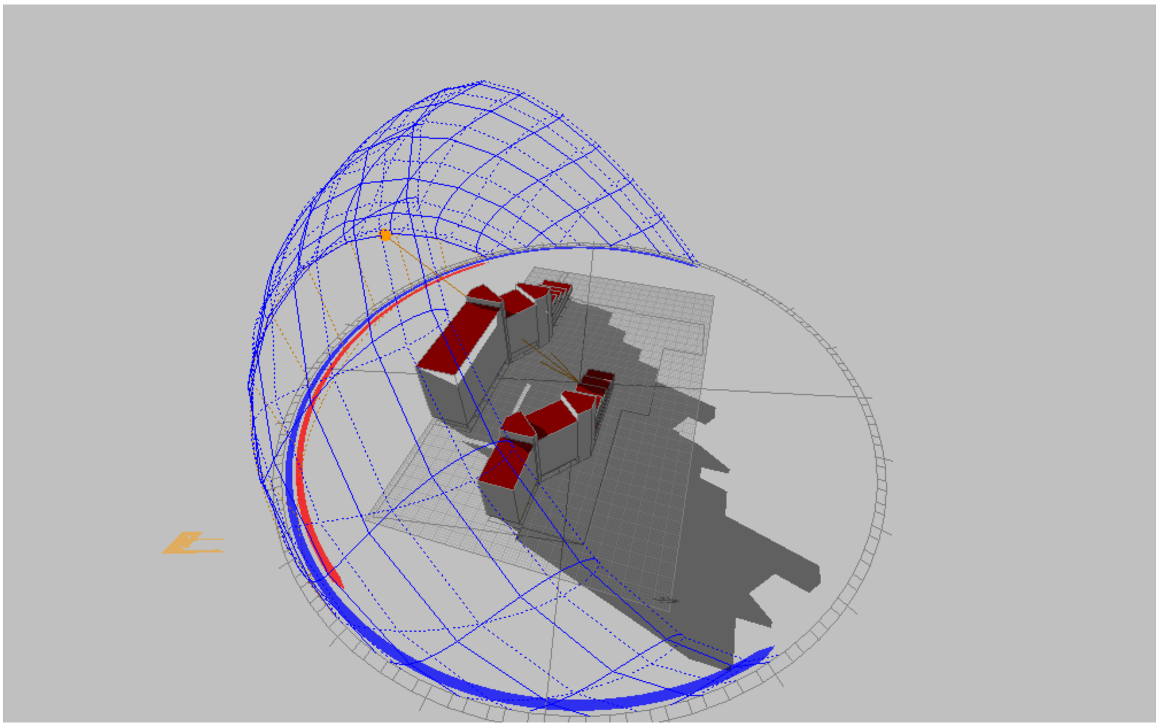


Figure 3-26: Shadow Analysis (Annual sun path) at 13:45 for 22nd December

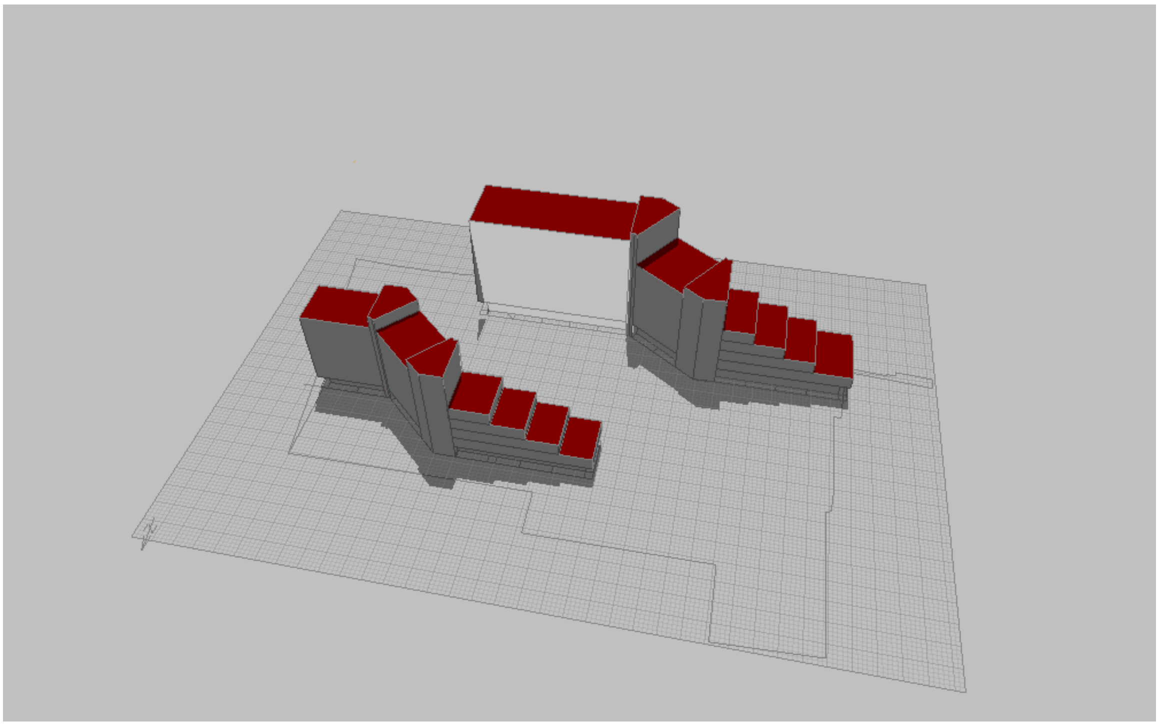


Figure 3-27: Shadow Analysis (daily sun path) at 13:45 for 22nd June

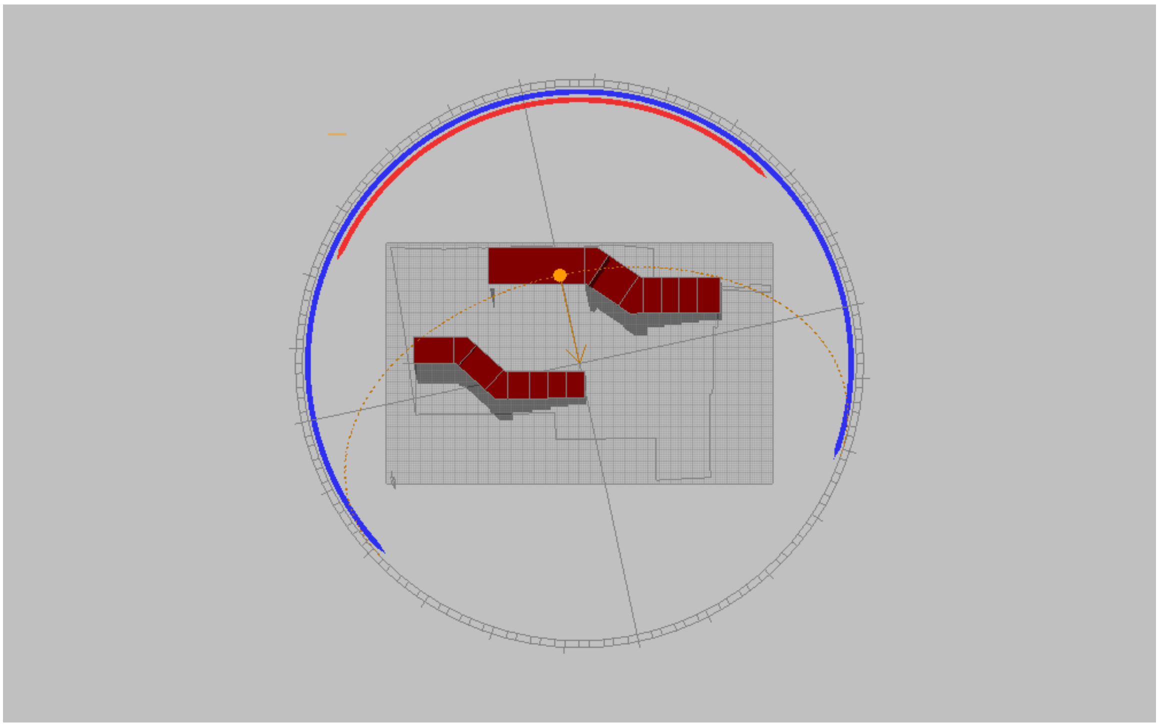


Figure 3-28: Shadow Analysis (daily sun path) at 13:45 for 22nd June (Top view)

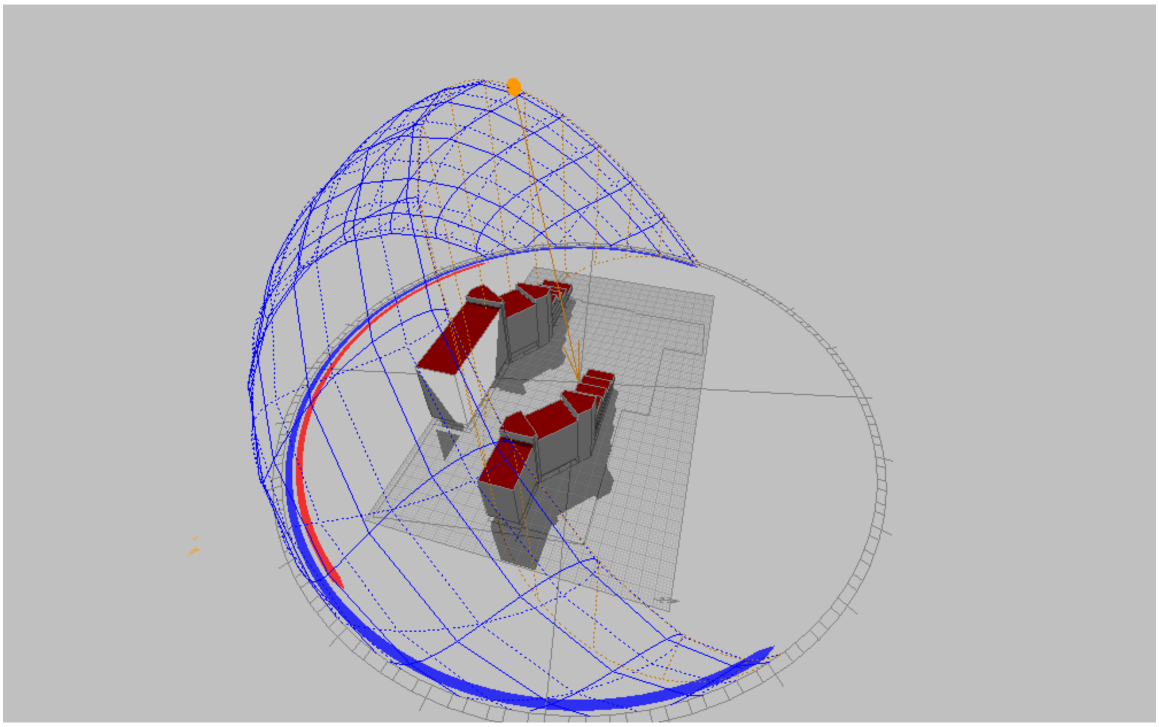


Figure 3-29: Shadow Analysis (Annual sun path) at 13:45 for 22nd June

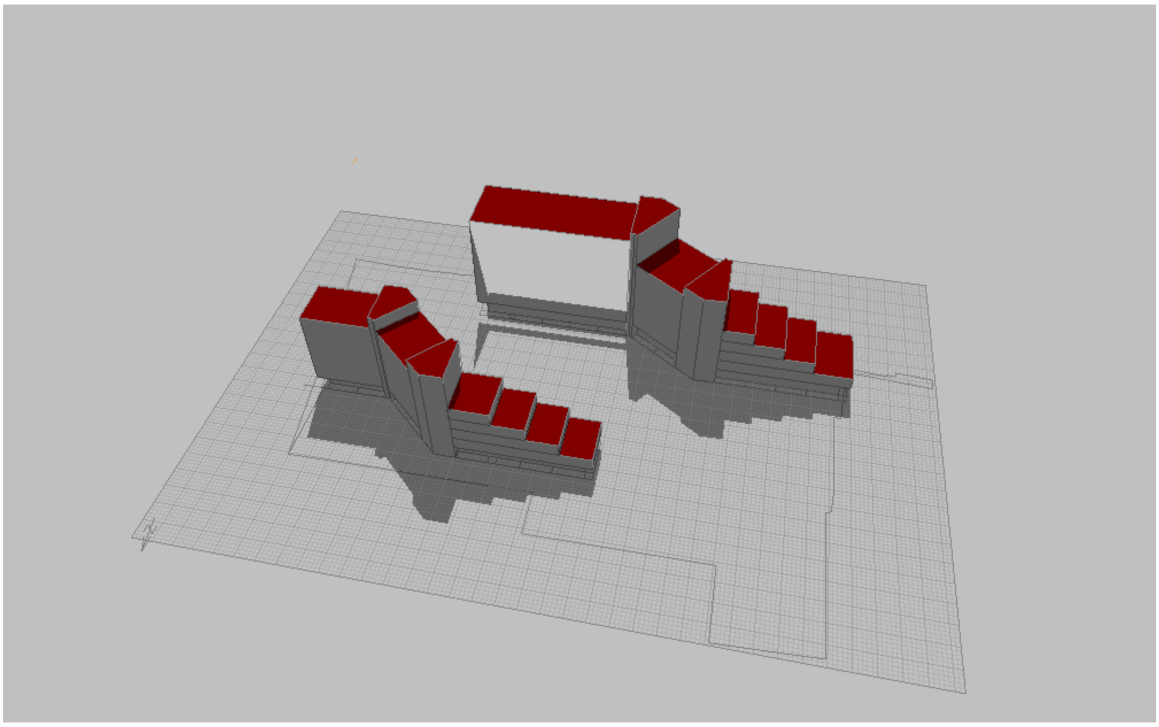


Figure 3-30: Shadow Analysis (Daily sun path) at 13:45 for 1st Sep

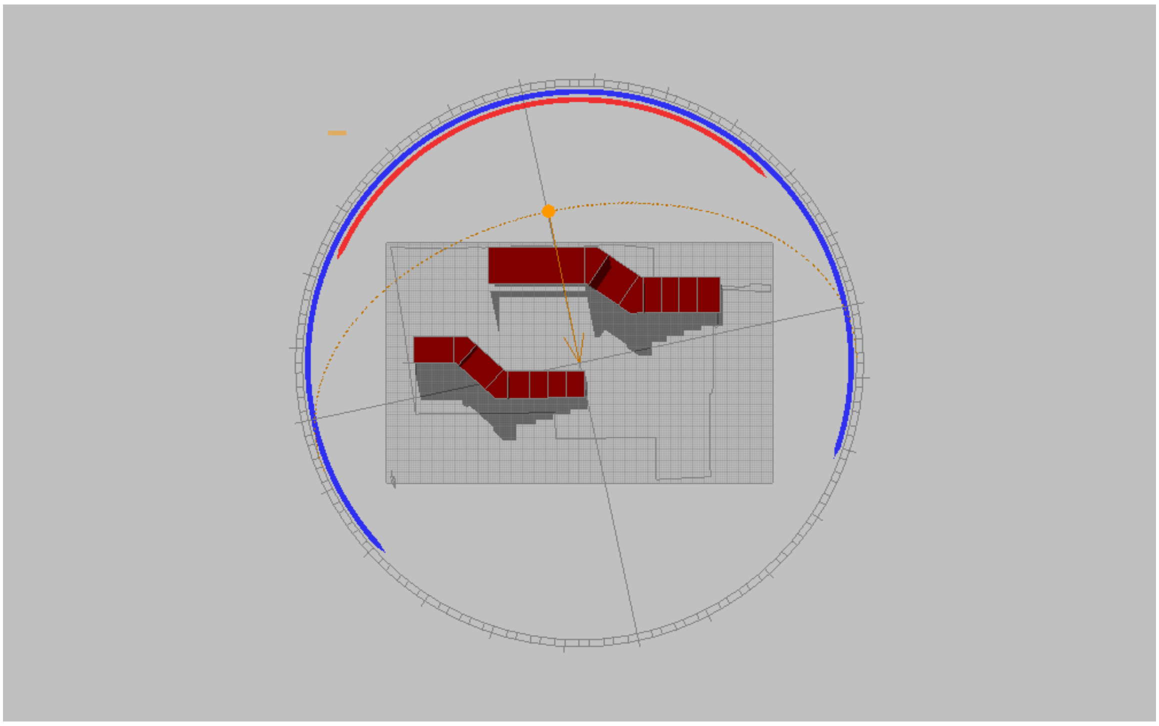


Figure 3-31: Shadow Analysis (Daily sun path) at 13:45 for 1st Sep. (Top view)

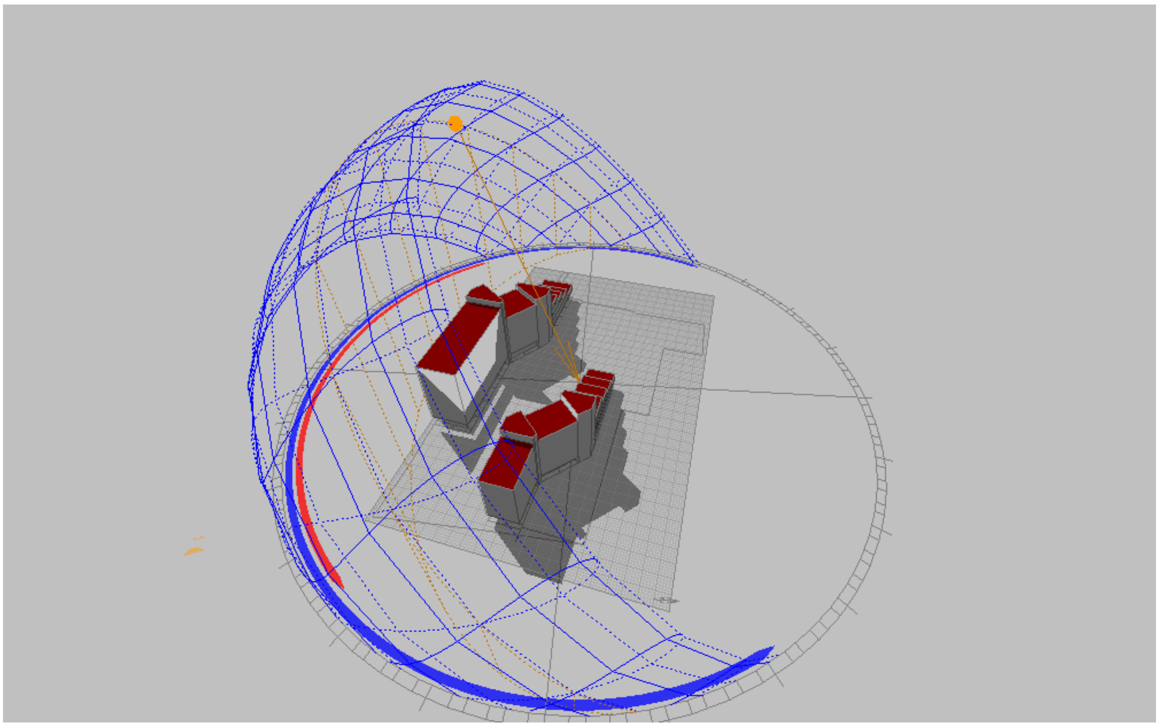


Figure 3-32: Shadow Analysis (Annual sun path) at 13:45 for 1st Sep

Based on the orientation analysis and the proposed site, and respective volume, of the building, it was seen that almost every part of building is exposed to sunlight while the real problem can arise in winter sun where on shortest day of the year (22nd December) at 13:45 when sun has got its peak, we observed that most of the building is under shade and hence it will be very cold considering the weather of Boston city in Winter season. So we decided to make the building closed and at the same time opened to have cross ventilation and daylight in mid-season and summer. We then came to the conclusion to divide whole building in different units not only on the basis of type of residence but also on the type of design.

3.5 Daylight analysis:

Daylight has many advantages over artificial light - not least the fact that it is a completely free, unlimited natural resource. Whilst artificial light is essential, it's provision uses a lot of energy, so reducing the requirement will dramatically cut energy use, and the CO2 emissions which result from this.

The concept of Daylight Factor (DF) was developed in the United Kingdom in the early 20th century. Daylight Factor is a ratio that represents the amount of illumination available indoors relative to the illumination present outdoors at the same time under overcast skies. Daylight Factor is typically calculated by dividing the horizontal work plane illumination indoors by the horizontal illumination on the roof of the building being tested and then multiplying by 100. For example, if there were 20,000 lux available outdoors and 400 lux available at any given point indoors, then the DF for that point would be calculated as follows DF = 400/20,000 *100 or DF=2

3.5.1 Criteria adopted:

Typical recommended minimum daylight factors for rooms with side lighting only

Table 2 Recommended daylight factor

Building type	**Location**	**Min. D.F. %**	**Avg. D.F. %**
Dwellings	Living rooms (over depth, but for minimum area 8m2)	**1**	**4-5**
Dwellings	Bedrooms (over~- depth, but for minimum area 6 m2	**0.5**	**1-2**
Dwellings	Kitchens (over -~- depth, but for minimum area 5 m2)	**2**	**2-3**

Daylight Factor less than 2%

- Room looks gloomy
- Often needs full artificial lighting during the day
- Decor is dominated by the appearance of artificial lights

Daylight Factor between 2 – 5%

- The optimum range of day lighting for efficient energy use
- Room appears to be predominantly lit by daylight
- Artificial lighting is required away from roof lights and on dull days

Daylight Factor greater than 5%

- Room appears to be strongly lit by daylight

- Artificial lighting rarely required during the day

Potential solar gain is a consideration and therefore careful specification is required. For our project we decided to see the luminance levels in our building and so we considered first one module and then multiple modules in order to see whether the daylight condition is same over all the modules in our building and is it sufficient for inhabitants or no. The results for Ecotect have been presented below. The analysis by Ecotect offers a numerical evaluation of the amount of daylight at various points in the building. By a general convention a daylight factor of about 2% is the minimum required for visibility inside the space.

For this reason we developed two cases which are described as follows:

Case 1:

a. <u>Analysis of one module at first floor (F.F of 3 units) without any kind of shading device and with windows and sun space:</u>

- Grid position 600 mm (desk height);
- Natural light levels;
- Overcast sky condition (CIE);
- Cleanliness of model windows and corresponding reduction in average 0.90

With external obstruction.

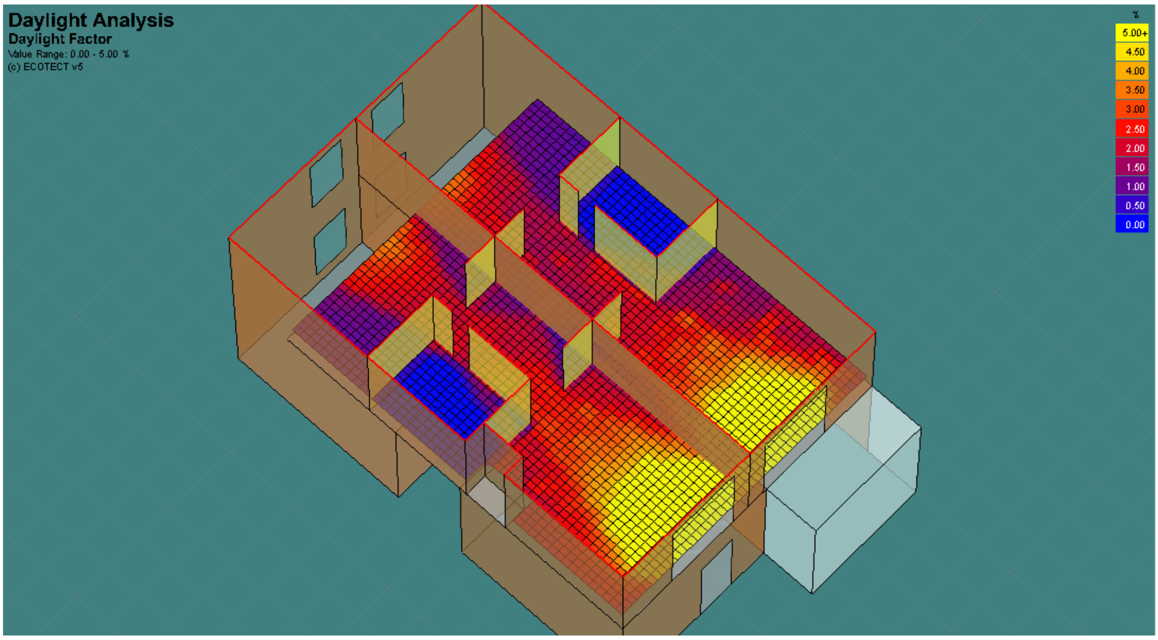


Figure 3-33: Daylight factor of first floor of one module

It can be said with confidence that the amount of available light is definitely sufficient to light up the space without any need to artificial illumination. The strategy adopted to keep the lower floor of module lightened was to keep the slab open at one end, so that the light coming from window not only illuminate the upper floor as well as the lower one.

b. Analysis of one module at first floor (G.F. of 3 units) without any kind of shading device and with windows and sun space:

- Grid position 600 mm (desk height);
- Natural light levels;
- Overcast sky condition (CIE);
- Cleanliness of model windows and corresponding reduction in average 0.90

With external obstruction.

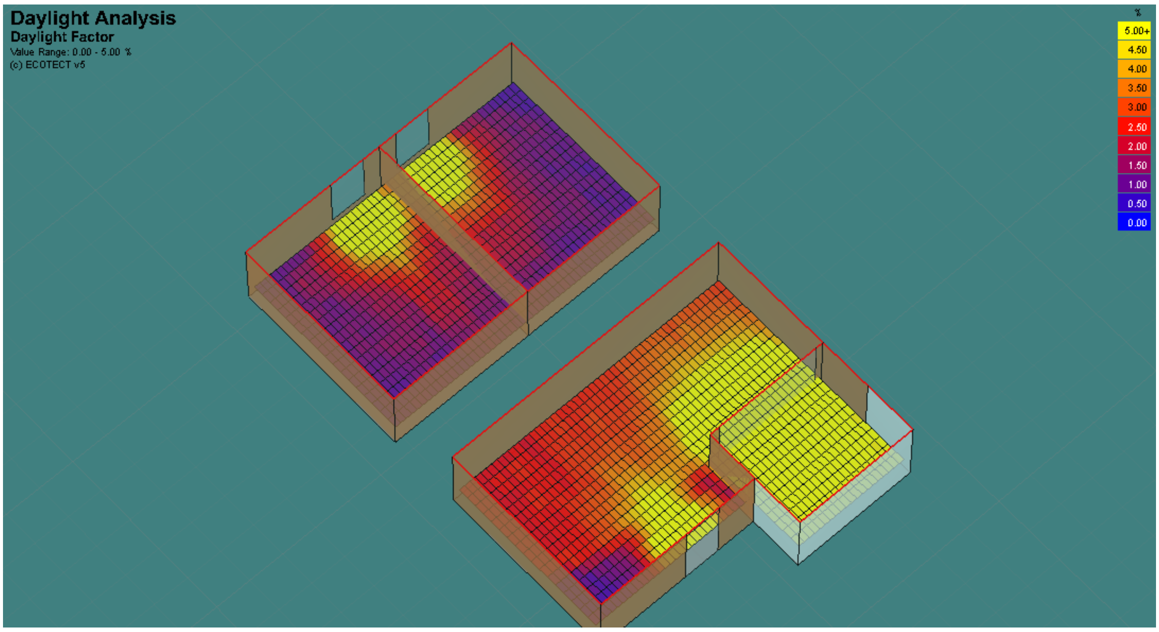


Figure 3-34: Daylight factor of ground floor of three units

Case 2:

c. <u>Analysis of three modules at first floor (F.F of 9 units) inside housing without any kind of shading device and with windows and sun space:</u>

- Grid position 600 mm (desk height);
- Natural light levels;
- Overcast sky condition (CIE);
- Cleanliness of model windows and corresponding reduction in average 0.90

With external obstruction.

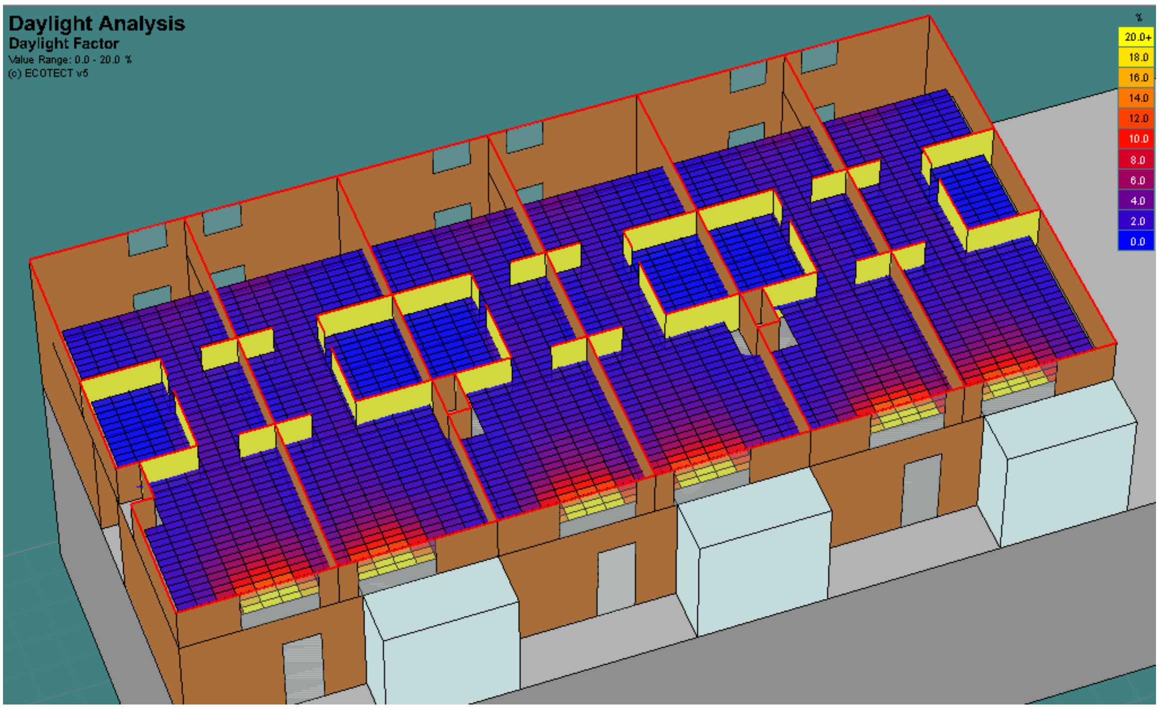


Figure 3-35: Daylight factor of first floor of six units with range 0-20%

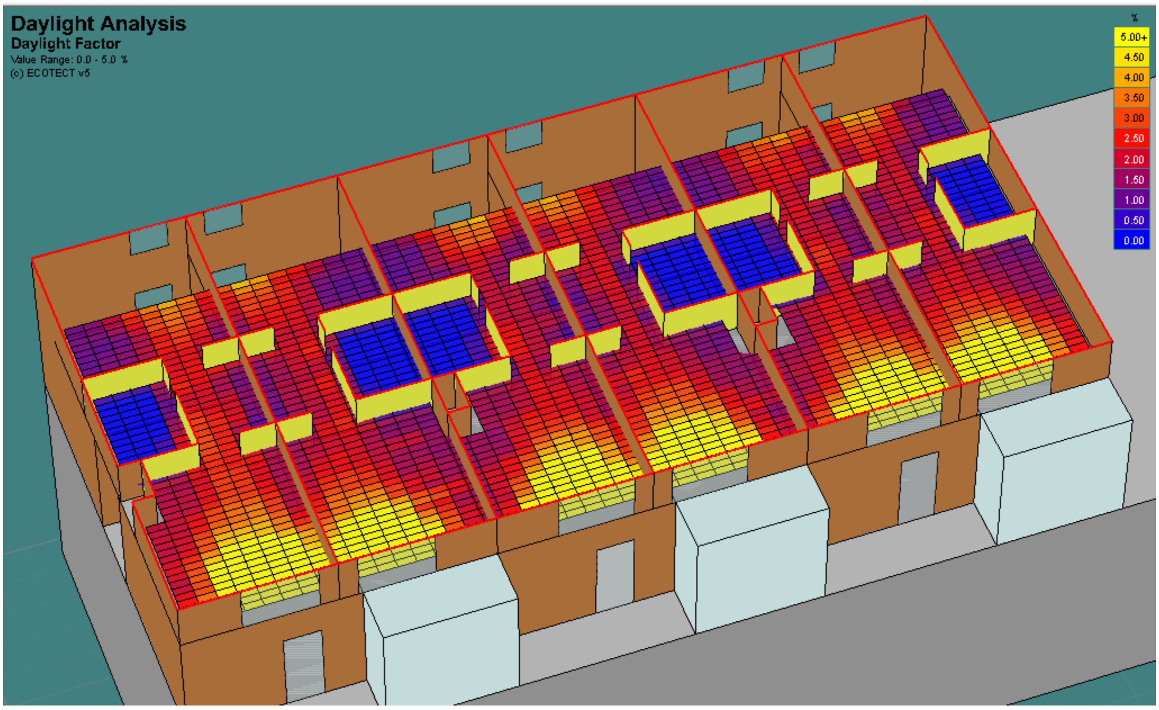


Figure 3-36: Daylight factor of first floor of six units with range 0-5%

It is clear from the results that the quality and amount of light is same for all the modules in the building that is ranging between 2 to 5% daylight factor value.

d. <u>Analysis of one module at first floor (G.F of 3 units) inside housing without any kind of shading device and with windows and sun space:</u>

- Grid position 600 mm (desk height);
- Natural light levels;
- Overcast sky condition (CIE);
- Cleanliness of model windows and corresponding reduction in average 0.90

With external obstruction.

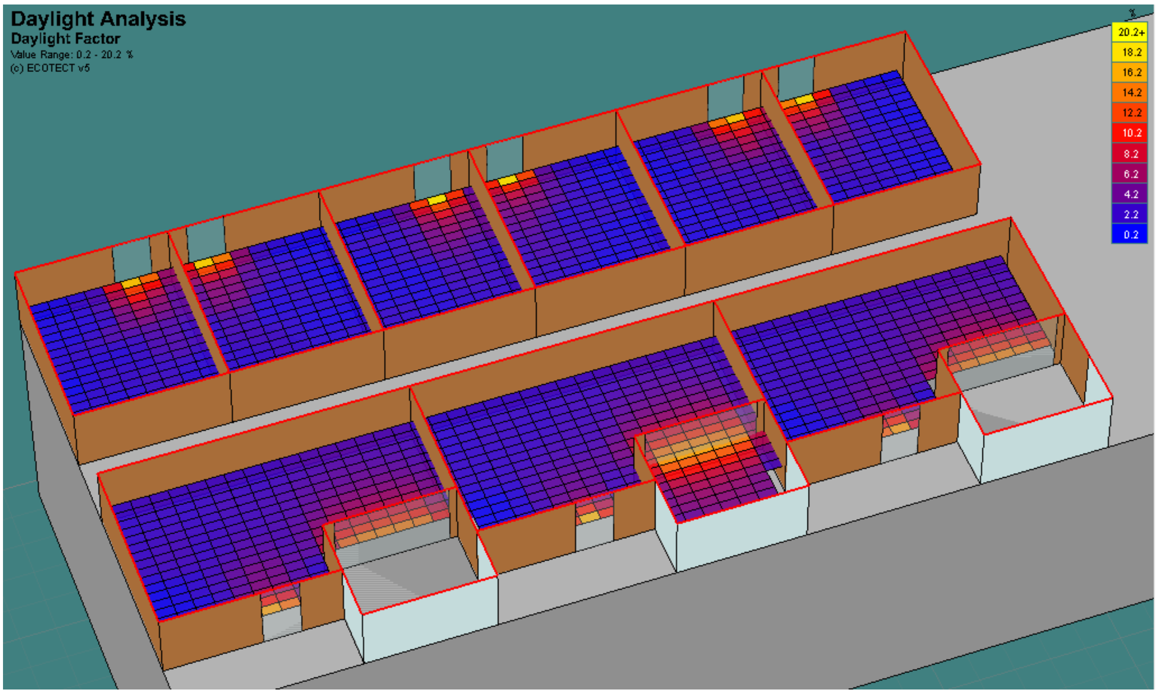


Figure 3-37: Daylight factor of ground floor of six units with range 0-20%

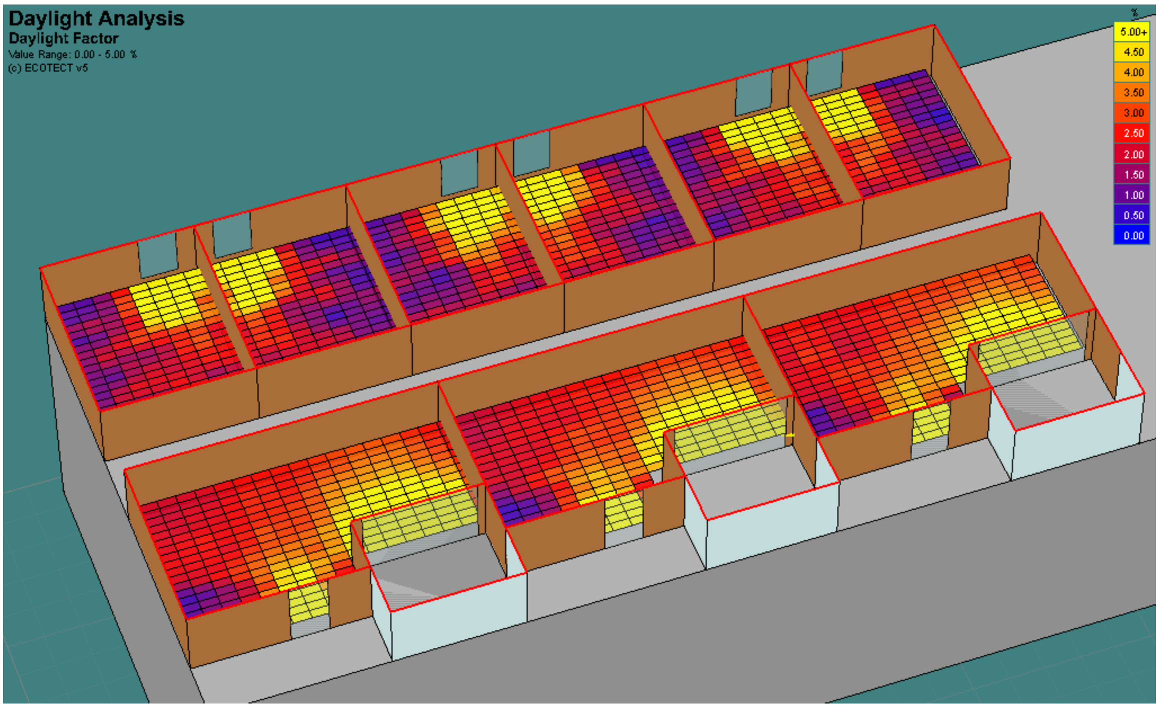


Figure 3-38: Daylight factor of ground floor of six units with range 0-5%

The same analysis as above was carried out for the first floor as well, as for the ground floor of module which has been presented above and the range of daylight factor is 2-5%.

3.6 ECOTECT Calculations and results:

3.6.1 Wall Solutions:

The below schemes will present the results generated from the software, as the final composition layers arrangement and thicknesses were determined accordingly, with respect to the building heating/cooling loads influence, which will be explained in the next part.

Interior-corridor

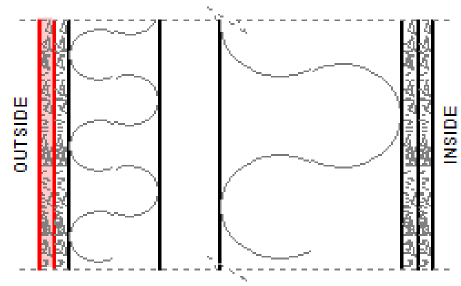
U-value 0.2 $W/m^2.K$

U-Value (W/m2.K):	0.2
Admittance (W/m2.K):	1.660
Solar Absorption (0-1):	0.495
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.02
Thermal Lag (hrs):	4
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	325.0
Weight (kg):	152.565

	Internal	External
Colour (Reflect.):	(R:0.561)	(R:0.561)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

Cellular Bonded
Cellular Sheet
Cellulose Acetate (High K)
Cellulose Acetate (Low K)
Cellulose Nitrate (Pyroxylin)
Cellulose Triacetate
Cellulosic Insulation
Cellulosic Insulation, Loose
Cement
Cement / Lime Plaster
Cement Backerboard

Calculate Thermal Properties



	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Plasterboard	12.5	950.0	840.000	0.160	35
2.	Plasterboard	12.5	950.0	840.000	0.160	35
3.	Earthwool insulation	75.0	1000.0	1700.000	0.035	45
4.	Air Gap	50.0	1.3	1004.000	5.560	0
5.	Rock Wool	150.0	200.0	710.000	0.034	45

Figure 3-39: U-value of wall type

Courtyard-Interior

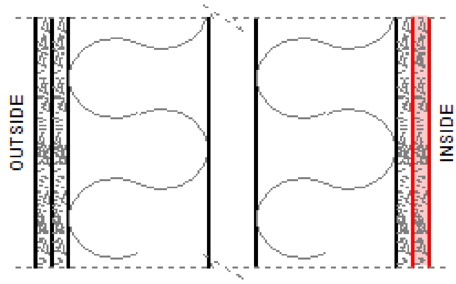
U-value 0.11 $W/m^2.K$

U-Value (W/m2.K):	0.110
Admittance (W/m2.K):	2.050
Solar Absorption (0-1):	0.495
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0
Thermal Lag (hrs):	4
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	422.0
Weight (kg):	248.465

	Internal	External
Colour (Reflect.):	(R:0.561)	(R:0.561)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

Butyl Rubber
Cellulosic Insulation
Exfoliated Vermiculite
Expanded Board, Rigid
Fibre Blanket, Bonded
Fibre Blanket, Metal Reinfor
Fibre Board, Resin Bonded
Fibre Quilt
Fibre Slab
Fibre Slag, Pipe Insulation
Fibre, Strawboard-Like

Calculate Thermal Properties

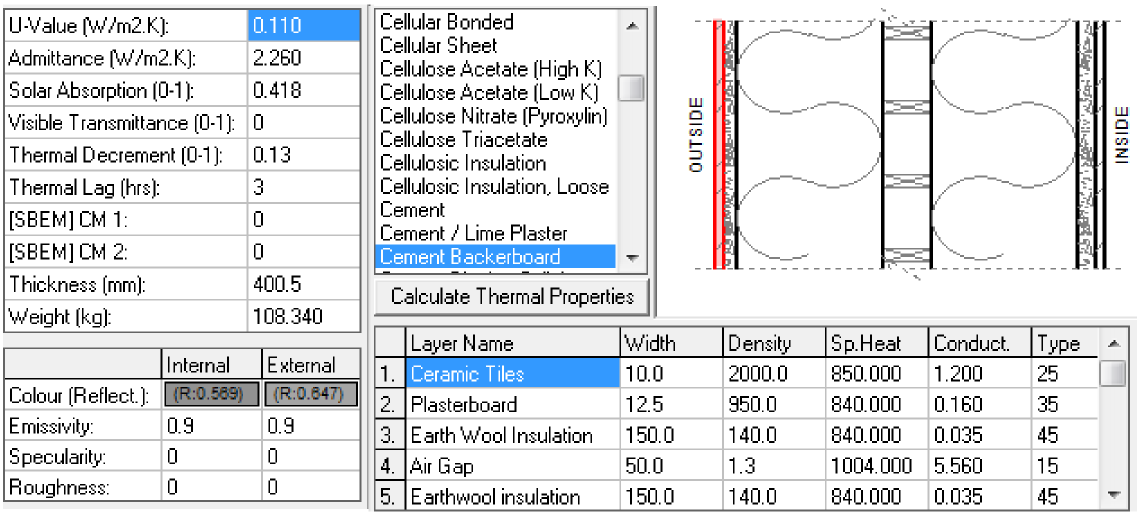


	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
3.	Rocksilk crimpact insulat	150.0	1000.0	1700.000	0.035	45
4.	Air Gap	50.0	1.3	1004.000	5.560	0
5.	Earth Wool	150.0	200.0	710.000	0.034	45
6.	Plasterboard	18.0	950.0	840.000	0.160	35
7.	Plasterboard	18.0	950.0	840.000	0.160	35

Figure 3-40: U-value of wall type

Kitchen-Bathroom

U-value 0.11 $W/m^2.K$



U-Value (W/m2.K):	0.110
Admittance (W/m2.K):	2.260
Solar Absorption (0-1):	0.418
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.13
Thermal Lag (hrs):	3
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	400.5
Weight (kg):	108.340

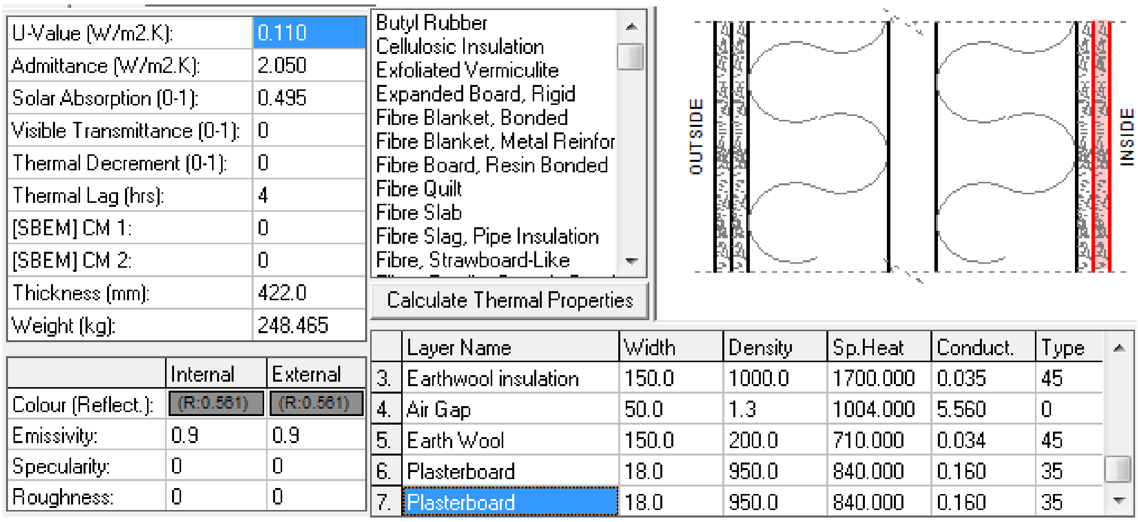
	Internal	External
Colour (Reflect.):	(R:0.569)	(R:0.647)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Ceramic Tiles	10.0	2000.0	850.000	1.200	25
2.	Plasterboard	12.5	950.0	840.000	0.160	35
3.	Earth Wool Insulation	150.0	140.0	840.000	0.035	45
4.	Air Gap	50.0	1.3	1004.000	5.560	15
5.	Earthwool insulation	150.0	140.0	840.000	0.035	45

Figure 3-41: U-value of wall type

Interior-interior

U-value 0.11 W/m^2.K



U-Value (W/m2.K):	0.110
Admittance (W/m2.K):	2.050
Solar Absorption (0-1):	0.495
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0
Thermal Lag (hrs):	4
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	422.0
Weight (kg):	248.465

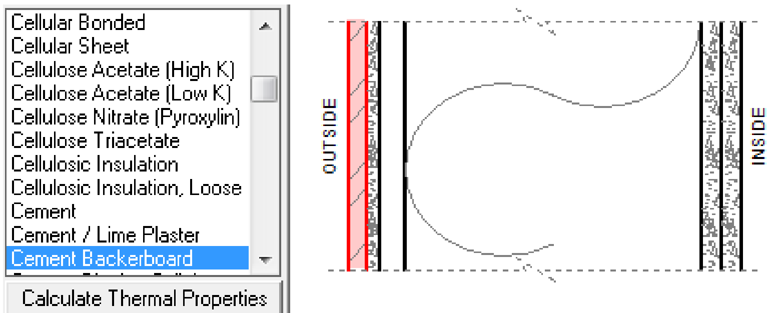
	Internal	External
Colour (Reflect.):	(R:0.561)	(R:0.561)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
3.	Earthwool insulation	150.0	1000.0	1700.000	0.035	45
4.	Air Gap	50.0	1.3	1004.000	5.560	0
5.	Earth Wool	150.0	200.0	710.000	0.034	45
6.	Plasterboard	18.0	950.0	840.000	0.160	35
7.	Plasterboard	18.0	950.0	840.000	0.160	35

Figure 3-42: U-value of wall type

Interior-bathroom

U-value 0.21 W/m^2.K



U-Value (W/m2.K):	0.210
Admittance (W/m2.K):	2.080
Solar Absorption (0-1):	0.495
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0
Thermal Lag (hrs):	4
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	198.5
Weight (kg):	204.225

	Internal	External
Colour (Reflect.):	(R:0.561)	(R:0.561)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

Figure 3-43: U-value of wall type

Interior-interior (Separation between two flats)

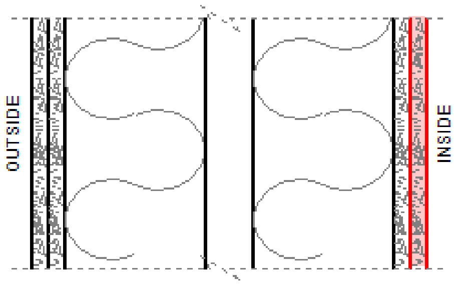
U-value 0.11 W/m^2.K

U-Value (W/m2.K):	0.110
Admittance (W/m2.K):	2.050
Solar Absorption (0-1):	0.495
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0
Thermal Lag (hrs):	4
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	422.0
Weight (kg):	248.465

	Internal	External
Colour (Reflect.):	(R:0.561)	(R:0.561)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

Butyl Rubber
Cellulosic Insulation
Exfoliated Vermiculite
Expanded Board, Rigid
Fibre Blanket, Bonded
Fibre Blanket, Metal Reinfor
Fibre Board, Resin Bonded
Fibre Quilt
Fibre Slab
Fibre Slag, Pipe Insulation
Fibre, Strawboard-Like

Calculate Thermal Properties



	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
3.	Earthwool insulation	150.0	1000.0	1700.000	0.035	45
4.	Air Gap	50.0	1.3	1004.000	5.560	0
5.	Earth Wool	150.0	200.0	710.000	0.034	45
6.	Plasterboard	18.0	950.0	840.000	0.160	35
7.	Plasterboard	18.0	950.0	840.000	0.160	35

Figure 3-44: U-value of wall type

Exterior-interior

U-value 0.14 W/m^2.K

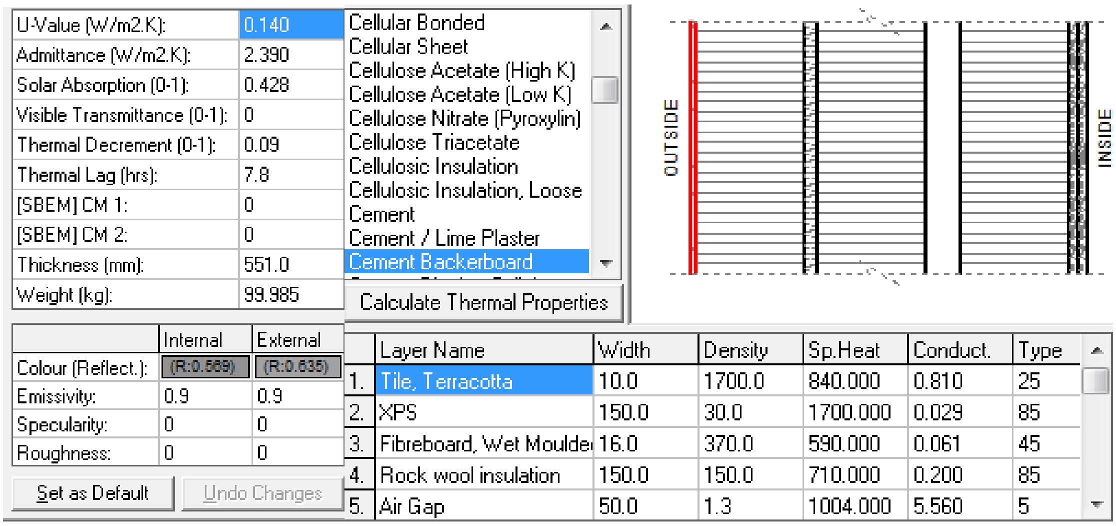


Figure 3-45: U-value of wall type

Exterior-staircase

U-value 0.14 W/m^2.K

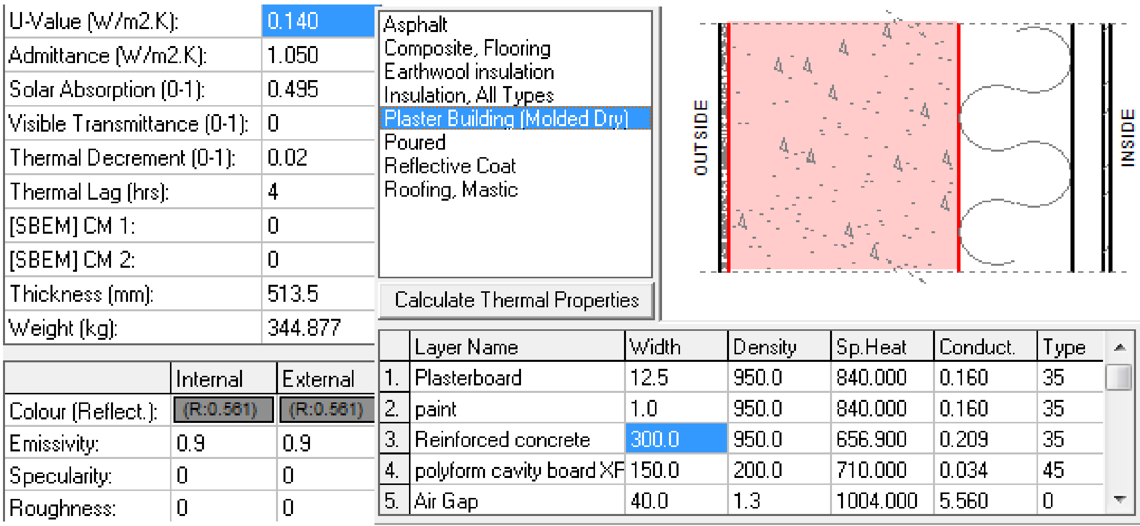


Figure 3-46: U-value of wall type

Staircase-flat

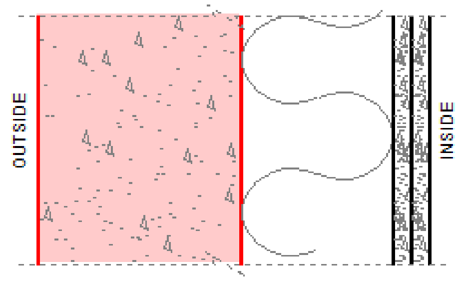
U-value 0.18 W/m^2.K

U-Value (W/m2.K):	0.180
Admittance (W/m2.K):	2.270
Solar Absorption (0-1):	0.428
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0
Thermal Lag (hrs):	7.8
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	386.0
Weight (kg):	374.200

	Internal	External
Colour (Reflect.):	(R:0.569)	(R:0.635)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

Cellular Bonded
Cellular Sheet
Cellulose Acetate (High K)
Cellulose Acetate (Low K)
Cellulose Nitrate (Pyroxylin)
Cellulose Triacetate
Cellulosic Insulation
Cellulosic Insulation, Loose
Cement
Cement / Lime Plaster
Cement Backerboard

Calculate Thermal Properties



	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Concrete Lightweight	200.0	950.0	656.900	0.209	35
2.	Earthwool insulation	150.0	1000.0	1700.000	0.035	45
3.	Plasterboard	18.0	950.0	840.000	0.160	35
4.	Plasterboard	18.0	950.0	840.000	0.160	35

Figure 3-47: U-value of wall type

Landfill-parking (basement)

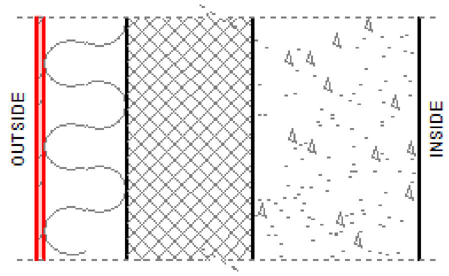
U-value 0.14 W/m^2.K

U-Value (W/m2.K):	0.140
Admittance (W/m2.K):	2.410
Solar Absorption (0-1):	0.7
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.09
Thermal Lag (hrs):	7.7
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	460.0
Weight (kg):	393.850

	Internal	External
Colour (Reflect.):	(R:0.624)	(R:0.474)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

Cellular Bonded
Cellular Sheet
Cellulose Acetate (High K)
Cellulose Acetate (Low K)
Cellulose Nitrate (Pyroxylin)
Cellulose Triacetate
Cellulosic Insulation
Cellulosic Insulation, Loose
Cement
Cement / Lime Plaster
Cement Backerboard

Calculate Thermal Properties

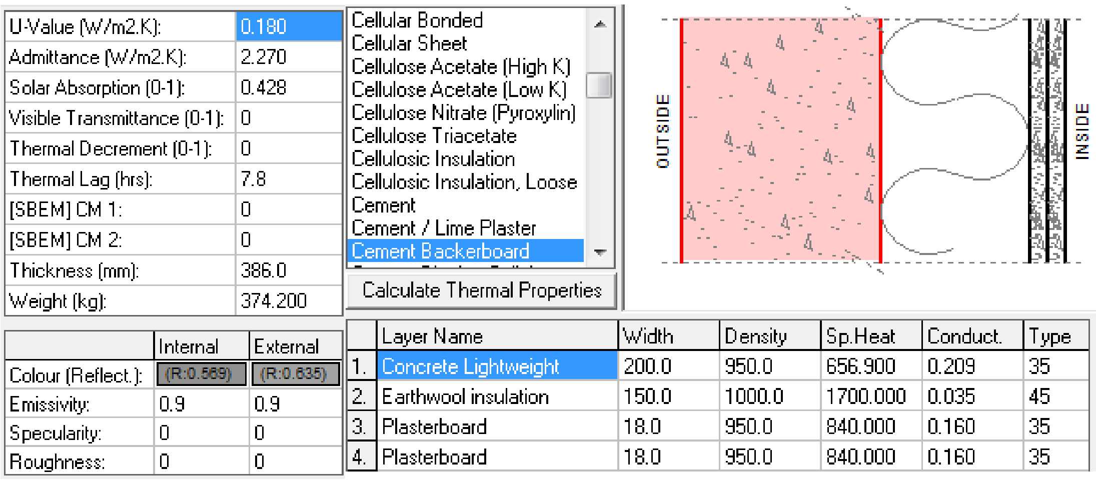


	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Earth, Common	10.0	1460.0	880.000	1.280	25
2.	Gravel	100.0	1840.0	840.000	0.360	45
3.	Polystyrene, Extruded (EPS)	150.0	35.0	1470.000	0.027	95
4.	Concrete Lightweight	200.0	950.0	656.900	0.209	35

Figure 3-48: U-value of wall type

Staircase-corridor

U-value 0.18 W/m^2.K



U-Value (W/m2.K):	0.180
Admittance (W/m2.K):	2.270
Solar Absorption (0-1):	0.428
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0
Thermal Lag (hrs):	7.8
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	386.0
Weight (kg):	374.200

	Internal	External
Colour (Reflect.):	(R:0.569)	(R:0.635)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

Cellular Bonded
Cellular Sheet
Cellulose Acetate (High K)
Cellulose Acetate (Low K)
Cellulose Nitrate (Pyroxylin)
Cellulose Triacetate
Cellulosic Insulation
Cellulosic Insulation, Loose
Cement
Cement / Lime Plaster
Cement Backerboard

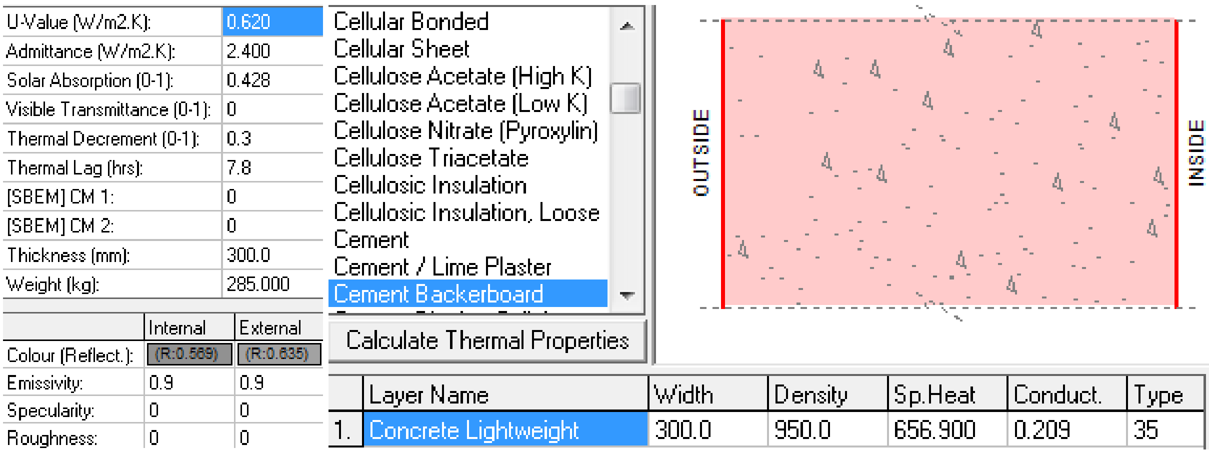
Calculate Thermal Properties

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Concrete Lightweight	200.0	950.0	656.900	0.209	35
2.	Earthwool insulation	150.0	1000.0	1700.000	0.035	45
3.	Plasterboard	18.0	950.0	840.000	0.160	35
4.	Plasterboard	18.0	950.0	840.000	0.160	35

Figure 3-49: U-value of wall type

parking-Electromechanical rooms

U-value 0.62 W/m^2.K



U-Value (W/m2.K):	0.620
Admittance (W/m2.K):	2.400
Solar Absorption (0-1):	0.428
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.3
Thermal Lag (hrs):	7.8
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	300.0
Weight (kg):	285.000

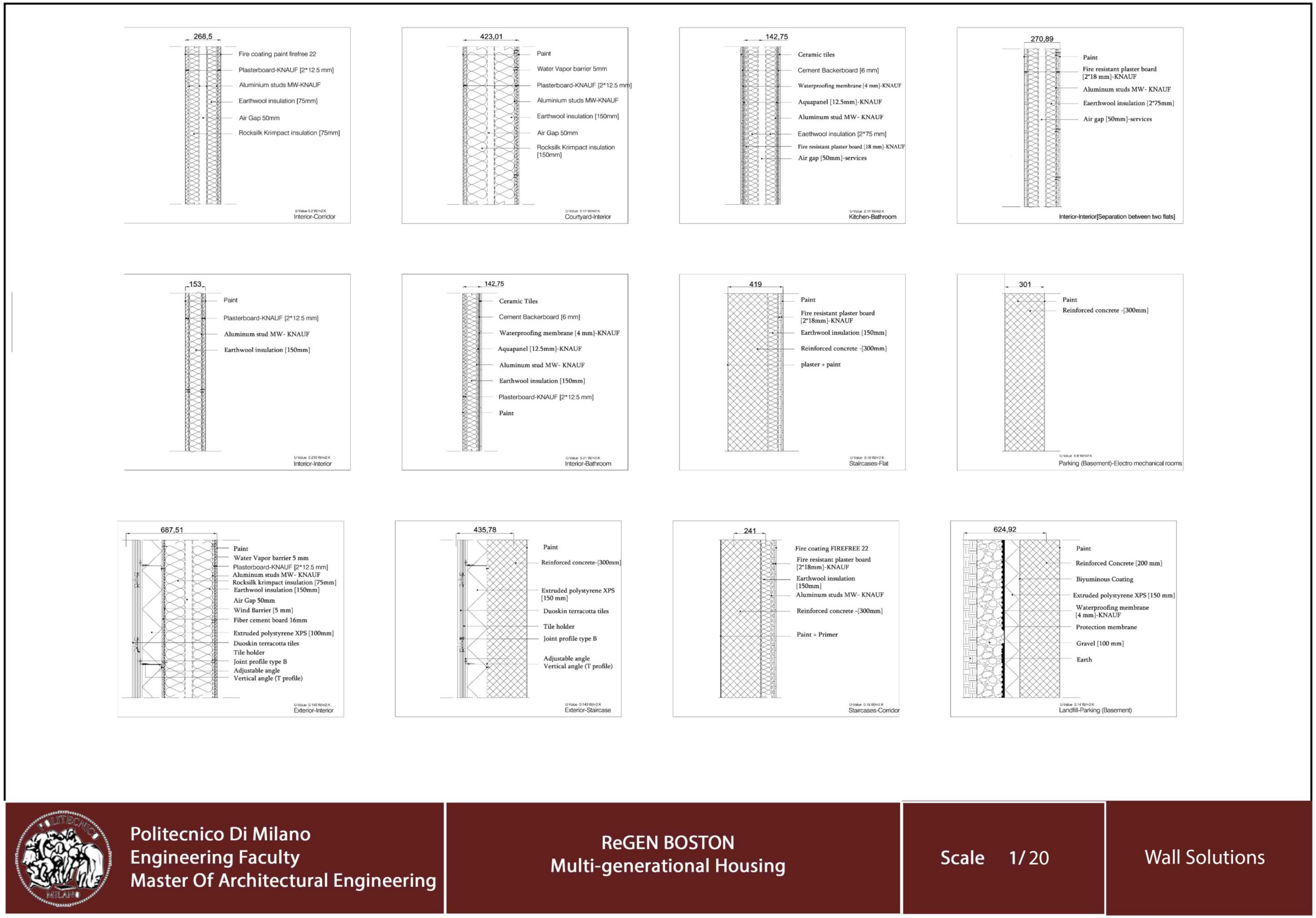
	Internal	External
Colour (Reflect.):	(R:0.569)	(R:0.635)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

Cellular Bonded
Cellular Sheet
Cellulose Acetate (High K)
Cellulose Acetate (Low K)
Cellulose Nitrate (Pyroxylin)
Cellulose Triacetate
Cellulosic Insulation
Cellulosic Insulation, Loose
Cement
Cement / Lime Plaster
Cement Backerboard

Calculate Thermal Properties

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Concrete Lightweight	300.0	950.0	656.900	0.209	35

Figure 3-50: U-value of wall type



TECH. DRAWING 1: Wall Solutions

3.6.2 SLAB SOLUTIONS:

Green roof

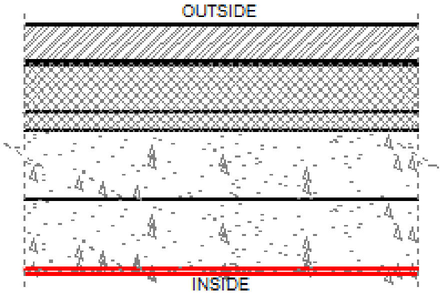
U-value 0.16 $W/m^2.K$

U-Value (W/m2.K):	0.160
Admittance (W/m2.K):	2.310
Solar Absorption (0-1):	0.5
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.02
Thermal Lag (hrs):	0.7
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	540.6
Weight (kg):	616.800

	Internal	External
Colour (Reflect.):	(R:0.753)	(R:0.753)
Emissivity:	0.89	0.89
Specularity:	0	0
Roughness:	0	0

Acoustic Tile
Afzelia, Minunga, Meranti
Aggregate
Aggregate (Sand, Gravel Or
Building Board, Tile And Lay
Calcium Silicate Brick
Ebonite, Expanded
Felt Sheathing
Glass Fibre Board, Organic I
Granolithic
Mineral Filler For Concrete

Calculate Thermal Properties



	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
4.	Cellular Sheet	40.0	140.0	840.000	0.048	95
5.	Cement Screed	150.0	2100.0	650.000	1.400	35
6.	Steel Stainless Series 30	0.6	8000.0	502.100	14.644	65
7.	Concrete Lightweight	150.0	950.0	656.900	0.209	35
8.	Plasterboard	10.0	950.0	840.000	0.160	35

Figure 3-51: U-value of roof type

Dry internal-dry internal

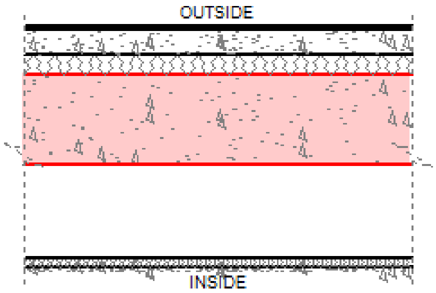
U-value 0.31 $W/m^2.K$

U-Value (W/m2.K):	0.310
Admittance (W/m2.K):	2.130
Solar Absorption (0-1):	0.326
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0
Thermal Lag (hrs):	4
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	682.6
Weight (kg):	824.638

	Internal	External
Colour (Reflect.):	(R:0.749)	(R:0.749)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

Acoustic Tile
Afzelia, Minunga, Meranti
Aggregate
Aggregate (Sand, Gravel Or
Building Board, Tile And Lay
Calcium Silicate Brick
Ebonite, Expanded
Felt Sheathing
Glass Fibre Board, Organic I
Granolithic
Mineral Filler For Concrete

Calculate Thermal Properties



	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Ceramic Tiles	12.0	3400.0	753.100	2.092	25
2.	Cement Mortar	68.0	1650.0	920.000	0.720	35
3.	Earthwool insulation	57.0	1000.0	1700.000	0.035	45
4.	Concrete Floor	250.0	2300.0	656.900	0.753	35
5.	Steel Stainless Series 30	0.6	8000.0	502.100	14.644	65

Figure 3-52: U-value of roof type

wet internal-wet internal

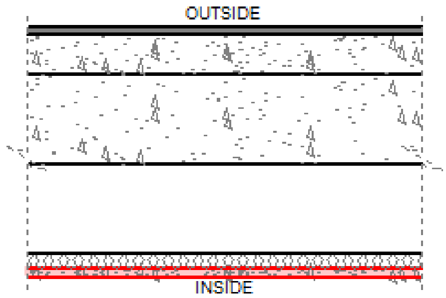
U-value 0.69 W/m^2.K

U-Value (W/m2.K):	0.690
Admittance (W/m2.K):	2.180
Solar Absorption (0-1):	0.326
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.03
Thermal Lag (hrs):	4
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	418.1
Weight (kg):	539.870

	Internal	External
Colour (Reflect.):	(R:0.749)	(R:0.749)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

Acoustic Tile
Afzelia, Minunga, Meranti
Aggregate
Aggregate (Sand, Gravel Or
Building Board, Tile And Lay
Calcium Silicate Brick
Ebonite, Expanded
Felt Sheathing
Glass Fibre Board, Organic I
Granolithic
Mineral Filler For Concrete

Calculate Thermal Properties



	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
3.	Concrete Floor	150.0	2300.0	656.900	0.753	35
4.	Steel Stainless Series 30	0.6	8000.0	502.100	14.644	65
5.	Air Gap	150.0	1.3	1004.000	5.560	0
6.	Earthwool insulation	25.0	1000.0	1700.000	0.035	45
7.	Plasterboard	12.5	950.0	840.000	0.160	35

Figure 3-53: U-value of roof type

Parking-Parking

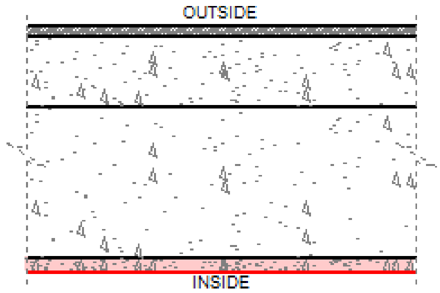
U-value 1.8W/m^2.K

U-Value (W/m2.K):	1.800
Admittance (W/m2.K):	3.670
Solar Absorption (0-1):	0.326
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.38
Thermal Lag (hrs):	4
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	243.1
Weight (kg):	514.675

	Internal	External
Colour (Reflect.):	(R:0.749)	(R:0.749)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

Acoustic Tile
Afzelia, Minunga, Meranti
Aggregate
Aggregate (Sand, Gravel Or
Building Board, Tile And La
Calcium Silicate Brick
Ebonite, Expanded
Felt Sheathing
Glass Fibre Board, Organic I
Granolithic
Mineral Filler For Concrete

Calculate Thermal Properties



	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Ceramic Tiles	12.0	3400.0	753.100	2.092	25
2.	Cement Mortar	68.0	1650.0	920.000	0.720	35
3.	Concrete Floor	150.0	2300.0	656.900	0.753	35
4.	Steel Stainless Series 300	0.6	8000.0	502.100	14.644	65
5.	Plasterboard	12.5	950.0	840.000	0.160	35

Figure 3-54: U-value of roof type

Dry internal -Parking

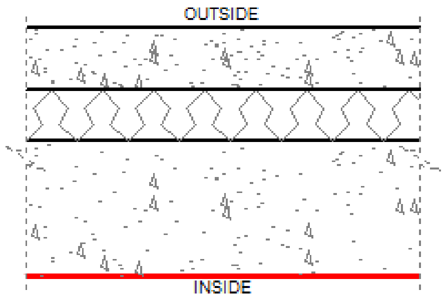
U-value 0.47 W/m^2.K

U-Value (W/m2.K):	0.480
Admittance (W/m2.K):	4.980
Solar Absorption (0-1):	0.326
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.12
Thermal Lag (hrs):	4
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	277.6
Weight (kg):	522.300

	Internal	External
Colour (Reflect.):	(R:0.749)	(R:0.749)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

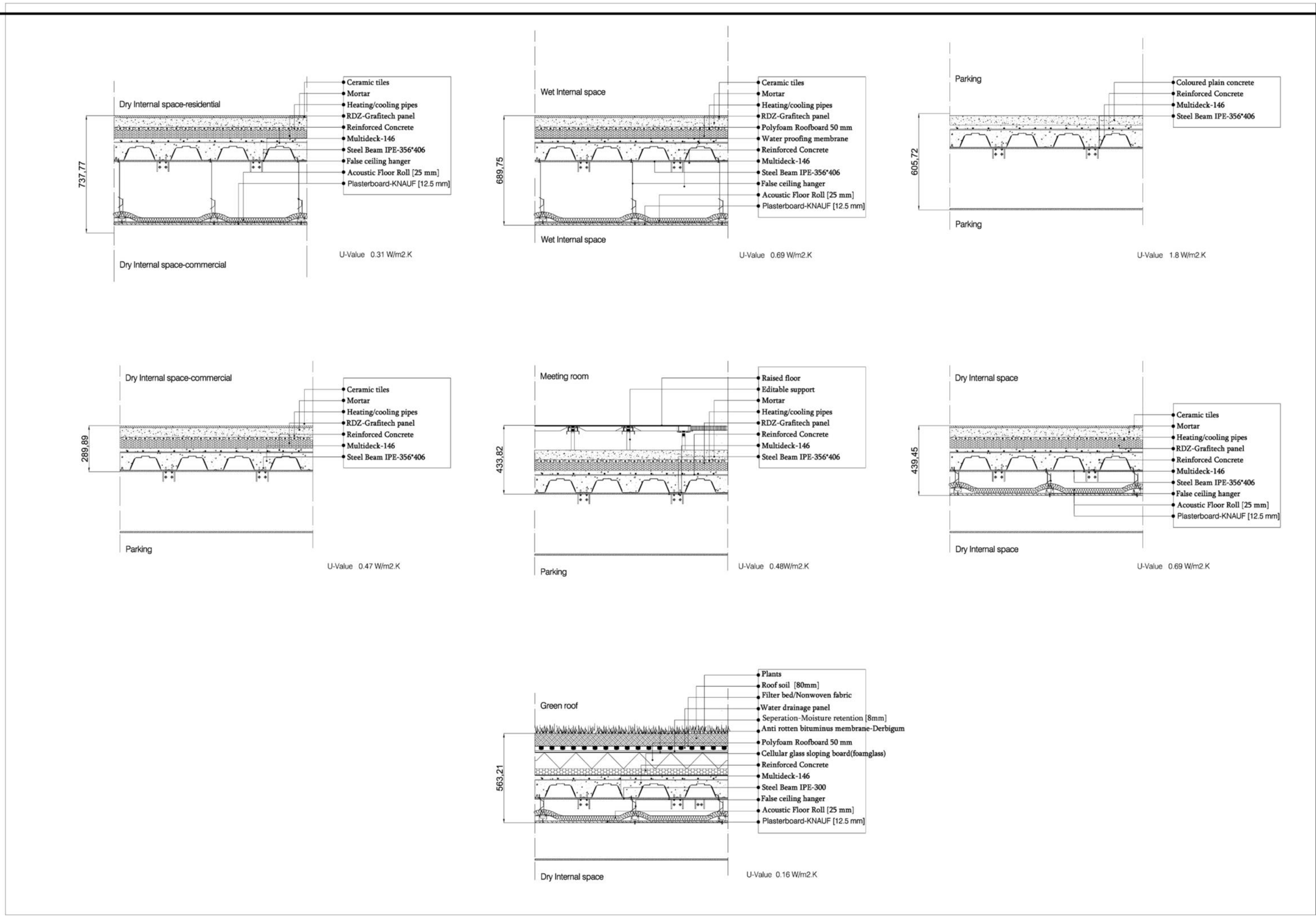
Acoustic Tile
Afzelia, Minunga, Meranti
Aggregate
Aggregate (Sand, Gravel Or
Building Board, Tile And La
Calcium Silicate Brick
Ebonite, Expanded
Felt Sheathing
Glass Fibre Board, Organic I
Granolithic
Mineral Filler For Concrete

Calculate Thermal Properties



	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Cement Mortar	70.0	1650.0	920.000	0.720	35
2.	Earthwood insulation	57.0	1000.0	1700.000	0.035	45
3.	Concrete Floor	150.0	2300.0	656.900	0.753	35
4.	Steel Stainless Series 300	0.6	8000.0	502.100	14.644	65

Figure 3-55: U-value of roof type



Politecnico Di Milano
Engineering Faculty
Master Of Architectural Engineering

ReGEN BOSTON
Multi-generational Housing

Scale 1/20

Slab Solutions

TECH. DRAWING 2: Slab Solution

3.7 Energy Calculation:

By adopting our calculated U-values we did thermal analysis by using Ecotect software and obtained the following results:

3.7.1 Active system: mixed mode system

Thermostat range: 20-26^{O}C (on at weekends as it is residential building)

Air chnege rate: 0.25

Max Heating: 28564 W at 21:00 on 22nd January

Max Cooling: 17077 W at 14:00 on 9th July

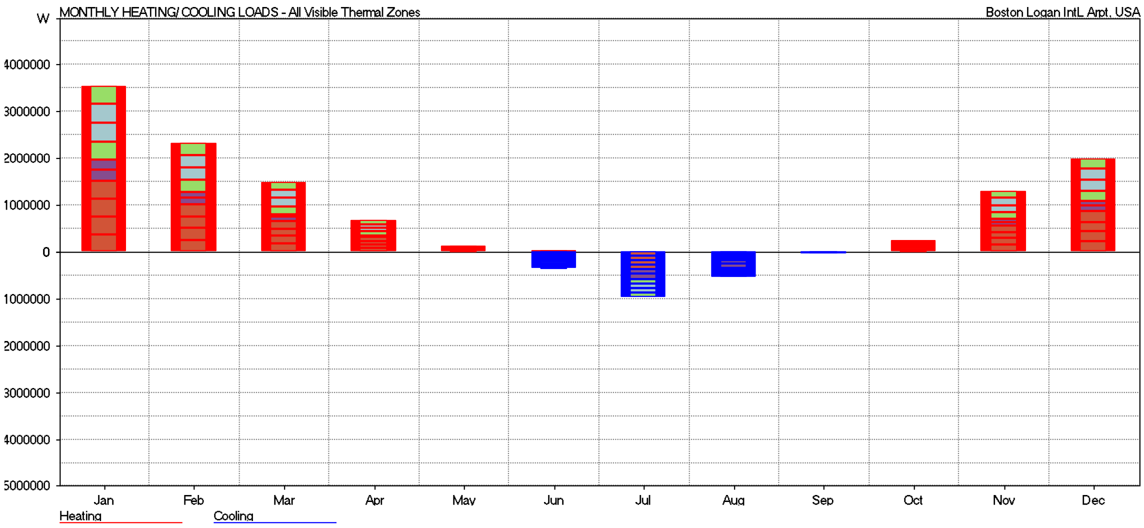


Table 3 Energy load with mixed mode system

	HEATING	COOLING	TOTAL
MONTH	(Wh)	(Wh)	(Wh)
Jan	3534269	0	3534269
Feb	2316286	0	2316286

Mar	1485711	0	1485711
Apr	661030	0	661030
May	112514	10175	122689
Jun	23646	358623	382269
Jul	0	986963	986963
Aug	0	542625	542625
Sep	43	28465	28508
Oct	249912	0	249912
Nov	1281611	0	1281611
Dec	1984364	0	1984364
TOTAL	11649386	1926851	13576237
PER M²	22641	3745	26386

3.7.2 Active system: Full air conditioning system

Thermostat range: 20-26^{O}C (on at weekends as it is residential building)

Air chnege rate: 0.25

Max Heating: 28564 W at 21:00 on 22nd January

Max Cooling: 17289 W at 14:00 on 9th July

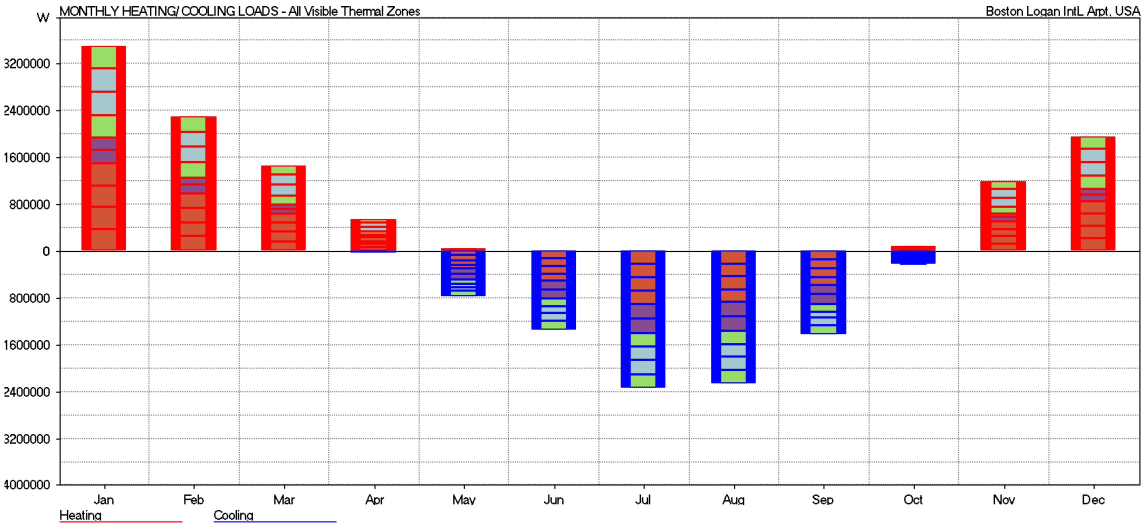


Table 4 Energy load Full air conditioning system

	HEATING	COOLING	TOTAL
MONTH	(Wh)	(Wh)	(Wh)
Jan	3499340	0	3499340
Feb	2286096	0	2286096
Mar	1455073	0	1455073
Apr	534064	10733	544796
May	42487	775116	817603
Jun	0	1348752	1348752
Jul	0	2354152	2354152
Aug	0	2263567	2263567
Sep	0	1440079	1440079
Oct	75582	231640	307222

Nov	1180466	0	1180466
Dec	1954166	0	1954166
TOTAL	11027274	8424040	19451314
PER M²	21432	16372	37804

3.7.3 Active system: Heating only system

Thermostat range: 20-26^{O}C (on at weekends as it is residential building)

Air chnege rate: 0.25

Max Heating: 28564 W at 21:00 on 22nd January

Max Cooling: 0.0 C - No Cooling.

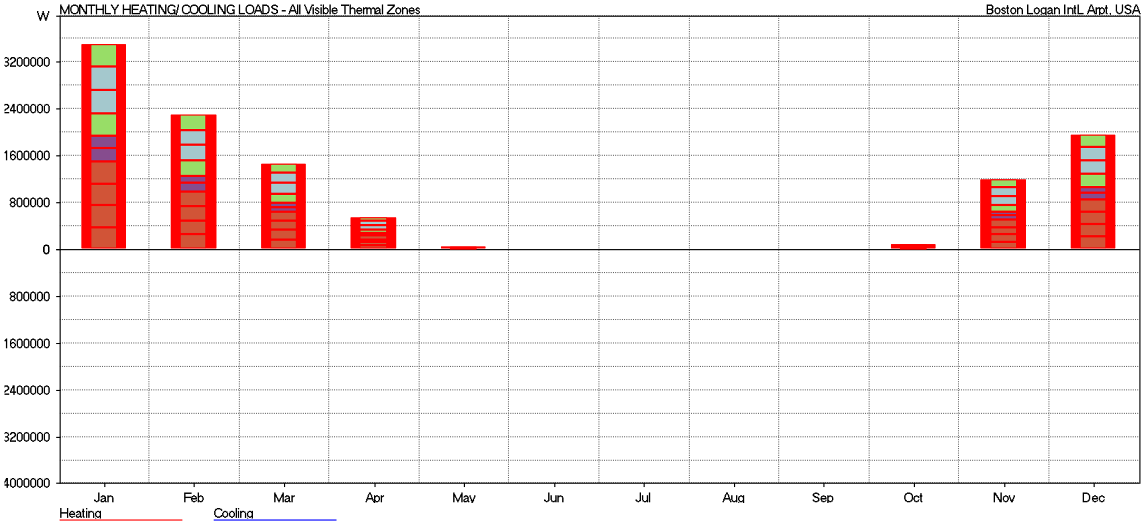


Table 5 Energy load with heating only system

	HEATING	**COOLING**	**TOTAL**
MONTH	(Wh)	(Wh)	(Wh)
Jan	3499340	0	3499340

Feb	2286096	0	2286096
Mar	1455073	0	1455073
Apr	534064	0	534064
May	42487	0	42487
Jun	0	0	0
Jul	0	0	0
Aug	0	0	0
Sep	0	0	0
Oct	75582	0	75582
Nov	1180466	0	1180466
Dec	1954166	0	1954166
TOTAL	11027274	0	11027274
PER M²	21432	0	21432

3.7.4 Active system: Cooling only system

Thermostat range: 20-26^{O}C (on at weekends as it is residential building)

Air chnege rate: 0.25

Max Heating: 0.0 C - No Heating.

Max Cooling: 17289 W at 14:00 on 9th July

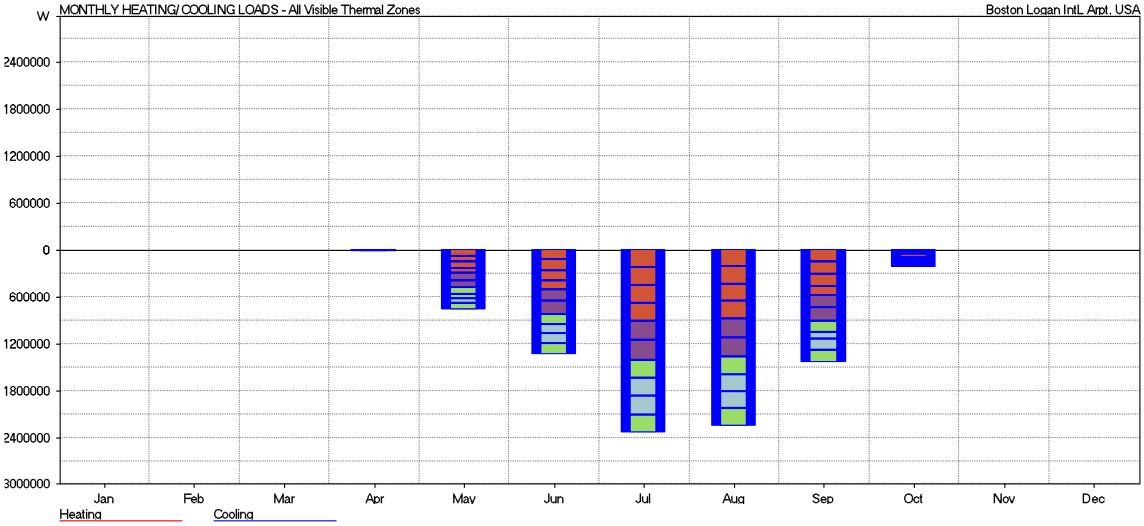


Table 6 energy load with cooling only system

	HEATING	COOLING	TOTAL
MONTH	(Wh)	(Wh)	(Wh)
Jan	0	0	0
Feb	0	0	0
Mar	0	0	0
Apr	0	10733	10733
May	0	775116	775116
Jun	0	1348752	1348752
Jul	0	2354152	2354152
Aug	0	2263567	2263567
Sep	0	1440079	1440079

Oct	0	231640	231640
Nov	0	0	0
Dec	0	0	0
TOTAL	0	8424040	8424040
PER M²	0	16372	16372

The comparison is made by changing Active system of the building and noting the variation in the Heating and cooling loads for different types of conditioning systems.

Table 7 variation in the Heating and cooling loads for different types of conditioning systems with ACH 0.25

Active System	Heating Load (Wh)	Cooling Load (Wh)	Heating Load (kWh/m2y)	Cooling Load (kWh/m2y)	ACH
Mixed mode system	11649386	1926851	22.641	3.745	0.25
Full air conditioning system	11027274	8424040	21.432	16372	
Heating only	11027274	0	21.432	0	
Cooling only	0	8424040	0	16372	

By the adoption of calculated U-values and strategies for our project, we obtained total thermal load with full air conditioning system a value equal to **37.7 kWh/m2 year** and with mixed mode system a value equal to **26.3 kWh/m2 year** which is a very good result in terms of passivehaus standards. The reason for this value per meter square is also because it is a housing project and so the heating and cooling system will be working even on weekends.

3.8 Ventilation: (Variation in the Air Changes per hour through the building):

Table 8 Variation in the air changes per hour through the building at ACH=0.25

Active System	Heating Load (Wh)	Cooling Load (Wh)	Heating Load (kWh/m2y)	Cooling Load (kWh/m2y)	ACH
Mixed mode system	11649386	1926851	22.641	3.745	0.25
Full air conditioning system	11027274	8424040	21.432	16372	
Heating only	11027274	0	21.432	0	
Cooling only	0	8424040	0	16372	

Table 9 Variation in the air changes per hour through the building at ACH=0.5

Active System	Heating Load (Wh)	Cooling Load (Wh)	Heating Load (kWh/m2y)	Cooling Load (kWh/m2y)	ACH
Mixed mode system	19884580	1828488	38.646	3.554	0.5
Full air conditioning system	19535292	6441557	37.967	12.519	
Heating only	19535292		37.967		
Cooling only	0	6441557	0	12.519	

Table 10 Variation in the air changes per hour through the building at ACH=1

Active System	Heating Load (Wh)	Cooling Load (Wh)	Heating Load (kWh/m2y)	Cooling Load (kWh/m2y)	ACH
Mixed mode system	37216328	1972014	72.331	3.833	1
Full air conditioning system	36884416	4017959	71.686	7.809	
Heating only	36884416	0	71.686	0	
Cooling only	0	4017959	0	7.809	

3.9 Observations:

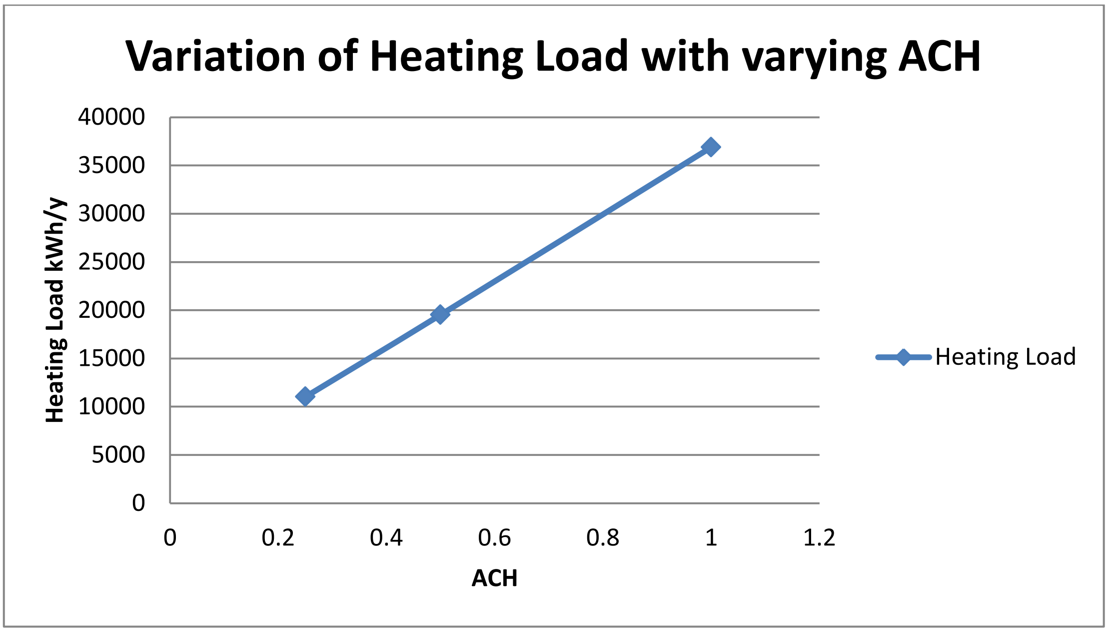
The following factors have an effect on the conditioning load of the building:

1. Lesser are the air changes per hour less is the load as there is a slower frequency of heat exchanging phenomena, and thus low energy utilization.
2. Type of Air Conditioning System has different impact on the energy loads for the corresponding air changes values. In our case the maximum decrease for heating load is achieved for Full Air Conditioning system.
3. The working hours and other parameters are kept constant and only Air Changes per hour have been varied for comparison purpose.

Now the comparison is made by changing Air Changes per hour through the building and noting the variation in the Heating and cooling by keeping conditioning systems same.

Table 11 Heating and cooling Variation with varying Air Changes per hour

Full Air Conditioning system with ACH	Heating Load kWh/y	Cooling Load kWh/y	Heating Load kWh/m2y	Cooling Load kWh/m2y
0.25	11027	8424	21.4	16.3
0.5	19535	6441	37.9	12.5
1	36884	4018	71.6	7.8



Graph 1

3.10 Window optioneering:

Effect of changing the size of window facing south on cooling and heating load:

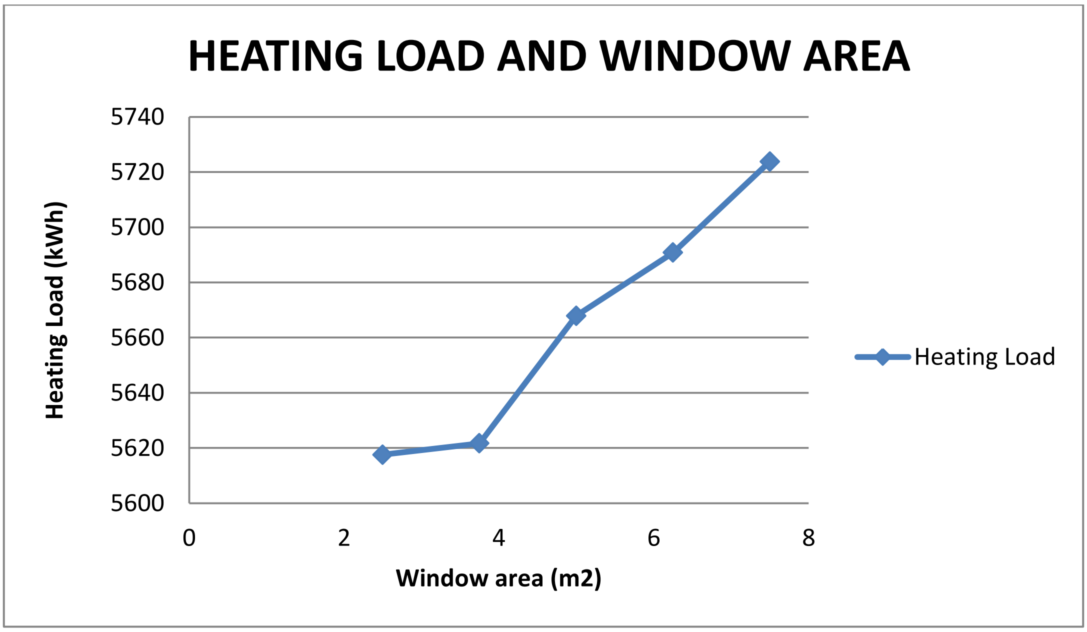
The study involved the observations in the heating and cooling loads with regard to the change in area of windows for our project specifically on the south face (We choose south facing because sun moves from east through the south to the west.so the critical facades are east, west and south. Whereas on the east and west side we have service area which is buffer zone and balconies for the solar radiations and hence more concerned side is south in this project). For the same purpose different calculations were made by varying the total window area of the building (increasing in this case) and noting the effect on the heating and cooling loads.

We decided to make analysis by Ecotect by changing window size in one module (unit) on south façade, as the project comprises of repetition of this module in anyway.

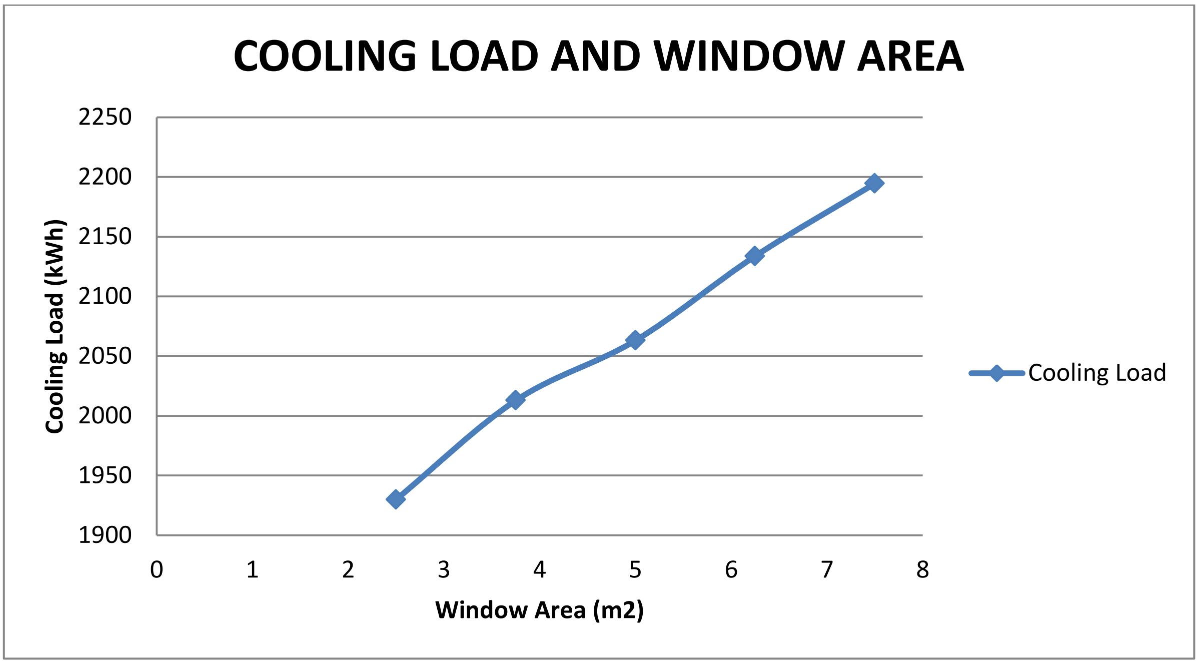
Following table is based on the varying window area and the heating and cooling load resulting due to the window sizes:

Table 12 variation in heating and cooling load due to different window sizes.

WINDOW	HEATING LOAD	COOLING LOAD	FLOOR AREA
AREA	(kWh)	(kWh)	m2
2.5	5617558	1929933	180.4
3.75	5621678	2012845	180.4
5	5667926	2063037	180.4
6.25	5690794	2133702	180.4
7.5	5723804	2194442	180.4



Graph 2



Graph 3

Hence based on these results we concluded the least window area. In view of above, lower is the size of the window, the lower are the heating and cooling loads for the area to be conditioned. But also at the same time it is clear that even increasing window size there is not a significant increase in the heating and cooling loads as compared to the north direction where even a small variation causes dramatic change in heating and cooling loads. This view also allows us to make window opening sizes bigger on south façade. To be on safe side we used the lowest window area in order to have low heating and cooling loads on individual modules.

3.11 Services and Integrated system schemes:

A very preliminary HVAC design was carried out. A schematic scheme was proposed based on the concept proposed for heating and cooling the space.

There were two options to give radiative floors or radiative ceilings but we opted for radiative floors because having good thermal mass is good for a radiative heating system to work well. Heat rises, so it makes scientific sense that a warm floor equals a warm room, while in case to cooling with radiant floor it can cause an uncomfortable environment as cold air is heavy and it stays down so there will be temperature difference in room .Based on this observation we decided to use all air, variable air volume with reheat AHU for conditioning air in summer.

Since the region has a dominant heating season as compared to the cooling season, radative floors were a good solution as it fulfilled the heating requirements quiet well. The radiative floors were then further connected to a geothermal heat pump, in order to cut down the amount of energy required to heat the floors drawing on the natural temperature gradient between the soil and outside air.

We are using Hydronic Radiant Floors - Water is by far the most effective and efficient way to transfer heat through flooring. Hydronic systems feature a pattern of tubing, which is supplied warm water via a pump and boiler combination. The temperature is controlled with either valves or a thermostat.

The other major reasons to choose this system are:

- Tactile and comfortable; allows you to walk around barefoot
- More efficient than transferring air through ducts, where energy is lost
- Better for people with allergies than forced-air systems
- Operates quietly
- Allows for flexible layout of the room

3.11.1 Description of Services System provided for the Building:

- **Heating Scheme:**

A schematic design was proposed for HVAC based on the concept proposed for heating and cooling the space. There were two options to give radiative floors or radiative ceilings but we opted for radiative floors because having good thermal mass is good for a radiative heating system to work well and since the floor was concrete floor it had good thermal mass to support the system and distribute the heat evenly. Additionally connections to the point specific radiators, at various points in the room could have been easily provided from the floor with very less piping. Since the region has a dominant heating season as compared to the cooling season, radative floors were a good solution as it fulfilled the heating requirements quiet well. The radiative floors were then further connected to a geothermal heat pump, in order to cut down the amount of energy required to heat the floors drawing on the natural temperature gradient between the soil and outside air. A schematic of the heating system connected to the geothermal pump has been shown below. The hot water supply has also been attached to the geothermal pump which is expected to fulfill the building heating requirements.

- **Cooling Scheme:**

The cooling requirements in the summer season shall not be fulfilled by the radiative floors Because of the potential for condensate formation on the cold radiant surface (resulting in water damage, mold and the like) Condensation caused by humidity is a limiting factor for the cooling capacity of a radiant cooling system. The surface temperature should not be equal or below the dew point temperature in the space. Some standards suggest a limit for the relative humidity in a space to 60% or 70%. An air temperature of 26°C (79°F) would mean a dew point between 17°C and 20°C (63°F and 68°F). There is, however, evidence that suggests decreasing the surface temperature to below the dew point temperature for a short period of time may not cause condensation.

As a result of the above discussion, for heating, ventilation and air conditioning we proposed variable air volume system. Unlike constant air volume (CAV) systems, which supply a constant airflow at a variable temperature, VAV systems vary the airflow at a constant temperature. The advantages of VAV systems over constant-volume systems include more precise temperature control, reduced compressor wear; lower energy consumption by system fans, less fan noise, and additional passive dehumidification. We integrated this system again with hot water system and geothermal heat pump.

Although the building has been constructed from all porous materials and thus the breathing nature of the envelope helps in maintaining a feeling of freshness in the interior space but this might still not be enough when large crowds gather in the rooms. Hence a mechanical ventilation system has also been provided, a basic schematic for which has been provided in the figure below.

3.11.2 Selection of HVAC System:

We choose all air reheat VAV system. Below is the description of the system.

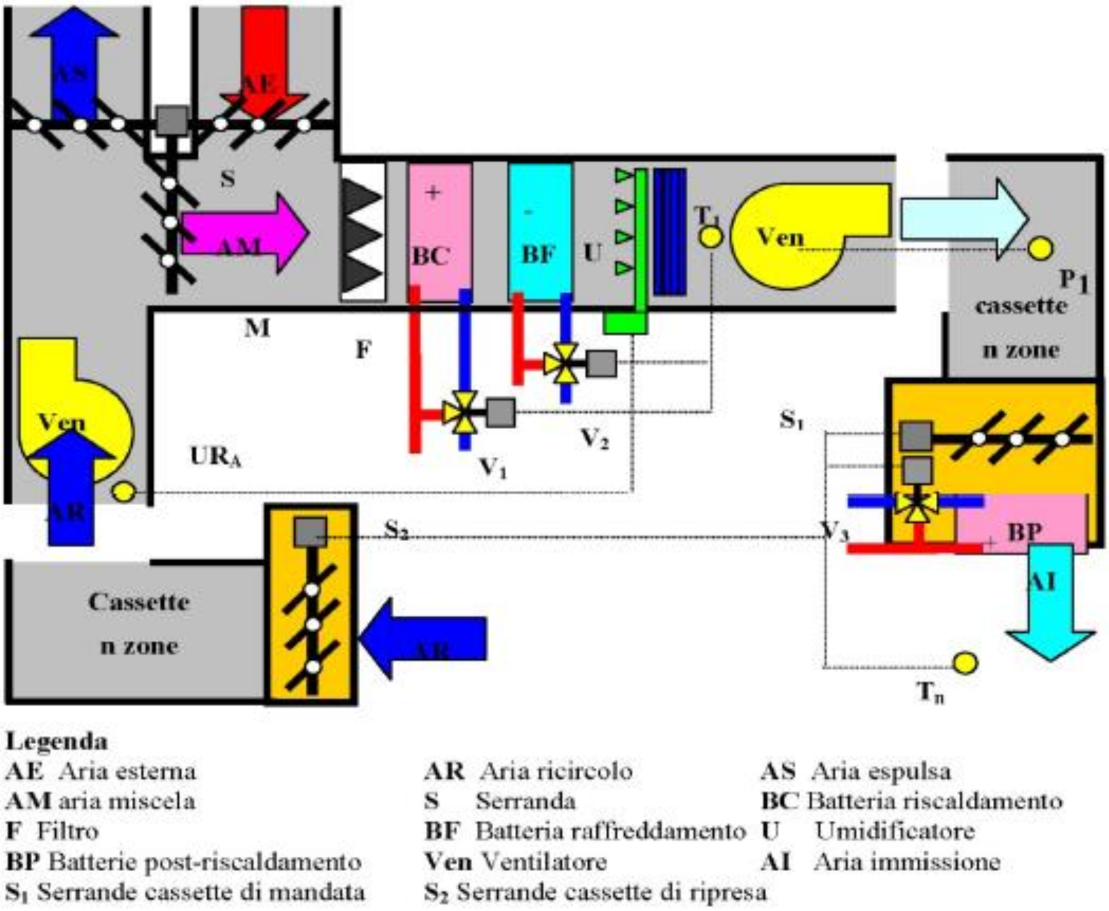


Figure 3-56: ALL air VAV reheat AHU

- **All air systems:**

All-air systems transfer cooled or heated air from a central plant via ducting, distributing air through a series of grilles or diffusers to the room or rooms being served. It normally comprises the cheapest equipment cost, but is not necessarily easy or cheap to install in a building due to the size of ducting required and the cost to install. It can be a problem to control temperature properly, and the system may be energy inefficient. All-air is generally rated in second place compared to other systems in relation to the amount of energy used to achieve the desired result.

- **Advantages of all air system:**

- Mechanical Equipment can be isolated.
- Complete absence of drain pipes, electrical wiring, and filters at the conditioned space.
- Seasonal changeover very simple and easy to automate.
- Very flexible – heating and cooling can occur in different zones simultaneously.

- **Disadvantages of all air system:**

- Additional duct clearance required. This can reduce usable floor space and increase building height.
- Air balancing is difficult and requires great care.

- **Variable air Volume system:**

Fortunately, comfort and saving energy go hand in hand with Variable Air Volume (VAV) systems. The ultimate is a VAV zone for each building occupant providing temperature satisfaction and avoiding the energy waste of any overcooling or overheating. In addition to comfort and energy savings, the benefits of a VAV zone for each occupant include higher worker productivity and improved ability to lease the space. Most buildings operate the majority of time in turndown and it is during turndown that VAV systems save energy because they match the reduced loads – both the exterior loads, such as temperature and solar, and the interior loads of occupancy, plugs, and lighting. Also the energy penalty of reheat is during turndown.

VAV systems have been commonly applied in various kinds of commercial office buildings for over 30 years. Many of these, however, have neither provided satisfactory comfort nor met baseline energy efficiency standards due to emphasis on first cost without considering the quick paybacks on any incremental cost of energy saving features or for achieving the other comfort benefits.

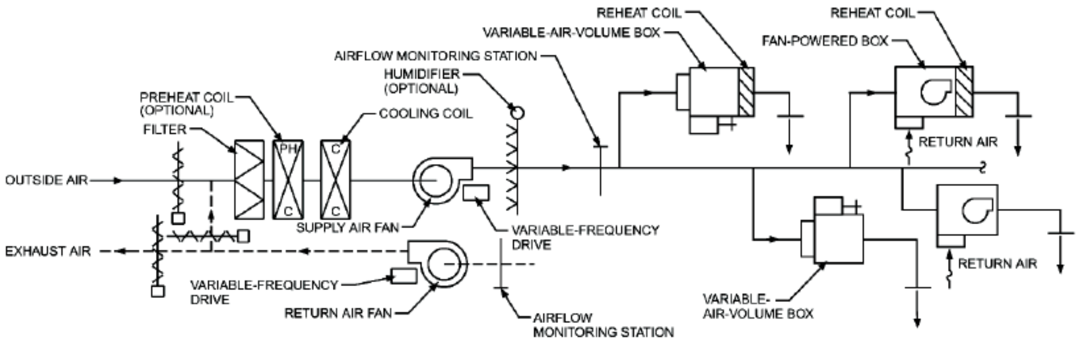


Figure 3-57: VAV system with reheat and induction and fan powered devices

3.11.3 Heat Recovery System:

Having adequate ventilation in your home is important for good health. It removes moisture and stale air along with odors and pollutants and replaces them with fresh air to breathe.

Usually, ventilation is achieved by simply opening windows and doors (known as ‘natural’ or ‘passive’ ventilation) and by using extractor fans in steamy rooms such as kitchens and bathrooms. Although this works well, it can account for around one third of space heating energy demand in an average home as a lot of warm air flows outside.

Draughts create a similar problem. While they serve to ventilate a home, they are a major source of heat loss and can make rooms feel uncomfortably chilly.

Modern energy efficient homes are more airtight (less draughty) than older buildings because they have to follow specifications for air-tightness in the Building Regulations. Because of these modern homes are sometimes fitted with Mechanical Ventilation with Heat Recovery (MVHR) systems also known as ‘whole house ventilation’ systems.

Benefits of using this system are given as follows:

- **Energy Saving** | Recovering the heat from your extract air instead of simply sending it to atmosphere can lead to significant energy savings by reducing the cost of your heating bill. With Heat Recovery Ventilation the fresh, filtered air entering your habitable rooms is on average only 1.5 Degrees Celsius cooler than that of the extract air leaving your home, as opposed to bringing fresh air into your home at outside temperatures via standard methods of ventilation such as Window Vents.

- **Whole House Ventilation** | A Heat Recovery Ventilation system continually extracts pollutants at their source and supplies fresh, filtered, warm air to your habitable rooms. This continual cycle of fresh air movement reduces the relative humidity in the home and eliminates problems associated with poor air quality such as condensation and mould growth. It also offers the end user fully controllable, comfort ventilation that can be set to suit their lifestyle.

- **Fresh Filtered Air** | Prior to the fresh air entering your habitable rooms it passes through G3/4 filters, this filter media has a micron rating that is capable of extracting particles such as pollen and other airborne pollutants from the air. This helps to provide a much more conducive environment for allergy sufferers and asthmatics alike.

- **Quiet Solution | Heat** Recovery Ventilation systems are extremely quiet when running; these systems are usually loft mounted or mounted at high level in a storage cupboard. They replace the need for individual extractor fans which can be noisy in operation within each wet room and also replace the need for Window Vents which may allow noise from outside to infiltrate the home.

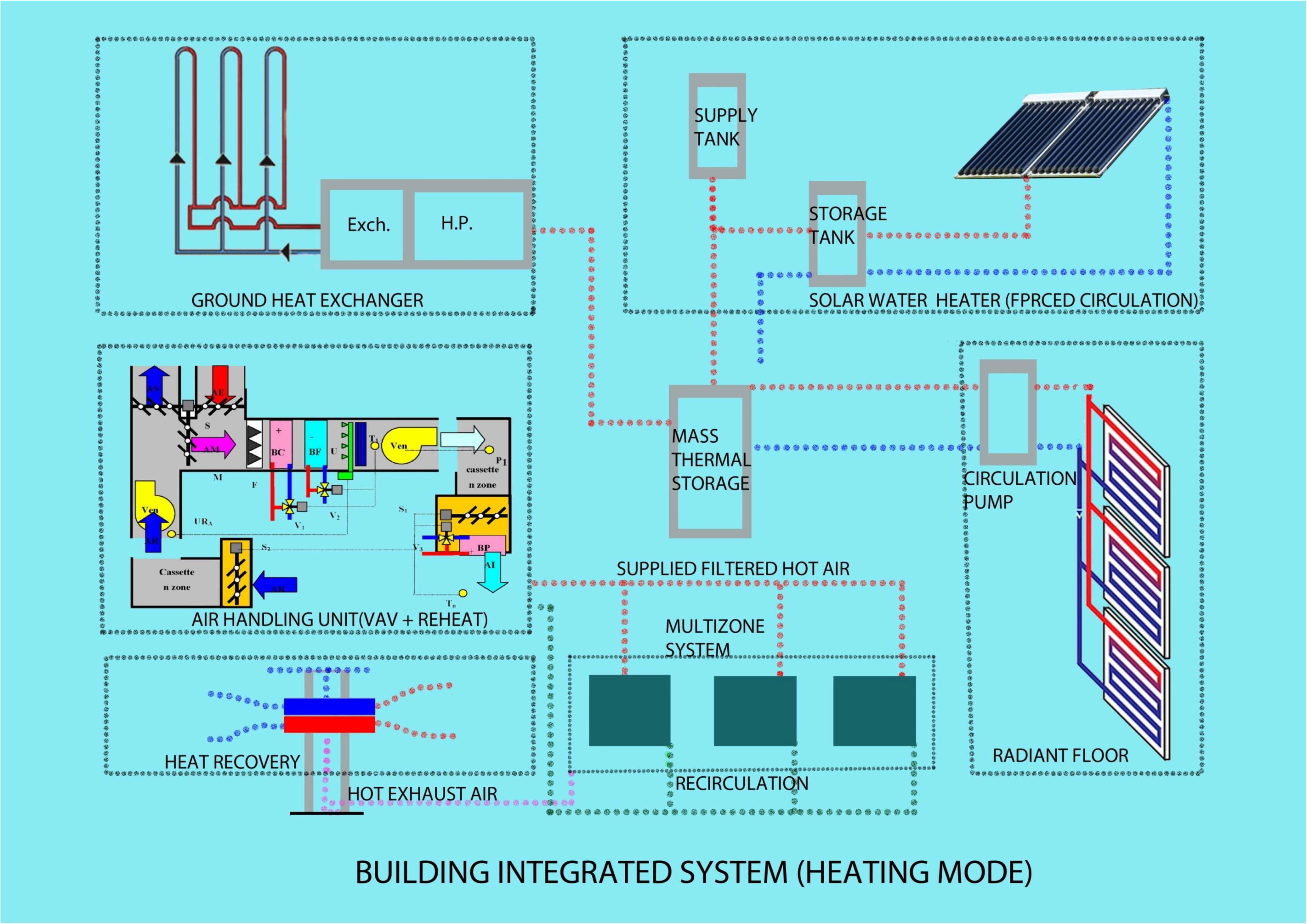
3.11.4 Radiant Floors for Heating:

Though technological advances have brought radiant floor heating into the public eye over the past decade or two, the concept of distributing heat from underneath the floor has been around for centuries. Today, radiant flooring is an efficient and effective means to heat your home, but it is not without a few drawbacks.

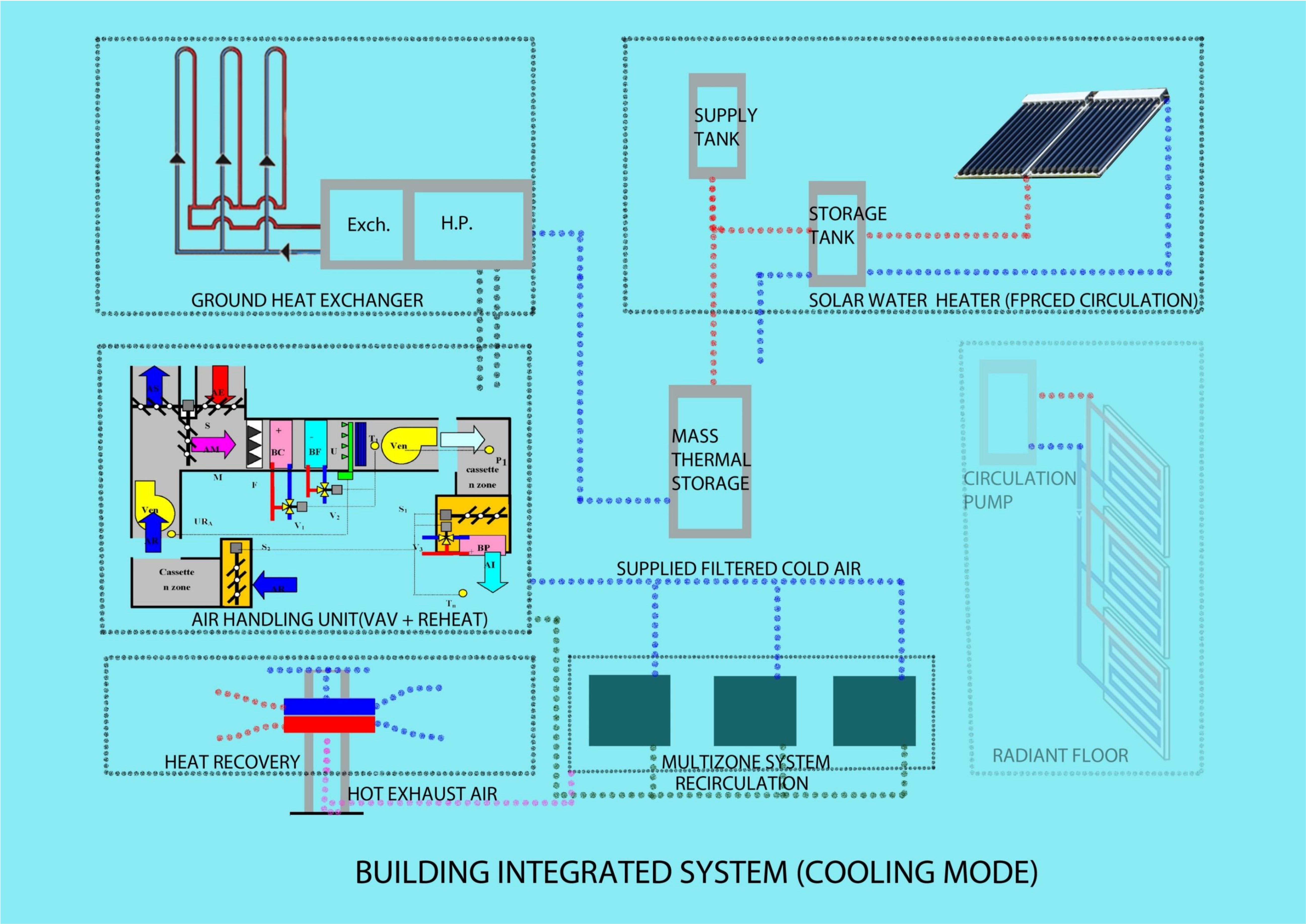
There are many benefits of using this type of system. Radiant flooring doesn't come out of a vent or baseboard, so it allows for more flexibility in placing furniture around the room. The heat produced is also more evenly distributed throughout the room, creating overall warmth that many find very comfortable.

The most compelling benefit of these systems, however, is their efficiency. Radiant floor heating systems that channel hot water use very little electricity in their operation, making them a perfect choice for those looking to beat high energy costs. Additionally, because there is no ductwork for traveling heat to get lost in, more of the heat that is produced makes it to the area it is intended to go.

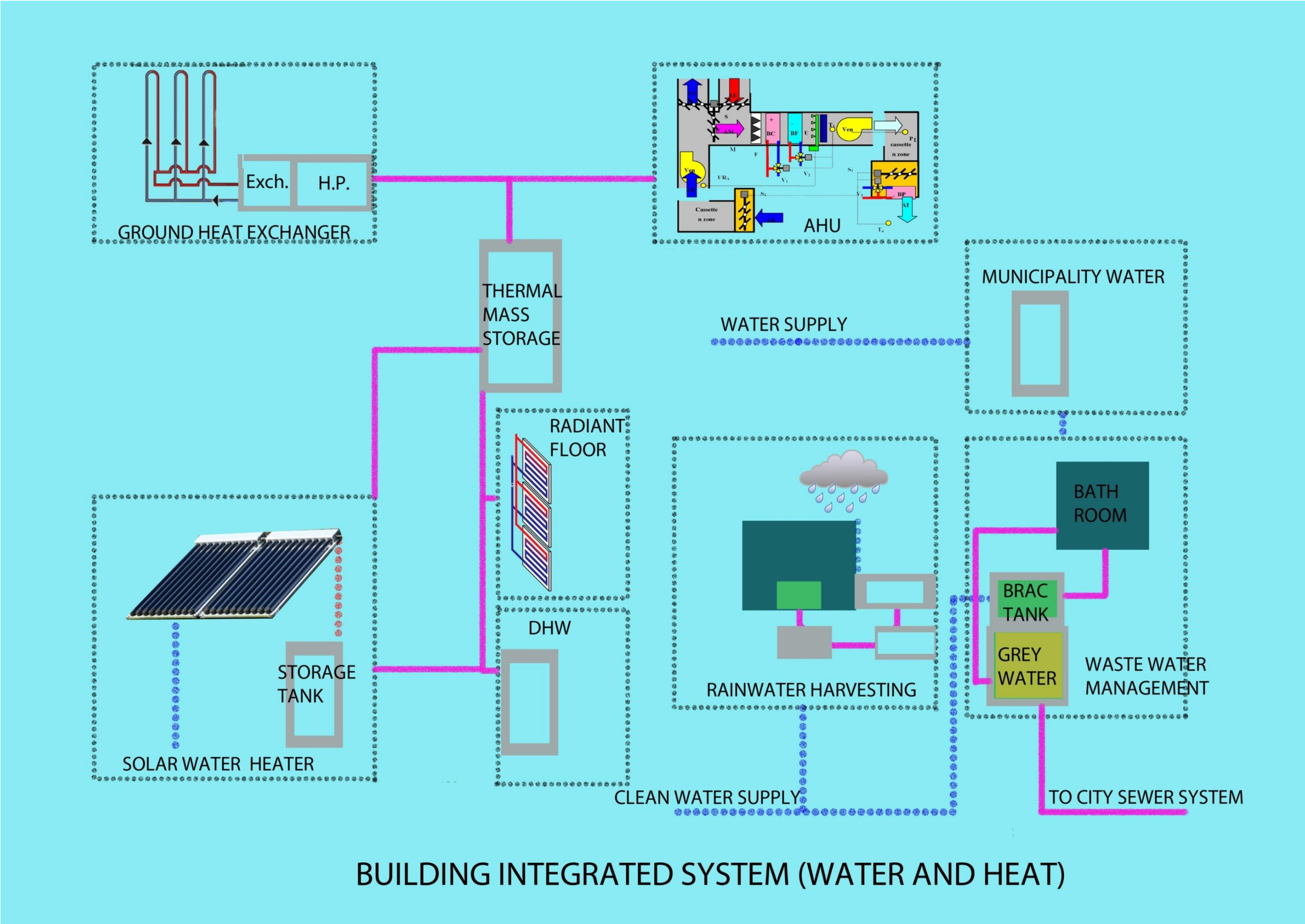
We made this choice for winter heating only as it is not very good system for summer cooling.



SCHEMATICS 1: Heating Mode



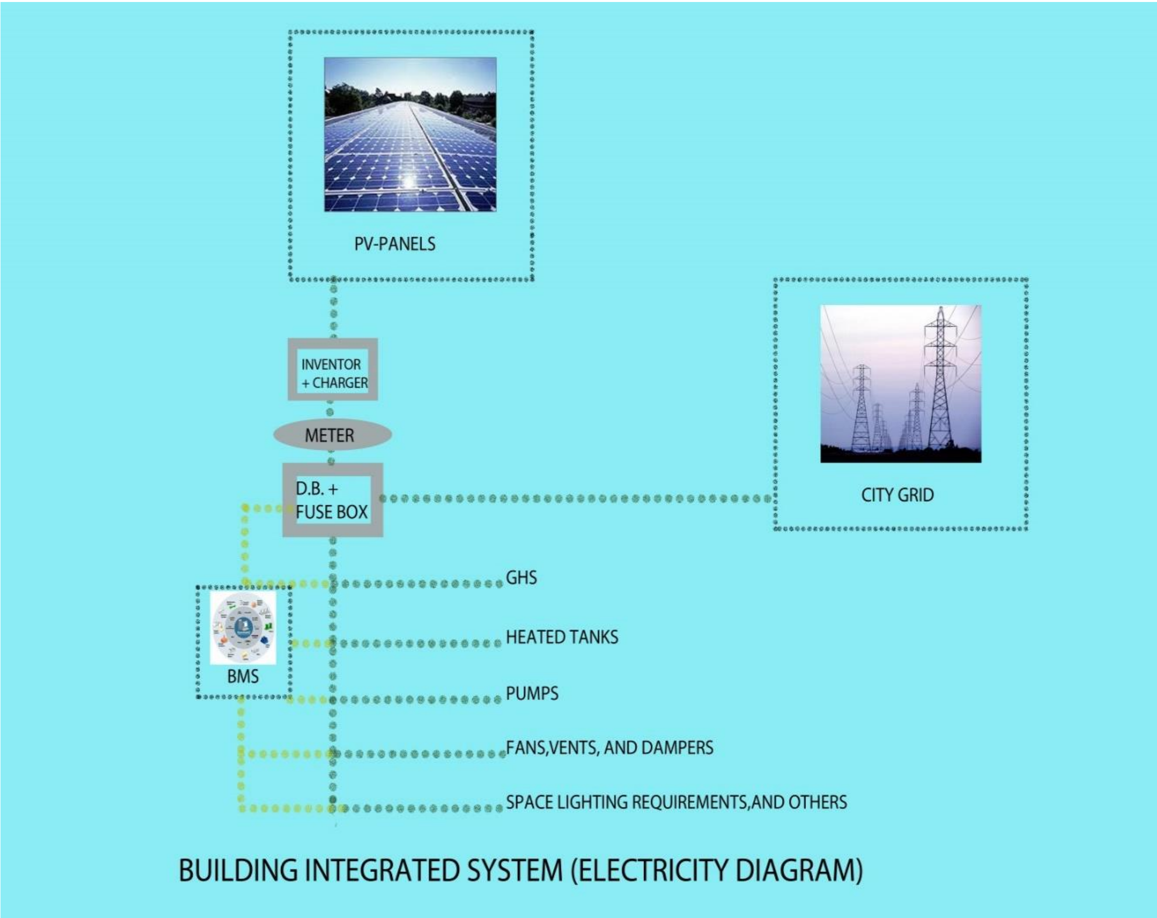
SCHEMATICS 2: Cooling Mode



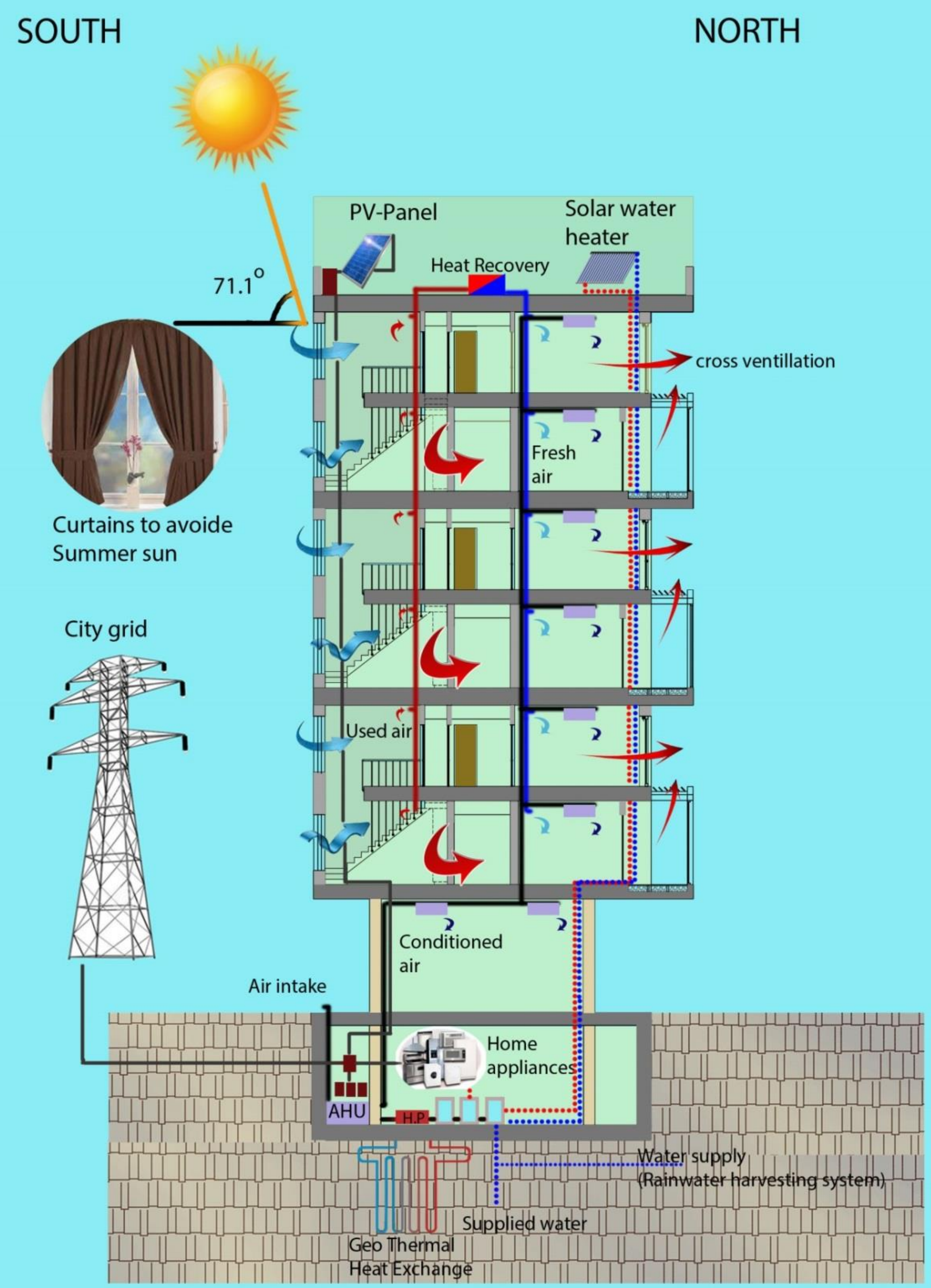
SCHEMATICS 3: Water and Heat

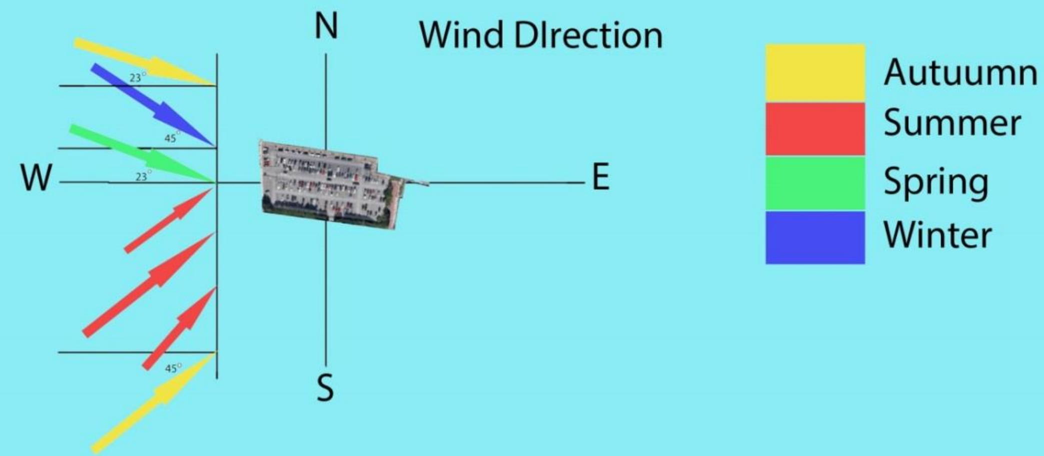
There is the need for extra ventilation system, in both the heating and cooling seasons in addition to the radiative floor system. Boston is a high humidity region and thus in days when windows cannot be opened there is a need to provide a mechanical ventilation system to maintain the prescribed indoor air quality. So we provided heat recovery unit as well as All-air VAV Reheat AHU in order to assure indoor quality according to standards.

Also solar water heating system is integrated with the heating and cooling system which can be seen through the schematic drawings given above.



SCHEMATICS 4: Electricity Network





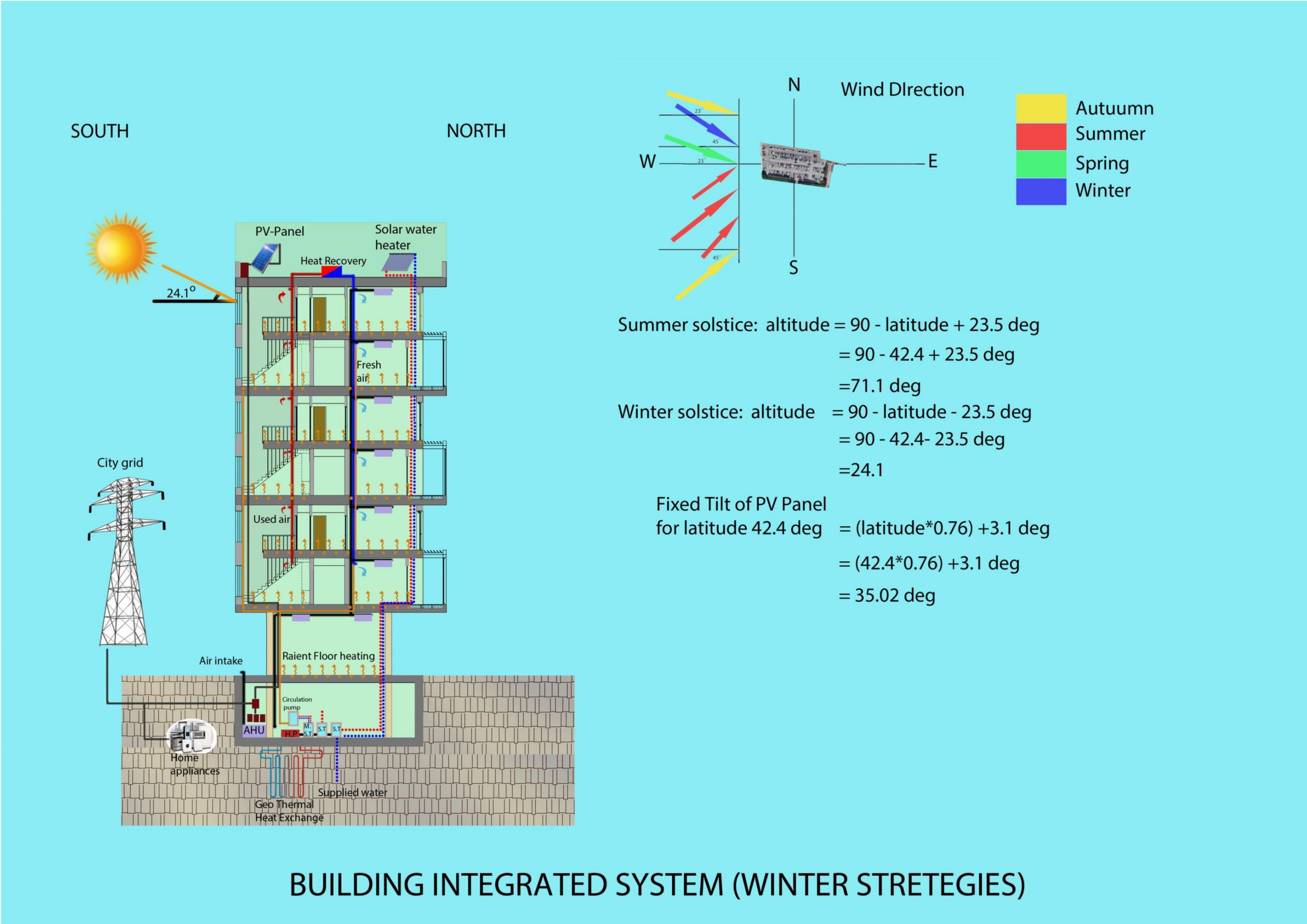
Summer solstice: altitude = 90 - latitude + 23.5 deg
= 90 - 42.4 + 23.5 deg
=71.1 deg

Winter solstice: altitude = 90 - latitude - 23.5 deg
= 90 - 42.4- 23.5 deg
=24.1

Fixed Tilt of PV Panel for latitude 42.4 deg = (latitude*0.76) +3.1 deg
= (42.4*0.76) +3.1 deg
= 35.02 deg

BUILDING INTEGRATED SYSTEM (SUMMER STRETEGIES)

SCHEMATICS 5: Summer stretegies



SCHEMATICS 6: Winter stretegies

3.12 Green strategies adopted and Technological solutions:

3.12.1 Orient the building for energy efficiency.

The first strategy in making the building energy efficient was to make full use of the orientation of the building. In our case we decided it based on shadow analysis which has already been discussed (section 3)

3.12.2 Natural Ventilation:

So for our case as the site is located in Boston harbor walk near the water front, we tried to do an analysis regarding wind directions and have sun path diagram using Ecotect software.

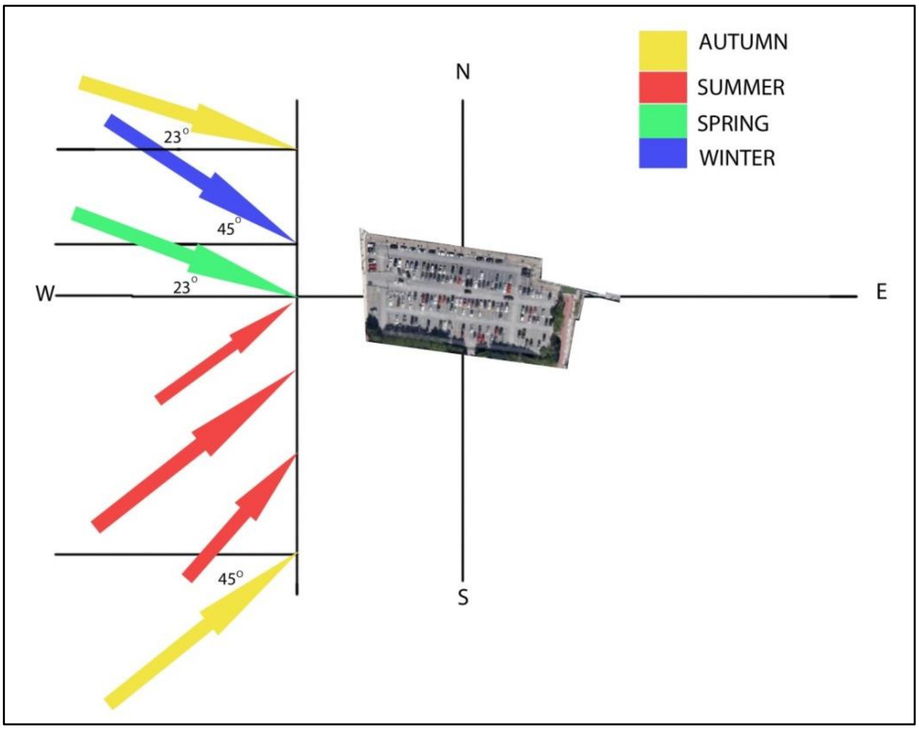


Figure 3-58: Wind Direction at Site

The winds in all seasons are following a specific axis and hence:

- In summer, wind is entering the site from SW and leaving in NE,
- In winter, wind is entering the site from NW and leaving in SE,
- In spring, wind is entering the site from NWW and leaving in SSE
- In autumn, wind is entering the site from SW and leaving in NE

Wind generates complex pressure distributions on buildings, particularly in urban environments. This assists ventilation, provided that openings are well distributed and flow paths within the building are available. As our building is oriented in a way that we let the wind cross through and also the housing is comprised of modules of flats , studios etc, so cross ventilation is a complicated process here. Also considering extreme cold and windy climate of Boston we considered cross ventilation as the matter within each module and we focused more on stack effect by creating a large atrium sort of corridor.

Stack ventilation is where air is driven through the building by vertical pressure differences developed by thermal buoyancy. The warm air inside the building is less dense than cooler air outside, and thus will try to escape from openings high up in the building envelope; cooler denser air will enter openings lower down. The process will continue if the air entering the building is continuously heated, typically by casual or solar gains.

Stack ventilation is one of the two natural ventilation mechanisms, the other being wind-induced. Since the same openings may contribute to both stack and wind pressure induced flows, they must not be considered in isolation.

The effectiveness of the stack effect, i.e. the volume of air that it drives, is dependent upon the height of the stack, the difference between the average temperature of the stack and the outside, and the effective area of the openings.

Stack ventilation occurs naturally whether we design it or not, and has been consciously used for centuries, in traditional and vernacular buildings ranging from Indian tepees to churches. However, modern analysis and design advice greatly extends its area of application to much larger buildings, with more exacting demands.

3.12.3 Place windows appropriately.

Light from the south is bright and direct; solar houses are oriented to the south for maximum heat gain. South-facing windows are often located beneath eaves or roof overhangs to block the high, intense summer sun, but allow in the warmth of the lower winter sun."

The right window placement will mean the difference between unwanted heat gain and lack of cool, flattering daylight. Proper window placement will facilitate cross breezes and ventilation, provided the house was oriented correctly in the first place. Low window openings on a house let in cool air and high window placement allows hot air to escape.

3.12.4 Insulate. Insulate. Insulate.

Siding and roofing will protect the house from bulk rain, and sealing stops the air flow, but a properly insulated house will keep its inhabitants comfortable. “A good, tight, well-insulated shell is about 70% of the solution,” Binkley says.

“To maintain comfort, the heat lost in the winter must be replaced by your heating system and the heat gained in the summer must be removed by your cooling system,” the DOE says. “Properly insulating your home will decrease this heat flow by providing an effective resistance to the flow of heat.” Still, the amount of insulation or R-value you'll need depends on your climate, type of heating and cooling system, and the section of the house you plan to insulate, according to the DOE. The type of insulation is a matter of preference. Some architects use foam because it (the closed-cell version) acts as a moisture barrier and air barrier and because it fills all nooks and crannies. Other pros use blow-in cellulose, while most builders stick with fiberglass batts. Either way, the concept is the same: the insulation must be installed properly to touch all six sides of the wall cavity. “Some types of insulation—such as foam board and dense-packed cellulose insulation—can be effective at reducing air flow as well as heat flow,”according to the government's Office of Energy Efficiency and Renewable Energy. “However, the most common type of insulation—fiberglass—does not stop air leakage. In older homes, dirty fiberglass insulation is a telltale sign of air movement (it collects dirt like a filter)."

3.12.5 Green roof

A green roof, or rooftop garden, is a vegetative layer grown on a rooftop. Green roofs provide shade and remove heat from the air through evapotranspiration, reducing temperatures of the roof surface and the surrounding air. On hot summer days, the surface temperature of a green roof can be cooler than the air temperature, whereas the surface of a conventional rooftop can be up to 90°F (50°C) warmer.

Green roofs can be installed on a wide range of buildings, from industrial facilities to private residences. They can be as simple as a 2-inch covering of hardy groundcover or as complex as a fully accessible park complete with trees. Green roofs are becoming popular in the United States, with roughly 8.5 million square feet installed or in progress as of June 2008.

In addition to mitigating urban heat islands, the benefits of green roofs include:

- Reduced energy use: Green roofs absorb heat and act as insulators for buildings, reducing energy needed to provide cooling and heating.
- Reduced air pollution and greenhouse gas emissions: By lowering air conditioning demand, green roofs can decrease the production of associated air pollution and greenhouse gas emissions.
- Vegetation can also remove air pollutants and greenhouse gas emissions through dry deposition and carbon sequestration and storage.
- Improved human health and comfort: Green roofs, by reducing heat transfer through the building roof, can improve indoor comfort and lower heat stress associated with heat waves.
- Enhanced storm water management and water quality: Green roofs can reduce and slow storm water runoff in the urban environment; they also filter pollutants from rainfall.
- Improved quality of life: Green roofs can provide aesthetic value and habitat for many

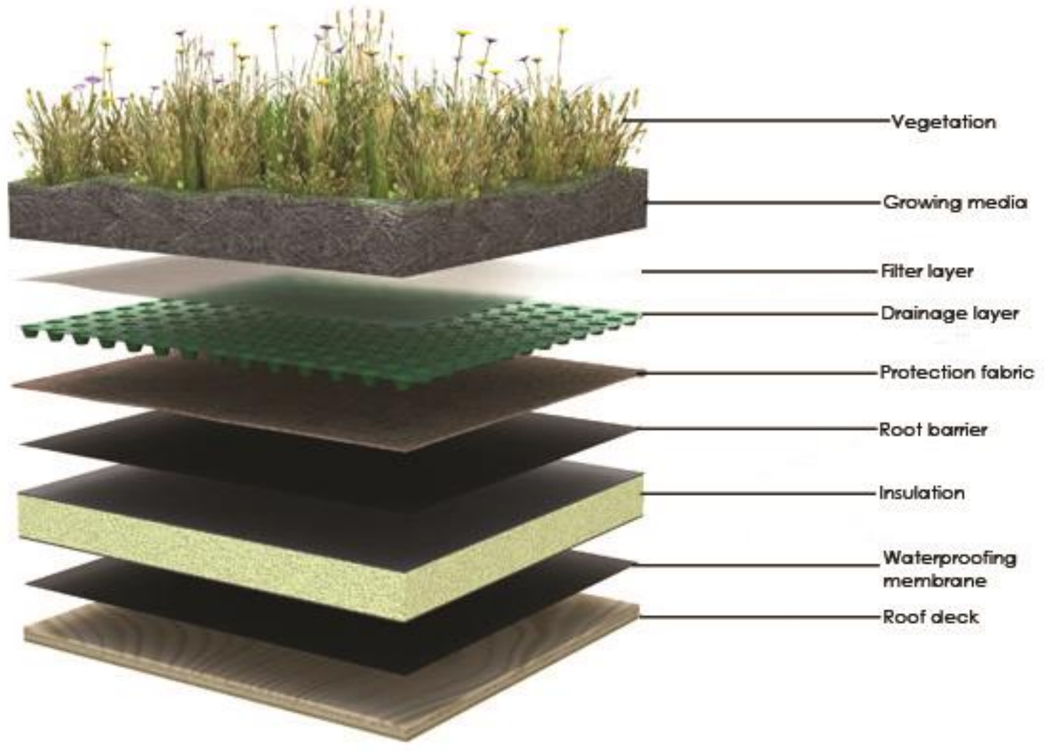


Figure 3-59: specification of green roof

1.1.1 Rainwater harvesting system:

Where it is possible to fit internal loft tanks, an indirect system may be preferable to the direct-pumped arrangement.

An indirect system works be collecting the rainwater into a common shared storage tank in the usual way, but then uses a single pump to deliver that water into numerous small header tanks, one in each property being served. Each header tank then has its own individual backup feed from the mains water supply. The mains water feed works completely independently so will always be available when required.

This means that each property is completely independent, so a landlords water supply is not required, and the result is a very robust system which is immune to the effects of pump or power failure. The pump will be controlled by its own controller, and this will supply the header tanks with rainwater until such time as there is no rainwater available (or no power). The mains water feeds will then automatically take over to maintain supply.

Note that the system will require a landlord’s power supply, and that the systems' controls must be located within a building

1.1.2 Use of PV panels:

Photovoltaic (PV) technology is the direct conversion of sunlight to electricity using semiconductor devices called solar cells. Photovoltaics are almost maintenance-free and have a long life span. The photoelectric conversion process produces no pollution and can make use of free solar energy. Overall, the longevity, simplicity, and minimal resources used to produce electricity via PV systems make this a highly sustainable technology.

While the cost is high for typical applications in buildings connected to the electric power grid, the integration of PVs into commercial buildings is projected to greatly increase over time. In fact, worldwide PV manufacturing is growing at a healthy annual rate of more than 20 percent, and the focus of research is to reduce the cost of PV systems, and to integrate PV into building design. In addition, PV Panels can be used for site lighting.

There are a number of ways in which Photovoltaic panels can be used on the building envelope. The most important thing to consider pertaining to their use is that they integrate well with the overall building envelope and become a part of the building architecture. They can be fixed on the walls or the roof, the opaque parts of the building in the form of photovoltaic cells of varying finishes or they can be integrated within the glazing elements. In case of the youth center building, the pv panels have been integrated within the glazed curtain wall to maintain the appearance of the building and generate electricity at the same time

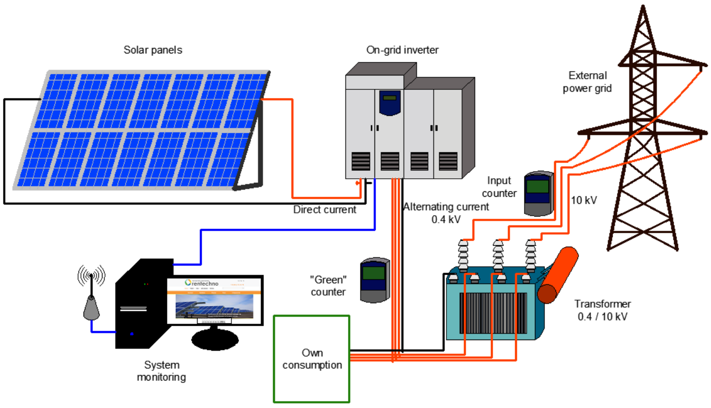


Figure 3-60: General scheme of PV panels

1.1.3 Solar collector for domestic hot water:

- Solar water heating systems include storage tanks and solar collectors. There are two types of solar water heating systems: active, which have circulating pumps and controls, and passive, which don't.
- Direct circulation systems:
  Pumps circulate household water through the collectors and into the home. They work well in climates where it rarely freezes.
- Indirect circulation systems:

Pumps circulate a non-freezing, heat-transfer fluid through the collectors and a heat exchanger. This heats the water that then flows into the home. They are popular in climates prone to freezing temperatures.

So for our case as the site is in Boston, because of extreme climate we choose indirect circulation system for domestic hot water.

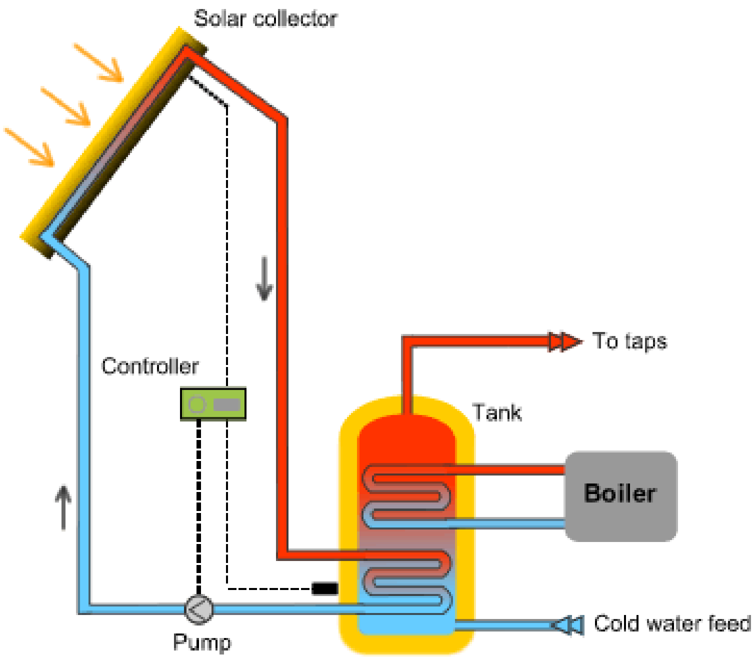


Figure 3-61: General Scheme of Solar water heater

1.1.4 Double/triple glazed windows:

Double glazing your windows or doors is a great way to save energy and minimize noise. It reduces the loss of heat from the home in the winter and the innermost panel of the glass is closer to room temperature. This means that anyone sitting near a window will feel much more comfortable. Also, if you have convection heating system in your home, double glazing is important as it will prevent heat loss from the uppermost areas of the house. In summer, double glazing will stop heat from entering the home, as it helps to reduce the amount of radiated heat gain. Generally, the insulation properties of double glazing are so great that you may save a significant amount on your heating or cooling bills. So it became inspiration for our project as well.

1.1.5 Natural and artificial lighting:

The dynamic nature of daylight, throughout the day and throughout the year, poses numerous challenges when designing buildings that seek to utilize this abundant natural resource to meet the luminance requirements of architectural spaces.

Daylight designs are most effective when properly integrated into the overall architecture of a building. Day lighting and solar control strategies that are addressed as an afterthought and added to an already designed building typically do not achieve a successful integration with the building design and space layout. Additionally, these types of strategies tend to be more costly to implement and more problematic in general. Therefore, it is best to address day lighting and solar control issues early in the design, when programming the various spaces.

Along with adequate solar control, integration with the electric lighting system design of a space is essential for a day lighting design to effectively provide increased building-wide energy savings.

1.1.6 Buffer zone /sun space:

A sunspace is a room which is designed to collect sunlight and heat. Sunspaces are also known as solar rooms, solariums, and sunrooms, and they are classically included in the designs of homes, although commercial structures can have sunspaces as well. Having a sunspace can cut down substantially on heating bills; it can also make a house more enjoyable to live in and increase the resale price of a home, for people who are concerned with property values.

I n our project we used sunspace in almost all units.

1.1.7 Rainwater harvesting system:

Rainwater harvesting is an innovative alternative water supply approach anyone can use. Rainwater harvesting captures, diverts, and stores rainwater for later use. Implementing rainwater harvesting is beneficial because it reduces demand on existing water supply, and reduces run-off, erosion, and contamination of surface water. Rainwater can be used for nearly any purpose that requires water. These include landscape use, storm water control, wildlife and livestock watering, in-home use, and fire protection.

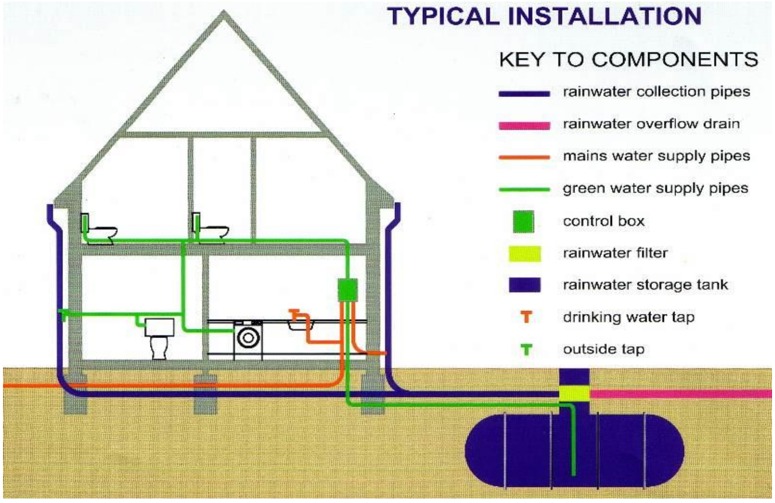
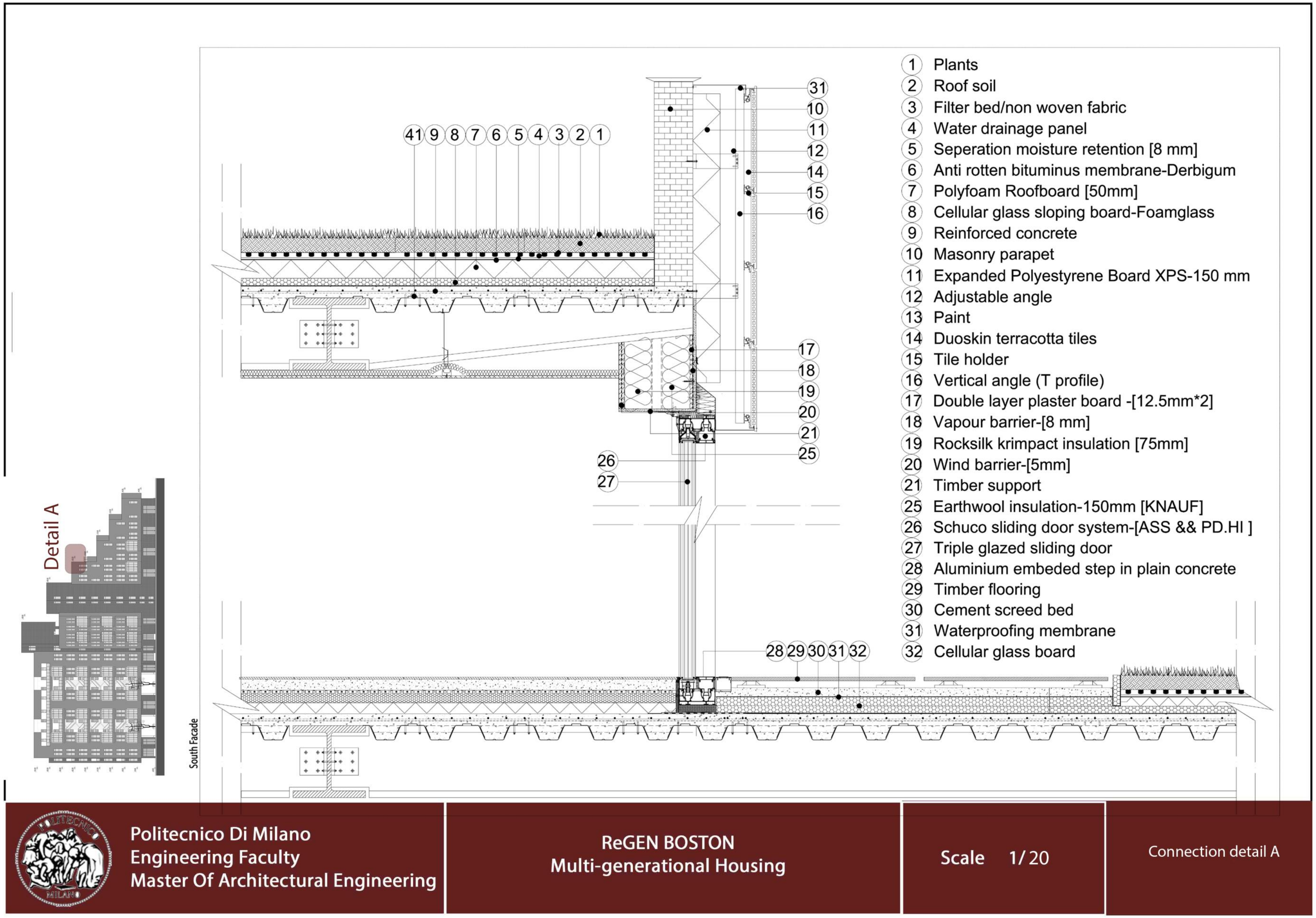
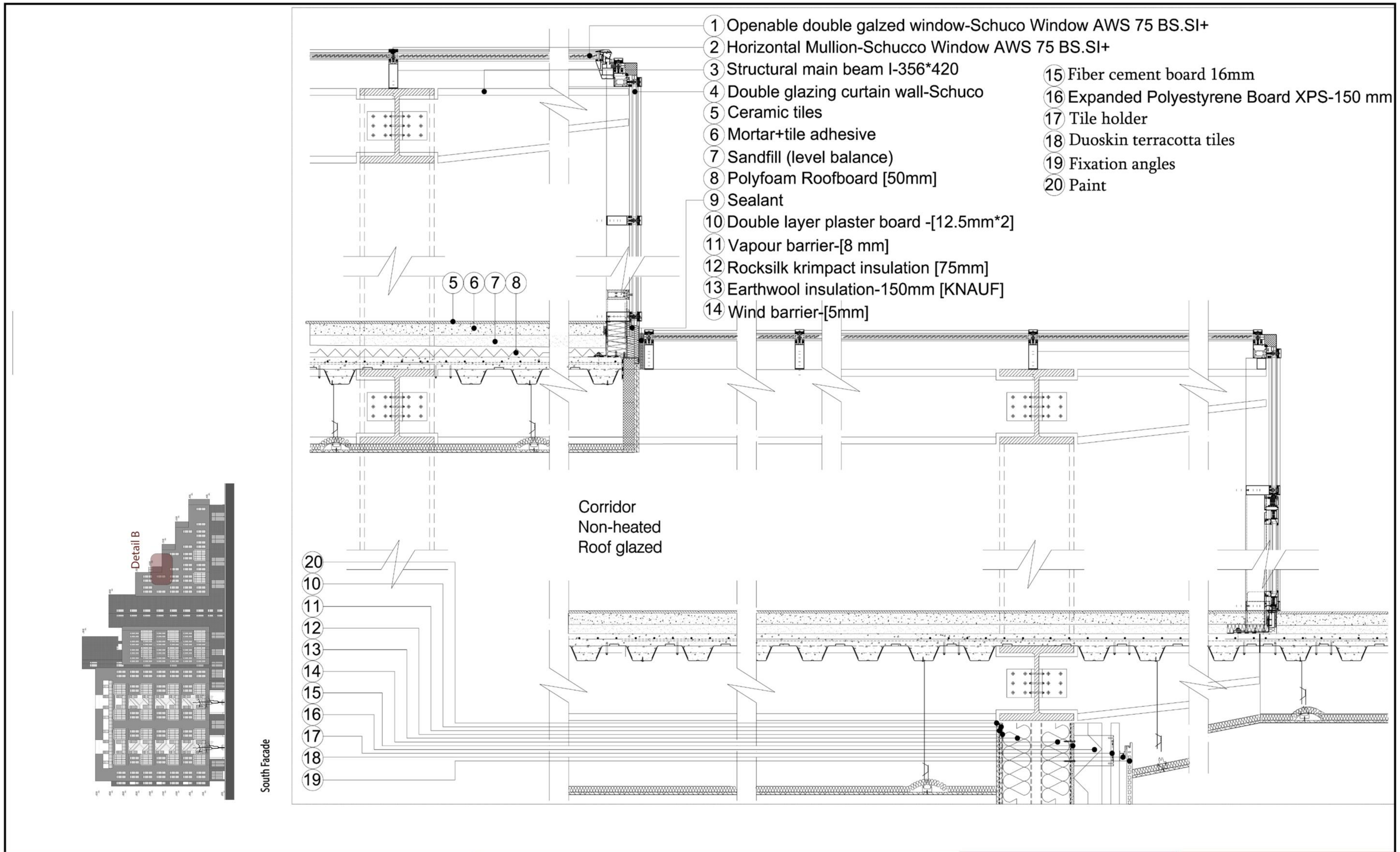


Figure 3-62: General Scheme of Rainwater harvesting syst

TECHNOLOGICAL DETAILS, DRAWINGS

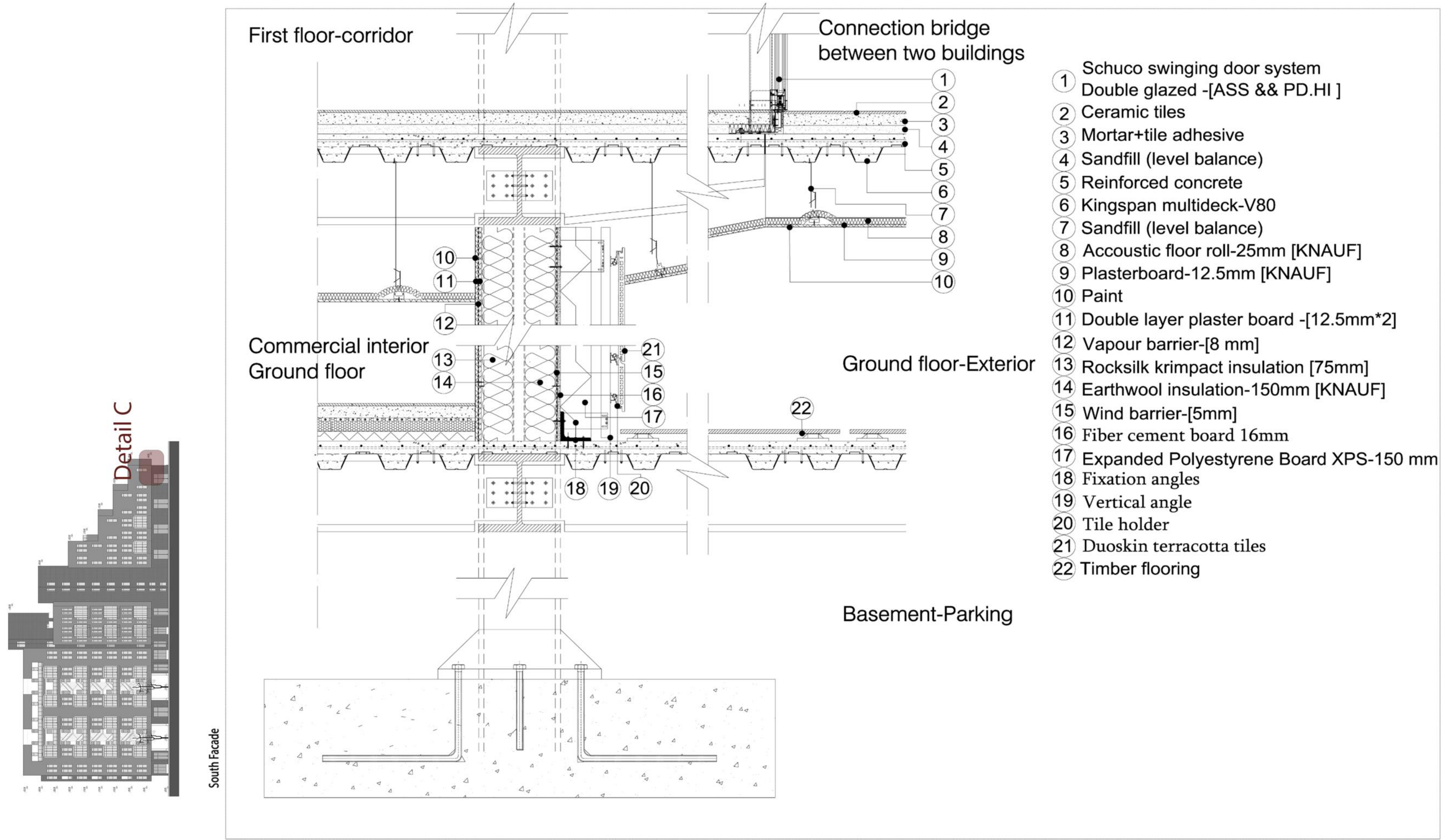


TECH. DRAWING 3: Connection detail A



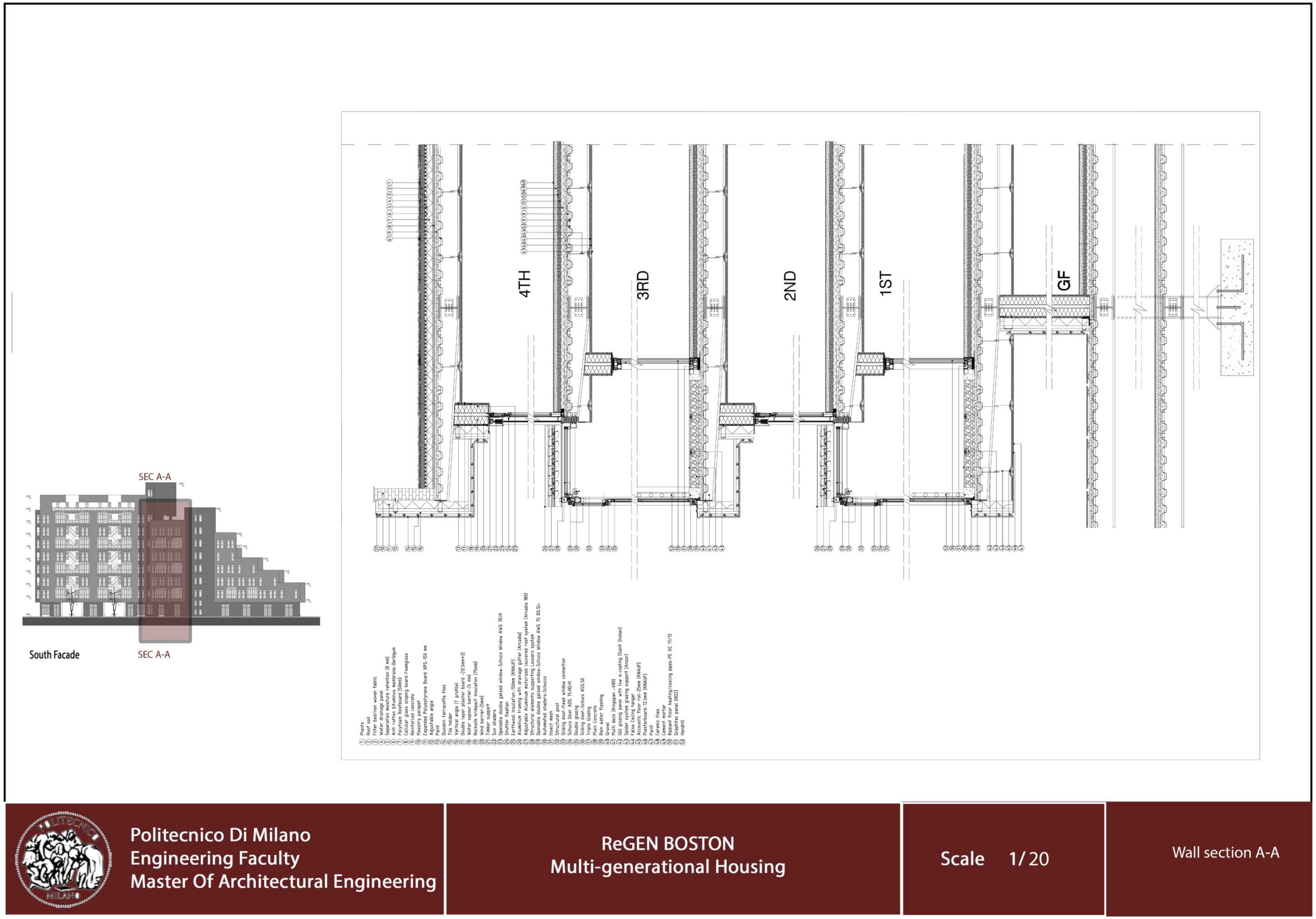
Politecnico Di Milano Engineering Faculty Master Of Architectural Engineering	ReGEN BOSTON Multi-generational Housing	Scale 1/20	Connection detail B

TECH. DRAWING 4: Connection detail B



Politecnico Di Milano Engineering Faculty Master Of Architectural Engineering	ReGEN BOSTON Multi-generational Housing	Scale 1/20	Connection detail C

TECH. DRAWING 5: Connection detail C



TECH. DRAWING 6: Blow Up, Wall Section A-

CHAPTER 4 Structural Design

4.1 Introduction

This chapter presents the necessary design and analysis which fulfills the structural integrity of the building of the project of a residential complex in Boston MA .The project consists of two separated buildings where we are focusing on the design on one of them keeping in consideration that the design of the other building follows the same methodologies. The building complex is divided into three buildings separated by structural gaps to attain a better lateral force resistance.

The Design was based on the Eurocode which stated the building according to its functions as a residential building as type C3 which is used for categories of use in the standard.
In the next three pages the architectural plans together with the position of the columns and structural gridlines are presented.

4.2 Acting loads

Gravitational loads are transmitted from the slab to the beams to columns to foundations and then finally to the ground.

When this load acts, it creates axial and flexural loads on the columns and creates shear and flexural loads on the beams, loads can be divided mainly into:

4.2.1.1 Dead loads

4.2.1.2 Wall loads (internal partitions, external walls and facades)

4.2.1.3 Snow loads

4.2.1.4 Live loads

4.2.1 Dead loads

Dead loads are the loads of concrete slab, beams and layers of insulation; Concrete slab lays over a system of main beams and secondary beams.

Spacing between main beams is 8 meters while the span between secondary beams is 4 meters in respect to each other.

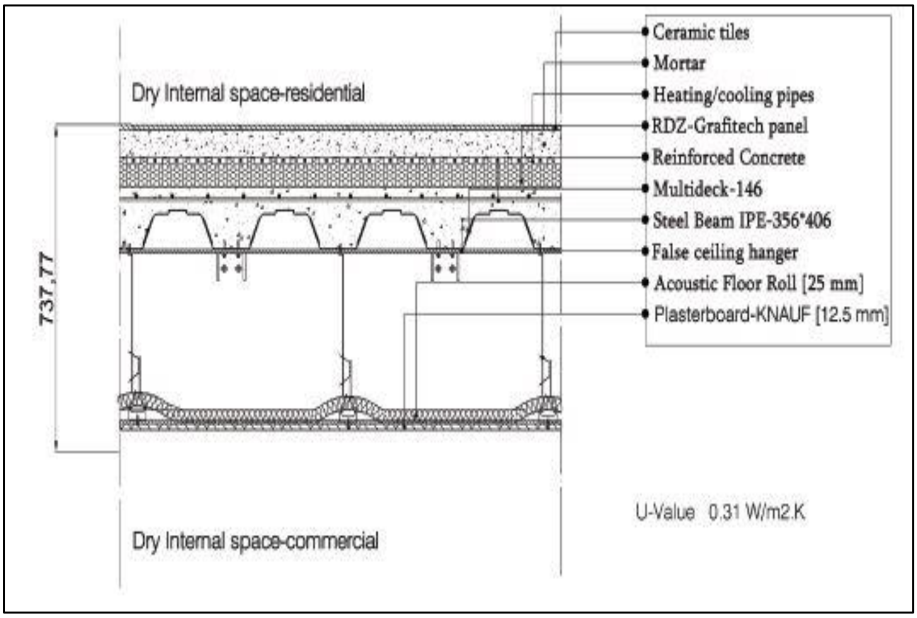


Figure 4-1: Technological solution for the intermediate floors

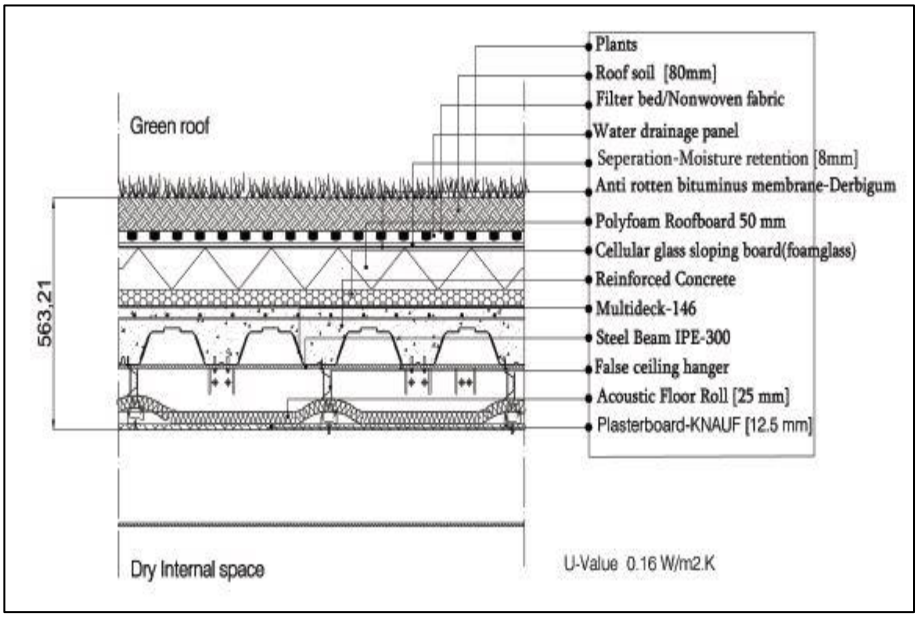


Figure 4-2: Technological solution for the roof

Table 13 Dead loads of the Ground and intermediate floors.

Dead Loads of the Ground and Intermediate floors			
Materials	Specific weight (Kg/m^3)	Thickness (cm)	Total weight of layer Kg/m^2
Finishing Tiles	2200.00	1.00	22.00
Mortar support	2100.00	6.00	126
Multideck sheets	-	-	15.00
Reinforced Concrete	2500.00	11.00	275.00
Suspended ceiling with gypsum boards	60.00	-	11.5
Total weight in kg per square meter	-	-	449.50

4.2.2 Wall loads (internal partitions, external walls and facades)

Referring to our project, the walls are not traditional masonry walls which of great weight ,but it is in the form of new technological dry assembled light weight solutions as a combination between series of layers of insulation and supports for cladding ,shades , etc.

Figure and Table below show the properties and specification of walls.

`

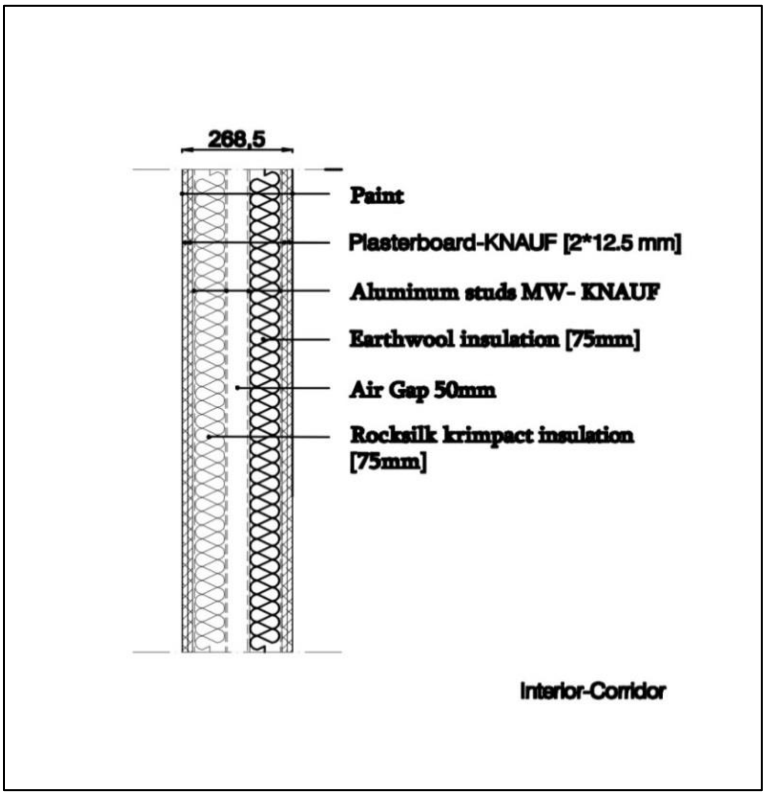


Figure 4-3: Vertical / Horizontal section of internal wall

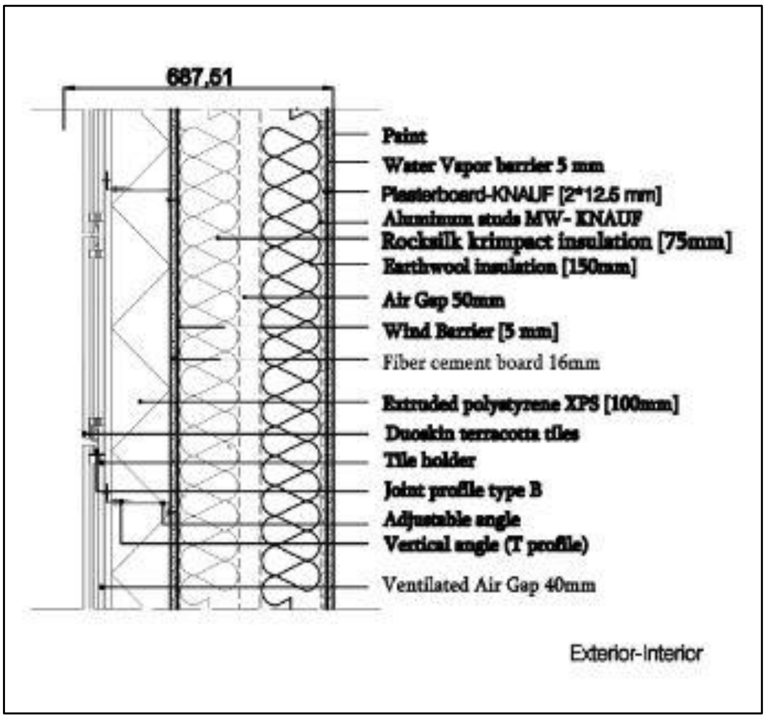


Figure 4-4: Vertical / Horizontal section of external wall

Table 14 Weight of the walls

Wall loads (internal partitions, external walls and facades	
Materials	Weight of wall in unit surface area (Kg/m^2)
Exterior and main interior walls	200.00
Bathroom separation partition	100.00

4.2.3 Snow loads

Properties of a roof or other factors mentioned below could cause the snow load to vary.

- The shape of the roof;
- Its thermal properties and the amount of heat generated under the roof;
- The roughness of its surface;
- The proximity of nearby buildings;
- The surrounding terrain;
- The local meteorological climate;

For the persistent / transient design situations: $S = \mu_i * Ce * Ct * S_k$

μ_i	is the snow load shape coefficient
$C e$	is the exposure coefficient
$C t$	is the thermal coefficient
S_k	is the characteristic value of snow load on the ground

The site has normal topography which means there is no significant removal of snow by wind on construction work, because of terrain, other construction works or trees. Therefore, C_e is chosen as 1. Ct is also assumed as 1 since the roof is very well insulated. Since the roof is flat, $\alpha = 0$ and $\mu_i = 0.8$.

These values are calculated based on the European code, but since the project is in the united states which follows the American code of practice, the values of S_k where calculated from the AISC to be equal to 212

$S = \mu_i * Ce * Ct * S_k = 0.8*1*1*212 = 169.6$ Kg/m^2

By considering the live load equal to 200 Kg/m^2 for the roof the total live load of the roof top is assumed as 200 (Kg/m^2).

4.2.4 Live loads

According to the Eurocode category of occupancy, regarding the residential function of the building, it is stated that the value of live load is supposed to be 200 kg/m^2 for the whole building and 150 kg/m^2 for the roof top, and because the snow load is higher than this value the live load of the roof is assumed to remain as 200 (Kg/m2).

Table 15 Dead and live loads

Total Dead and Live Loads		
	Dead Load Kg/m^2	Live Load Kg/m^2
Floors	450	200

4.3 Structural gap

It was decided to divide the building into three separate buildings from the structural perspective in order to attain a better performance of lateral forces resistance since the length of the building is more than 75 m and hence, it is preferable to have a structural gap each 40-50 mm but because of the building morphology, the allocation criteria of structural gaps was decided based on the form of block to attain higher lateral load resistance.

4.4 Load combinations

The combination of loads is to represent the maximum state of stresses that in term represent the most unfavorable conditions for the structure, taking the probability of occurrence of these loads simultaneously and in the specified combination.

According to the methodology selected, partial factors ϒf will be applied for safety reasons to the characteristic actions followed by the combination of the actions that will include a factor (Ψ) that takes into account the probability of happening of these mixed actions. Since all of the assumed loads would happen simultaneously in a very rare situation, therefore, it is necessary to have load combinations in which only part of the loads are acting at an instance based on their probability of occurrence.

Serviceability limit state: LC = Σi Gk,i + Qk,1 + Σj γQj ψ0j Qkj where:

Gk,i are the characteristic values of permanent actions

Qk1 is the characteristic value of the dominant variable action

ψ0j Qkj are the combination (ψ0j = 0.7) values of all other variable actions.

Ultimate limit state: LC = ΣI γGi Gik + γQ1 Q1k + Σj ψ0j γQj Qjk where:

Table 16: γ calculation

Persistent and transient design situations	Permanent actions		Leading variable action (*)	Accompanying variable actions	
	Unfavourable	Favourable		Main (if any)	Others
(Eq. 6.10)	$\gamma_{Gj,sup}G_{kj,sup}$	$\gamma_{Gj,inf}G_{kj,inf}$	$\gamma_{Q,1}Q_{k,1}$		$\gamma_{Q,i}\psi_{0,i}Q_{k,i}$

(*) Variable actions are those considered in Table A1.1

NOTE 1 The γ values may be set by the National annex. The recommended set of values for γ are :

$\gamma_{Gj,sup}$ = 1,10

$\gamma_{Gj,inf}$ = 0,90

$\gamma_{Q,1}$ = 1,50 where unfavourable (0 where favourable)

$\gamma_{Q,i}$ = 1,50 where unfavourable (0 where favourable)

NOTE 2 In cases where the verification of static equilibrium also involves the resistance of structural members, as an alternative to two separate verifications based on Tables A1.2(A) and A1.2(B), a combined verification, based on Table A1.2(A), may be adopted, if allowed by the National annex, with the following set of recommended values. The recommended values may be altered by the National annex.

$\gamma_{Gj,sup}$ = 1,35

$\gamma_{Gj,inf}$ = 1,15

$\gamma_{Q,1}$ = 1,50 where unfavourable (0 where favourable)

$\gamma_{Q,i}$ = 1,50 where unfavourable (0 where favourable)

provided that applying $\gamma_{Gj,inf}$ = 1,00 both to the favourable part and to the unfavourable part of permanent actions does not give a more unfavourable effect.

Table 17 Recommended values of ψ factors for buildings

Table A1.1 - Recommended values of ψ factors for buildings

Action	ψ_0	ψ_1	ψ_2
Imposed loads in buildings, category (see EN 1991-1-1)			
Category A : domestic, residential areas	0,7	0,5	0,3
Category B : office areas	0,7	0,5	0,3
Category C : congregation areas	0,7	0,7	0,6
Category D : shopping areas	0,7	0,7	0,6
Category E : storage areas	1,0	0,9	0,8
Category F : traffic area, vehicle weight ≤ 30kN	0,7	0,7	0,6
Category G : traffic area, 30kN < vehicle weight ≤ 160kN	0,7	0,5	0,3
Category H : roofs	0	0	0
Snow loads on buildings (see EN 1991-1-3)*			
Finland, Iceland, Norway, Sweden	0,70	0,50	0,20
Remainder of CEN Member States, for sites located at altitude H > 1000 m a.s.l.	0,70	0,50	0,20
Remainder of CEN Member States, for sites located at altitude H ≤ 1000 m a.s.l.	0,50	0,20	0
Wind loads on buildings (see EN 1991-1-4)	0,6	0,2	0
Temperature (non-fire) in buildings (see EN 1991-1-5)	0,6	0,5	0

NOTE The ψ values may be set by the National annex.
* For countries not mentioned below, see relevant local conditions.

Table 18 Load combinations

Load combinations	
Comb C1	1.35 DEAD
Comb C2	1.35 DEAD + 1.5 LIVE
Comb C3	1 DEAD + 0.45 LIVE + 1 EQY
Comb C4	1 DEAD + 0.45 LIVE - 1 EQY
Comb C5	1 DEAD + 0.45 LIVE + 1 EQX
Comb C6	1 DEAD + 0.45 LIVE - 1 EQX
Comb C7	1 DEAD + 1 EQY
Comb C8	1 DEAD - 1 EQY
Comb C9	1 DEAD + 1 EQX
Comb C10	1 DEAD - 1 EQX

4.5 Brief:

The project is composed of two separate buildings, the one which we are focusing on from the perspective of structural design is a typical six floors residential building laying over a full land capacity of two underground floors of car parking which are surrounded from the four borders by retaining walls taking into considerations the site situation since it is on seashore and there is expected raise of 60 cm in seawater level in the coming 100 years which is considered as a big increase. The building structure is of a beam to column system formed in the form of equal spacing grids laying over a two underground floor parking following the same grid, the slab used is a Kingspan Multideck which gives relatively big unpropped span with the least slab thickness

For better understanding of the structure, we went through the process of structure through manual calculations for the desired structure and verified through different checks For the purpose of this project after calculation of the required forces and designing the elements, the necessary checks were performed to have confirmation that the element will be able to sustain the loads applied upon and remain stable. It was not possible to design all the elements of the structure, so typical horizontal and vertical elements were chosen to cover most of the structure and the rest of the elements would be designed on the same lines in accordance with the Euro code requirements

- **Steel Properties**

Specific weight: 7850 kg/cm^3

Elastic modulus E: 2.04*1010 kg/cm^2

Poison ratio: 0.30

Yielding strength Fy: 2400kg/cm^2

Ultimate strength Fu: 4000kg/cm^2

- **Concrete properties**

Specific weight: 2400 kg/cm^3

Elastic modulus E: $2.20*10^9$ kg/cm^2

Poison ratio: 0.20

Compressive strength Fc: 2400kg/cm^2

Reinforcement yielding strength F_y: 3000 kg/cm^2.

4.6 Preliminary design of elements

Preliminary design of a beam and column are introduced as a sample of calculations of all the elements considering that all the rest of elements are following the same procedures of calculations.

Section properties are introduced from Euro code standard for steel Structures.

4.6.1 Conceptual hand calculation for frame E Under vertical load

Empirical method of calculation is used to calculate approximated values of the stresses of the frame considering that the point of zero moment is used to be 0.1L from the support although it might varies during complex calculations depending on the columns rigidity. The main purpose of the conceptual design of sections is to give sufficiently accurate results.

The calculations are presented for all of the beams of the frame and hence its reactions on the columns are then used for the columns design

In order to calculate the distributed load all over the beams

$O.W_{beam}$ = 1.80 KN/m

$O.W_{walls}$ = 1.00 KN/m

$O.W_{slab+F.C+Ins.}$= 4.4 KN/m^2 (D.L)

L.L= 2 KN/m2

Based on the load combination

W_s=(1.35*4.4)+(1.5*2) = 8.95 = 9

W=$O.W_{beam}$ + $O.W_{walls}$ + W_s*L_s/2*2/3

=1.80+1.0+(1.35*4.4)+(1.5*2)*2/3*4 = 26.65 KN/m

Table19 Analysis Data

Ground and First floors	Shear forces at the supports of the beams	V1+ = 0.45qL= 0.45*26.65*4.5= 55 KN V2+ = 0.45qL= 0.45*26.65*8= 98 KN V2- = 0.6qL= 0.6*26.65*8= 127 KN V3+ = 0.5qL= 0.5*26.65*8= 106 KN V3- = 0.6qL= 0.6*26.65*8= 127 KN V4+ = 0.5qL= 0.5*26.65*8= 106 KN V4-=V5+=V5-=V6+=V6-= V4+ = 0.5qL= 0.5*26.65*8= 106 KN V7-=0.45qL=0.45*26.65*8=95 KN
	Moment at the edges and in the middle of the beams	M12- = 0.042qL2= 0.042*26.65*4.52= 22.65 KN.m M12+ =0.083 qL2= 0.083*26.65*4.52=44.8 KN.m M23+= 0.083qL2 = 0.083*26.65*4.52= 141.6 KN.m M23-= 0.042qL2= 0.042*26.65*82=71.63 KN.m M34+= 0.0625qL2 = 0.0625*26.5*82= 106.7 KN.m M34-= 0.1qL2 = 0.1*26.5*82= 170.56 KN.m M45+= 0.0625qL2 = 0.0625*26.5*82= 106.7 KN.m M45-= 0.083qL2 = 0.083*26.65*82= 141.6 KN.m M56+= 0.0625qL2 = 0.0625*26.65*82= 106.7 KN.m M56-= 0.083qL2 = 0.083*26.65*82= 141.6 KN.m M67+= 0.083qL2 = 0.083*26.65*82= 141.6 KN.m M67-= 0.083qL2 = 0.083*26.65*82= 141.6 KN.m M7= 0.042qL2 = 0.042*26.65*82= 71.63 KN.m
Second floor	Shear forces at the supports of the beams	V1+ = 0.45qL= 0.45*26.65*4.5= 55 KN V2+ = 0.45qL= 0.45*26.65*8= 98 KN V2- = 0.6qL= 0.6*26.65*8= 127 KN V3+ = 0.5qL= 0.5*26.65*8= 106 KN V3- = 0.6qL= 0.6*26.65*8= 127 KN V4+ = 0.5qL= 0.5*26.65*8= 106 KN V4-=V5+=V5-= V4+= 0.5qL= 0.5*26.65*8= 106 KN V6-=0.45qL=0.45*26.65*8=95 KN

	Moment at the edges and in the middle of the beams	M12- = 0.042qL2= 0.042*26.65*4.52= 22.65 KN.m M12+ =0.083 qL2= 0.083*26.65*4.52=44.8 KN.m M23+= 0.083qL2 = 0.083*26.65*4.52= 141.6 KN.m M23+= 0.083qL2 = 0.083*26.65*4.52= 141.6 KN.m M23-= 0.042qL2= 0.042*26.65*82=71.63 KN.m M34+=0.0625qL2 = 0.0625*26.5*82= 106.7 KN.m M34-= 0.1qL2 = 0.1*26.5*82= 170.56 KN.m M45+= 0.0625qL2 = 0.0625*26.5*82= 106.7 KN.m M45-= 0.083qL2 = 0.083*26.65*82= 141.6 KN.m M56+= 0.083qL2 = 0.083*26.65*82= 141.6 KN.m M56-= 0.083qL2 = 0.083*26.65*82= 141.6 KN.m M6= 0.042qL2 = 0.042*26.65*82= 71.63 KN.m
Third floor	Shear forces at the supports of the beams	V1+ = 0.45qL= 0.45*26.65*4.5= 55 KN V2+ = 0.45qL= 0.45*26.65*8= 98 KN V2- = 0.6qL= 0.6*26.65*8= 127 KN V3+ = 0.5qL= 0.5*26.65*8= 106 KN V3- = 0.6qL= 0.6*26.65*8= 127 KN V4+ = 0.5qL= 0.5*26.65*8= 106 KN= V4- V5-=0.45qL=0.45*26.65*8=95 KN
	Moment at the edges and in the middle of the beams	M12- = 0.042qL2= 0.042*26.65*4.52= 22.65 KN.m M12+ =0.083 qL2= 0.083*26.65*4.52=44.8 KN.m M23+= 0.083qL2 = 0.083*26.65*4.52= 141.6 KN.m M23-= 0.042qL2= 0.042*26.65*82=71.63 KN.m M34+=0.0625qL2 = 0.0625*26.5*82= 106.7 KN.m M34-= 0.1qL2 = 0.1*26.5*82= 170.56 KN.m M45+= 0.0625qL2 = 0.0625*26.5*82= 106.7 KN.m M45-= 0.083qL2 = 0.083*26.65*82= 141.6 KN.m M5= 0.042qL2 = 0.042*26.65*82= 71.63 KN.m

Fourth floor	Shear forces at the supports of the beams	V1+ = 0.45qL= 0.45*26.65*4.5= 55 KN V2+ = 0.45qL= 0.45*26.65*8= 98 KN V2- = 0.6qL= 0.6*26.65*8= 127 KN V3+ = 0.5qL= 0.5*26.65*8= 106 KN V3- = 0.6qL= 0.6*26.65*8= 127 KN V4+ = 0.5qL= 0.5*26.65*8= 106 KN V4-= 0.5qL= 0.5*26.65*8= 106 KN
	Moment at the edges and in the middle of the beams	M12- = 0.042qL2= 0.042*26.65*4.52= 22.65 KN.m M12+ =0.083 qL2= 0.083*26.65*4.52=44.8 KN.m M23+= 0.11qL2 = 0.11*26.65*4.52= 187.6 KN.m M23-= 0.09qL2= 0.09*26.65*82=153.5 KN.m M34+= 0.11qL2 = 0.11*26.65*4.52= 187.6 KN.m M34-= 0.09qL2= 0.09*26.65*82=153.5 KN.m M4= 0.042qL2 = 0.042*26.65*82= 71.63 KN.m
Fifth floor	Shear forces at the supports of the beams	V = 0.5qL= 0.5*26.65*8= 106 KN

	Moment at the edges and in the middle of the beams	M12- = 0.042qL2= 0.042*26.65*4.52= 22.65 KN.m M12+ =0.125 qL2= 0.125*26.65*4.52=67.75 KN.m M2= 0.042qL2= 0.042*26.65*4.52= 22.65 KN.m

4.6.2 Design of columns:

A typical column is chosen to be as a sample of calculations since the straining actions were previously calculated, the column is chosen in the lowest floor (basement 2) to be the most critical case and then the acting loads on the column decreases. it is found that:

Moment at level 1 applied on the column due to gravitational forces:

M_c = (71.63 (KN.m) – 22.65 (KN.m)) = 49 KN.m

Also the summation of the beams' shear forces at their supports (axial loads for columns) would

give the following axial force at level -2:

P_c= (127*8)+(79*8) = 1657KN

C40*40 column was chosen for the preliminary design of columns with plates thickness of 25 mm.

The column section which was used is of the following properties

Table 20 Hollow box section properties

Section	Area cm^2	Moment of Inertia over neutral axes cm^4 $I_x = I_y = bh^3/12+Ad^2$
C40*40	400	$I_x = I_y = (40*2.5^3/12+40*2.5*21.125^2)*2+2*2.5*40^3/12 = 116023.95$ cm^4

- **Euro code approach for column designing:**

Design Process:

1- Determine the $N_{b,y,Rd}$ and $N_{b,z,Rd}$ maximum axial loads to prevent buckling

2- Determine $M_{b,R}$ Maximum moment to prevent torsional buckling

3- Determine $M_{cb,z,Rd}$

4- Determine C_{my}, C_{mz} and C_{mLT} based on the shape of the bending moment diagram

5- Determine the K factors

6- Verify the biaxial bending combined with flexural buckling about the major axis using: $\frac{N_{Ed}}{N_{b,y,Rd}} + k_{yy}\frac{M_{y,Ed}}{M_{b,Rd}} + k_{yz}\frac{M_{z,Ed}}{M_{cb,z,Rd}} \leq 1$

7- Verify for biaxial bending combined with flexural buckling about the minor axis using: $\frac{N_{Ed}}{N_{b,z,Rd}} + k_{zy}\frac{M_{y,Ed}}{M_{b,Rd}} + k_{zz}\frac{M_{z,Ed}}{M_{cb,z,Rd}} \leq 1$

Class of cross section

In order to define the class of cross section, we should obtain the maximum value of *C/t* from the table 5.2 of the Eurocode 3. There are 4 classifications that start with the class number one which is working in Plastic range and class number 4 which is prone to local buckling before reaching the maximum resistance of the cross section.

$$\alpha = \frac{1}{2}\left(1 + \frac{N_{Ed}}{f_y c\, t_w}\right)$$

$$\psi = \frac{2N_{Ed}}{Af_y} - 1$$

α = 0.5 * (1+ 270000 kg/ (2400 kg/cm^2*4.76 *29) = 0.907

Ψ = 2*270000 kg/ (784cm^2*2400 kg/cm^2) -1 = - 0.71

For the steel type S275 the maximum value of *C/t* for having class number one is obtained by 365/ (13α -1) when the alpha value is more than 0.5. Therefore:

Max C/t = 365/ (13*0.907-1) = 34.11

For the selected column: C/t = 29 cm /4.76 cm=6< 34.11 → class type one for cross section.

- **Partial factors for resistance:**

The partial factors y_m should be applied to the various characteristic values of resistance in this section is given as:

Resistance of cross-section whatever the class is: $y_{M0} = 1.00$
Resistance of members to instability: $y_{M1} = 1.00$
Resistance of cross-sections in tension to fracture: $y_{M2} = 1.10$

- **Plastic modulus of the cross section (Wpl)**

$W_{pl\ x\text{-}x}$= 14235 cm^3

$W_{pl\ y\text{-}y}$=7108 cm^3

- **Column buckling resistance**

A compression member should be verified against buckling as follows:

$$\frac{N_{Ed}}{N_{b,Rd}} \leq 1.0$$

Where:

N_{Ed} is the design value of the compression force

$N_{b,Rd}$ is the design buckling resistance of the compression member

The design buckling resistance of a compression member should be taken as:

$$N_{b,Rd} = \chi \frac{Af_y}{\gamma_{M1}}$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} \text{ but } \chi \leq 1$$

$$\phi = 0.5\left[1 + \alpha\left(\bar{\lambda} - 0.2\right) + \bar{\lambda}^2\right]$$

α is the imperfection factor and could be found from table. For the cross section of UKC 356*406   α=a=0.21

Table 21 Imperfection Factor section properties

Buckling curve	a	b	c	d
Imperfection factor α	0.21	0.34	0.49	0.76

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} \quad \text{but } \chi \leq 1$$

The non-dimensional slenderness $\bar{\lambda}$ is given by:

$$\bar{\lambda} = \sqrt{\frac{Af_y}{N_{cr}}}$$

N_{cr} is the elastic critical force for the relevant buckling mode For flexural, or strut buckling, N_{cr} is the Euler load, i.e.

$$N_{cr} = \frac{\pi^2 EI}{L^2}$$

N_{cr}= Π^2*E*I/L^2=3.14^2 * 2.04*10^4*98125/500^2 = 6355276.319 kg = 78945.8 T

λ = √(784.84*2400/78945.8)=0.15

Φ = 0.5* [1+0.21(0.15-0.2) +0.15^2]=0.506

X = 1/ (0.506 + √(0.506^2 – 0.15^2)= 1

$N_{b,Rd}$ = 1 * 784.84 cm^2 *2400 kg/cm^2 = 1883616 kg

4.6.2.1 $\frac{N_{Ed}}{N_{b,Rd}} \leq 1.0$ =280427/1883616 = 0.15 < 1.0 O.K

Bending resistance

The design buckling resistance of a laterally unrestrained element should be taken as:

$$M_{b,Rd} = \chi_{LT} W_y \frac{f_y}{\gamma_{M1}}$$

X_{LT} is the reduction factor for lateral-torsional buckling.

$$\chi_{LT} = \frac{1}{\phi_{LT} + \sqrt{\phi_{LT}^2 - \beta \bar{\lambda}_{LT}^2}} \quad \text{but } \chi_{LT} \leq 1$$

$$\phi_{LT} = 0.5\left[1 + \alpha_{LT}\left(\bar{\lambda}_{LT} - \bar{\lambda}_{LT,0}\right) + \beta \bar{\lambda}_{LT}^2\right]$$

$\bar{\lambda}_{LT,0}$ = 0.4 for rolled sections β = 0.75 for rolled sections

$$\bar{\lambda}_{LT} = \frac{L/i_z}{96}$$

ƛ = 500 cm/(11cm*96) = 0.47

Φ_{LT} = 0.5* [1+0.21*(0.47-.04)+0.75*.0.4^2] = 0.567

χ = 1/ [0.567+ √(0.567^2-0.75*0.4^2)] = 0.98 <1

$M_{b,Rd}$ = 0.98*4629*2400/1 = 10891765 kg.cm

M_{ED}/M_{bRD} = 418083/1891765=0.04 < 1 O.K

Safe section but not economic

use smaller section

C40*40

$$\alpha = \frac{1}{2}\left(1 + \frac{N_{Ed}}{f_y c\, t_w}\right)$$

$$\psi = \frac{2N_{Ed}}{Af_y} - 1$$

α = 0.5 * (1+ 280427kg/ (2400 kg/cm^2*4.0*25) = 1.16

Ψ = 2*280427kg/ (400cm^2*2400 kg/cm^2) -1 = - 0.41

For the steel type S275 the maximum value of *C/t* for having class number one is obtained by 365/ (13α -1) when the alpha value is more than 0.5. Therefore:

Max C/t = 365/ (13*0.86-1) = 32.65

For the selected column: C/t = 40 cm /2.5 cm=16< 32.65→ class type one for cross section

- **Partial factors for resistance**

The partial factors y_m should be applied to the various characteristic values of resistance in this section is given as:

Resistance of cross-section whatever the class is: y_{M0} = 1.00
Resistance of members to instability: y_{M1} = 1.00
Resistance of cross-sections in tension to fracture: y_{M2} = 1.10

- **Plastic modulus of the cross section (Wpl)**

W_{pl} = 6781.25 cm^3

- **Column buckling resistance**

A compression member should be verified against buckling as follows:

$$\frac{N_{Ed}}{N_{b,Rd}} \leq 1.0$$ Where:

The design buckling resistance of a compression member should be taken as:

$$N_{b,Rd} = \chi \frac{Af_y}{\gamma_{M1}}$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \overline{\lambda}^2}} \text{ but } \chi \leq 1$$

$$\phi = 0.5\left[1 + \alpha\left(\overline{\lambda} - 0.2\right) + \overline{\lambda}^2\right]$$

α is the imperfection factor and could be found from table. For the cross section of C 40*40   α=a=0.21.

Table 22 Imperfection Factor section properties

Buckling curve	a	b	c	d
Imperfection factor α	0.21	0.34	0.49	0.76

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} \text{ but } \chi \leq 1$$

The non-dimensional slenderness $\bar{\lambda}$ is given by:

$$\bar{\lambda} = \sqrt{\frac{A f_y}{N_{cr}}}$$

N_{cr} is the elastic critical force for the relevant buckling mode For flexural, or strut buckling, N_{cr} is the Euler load, i.e.

$$N_{cr} = \frac{\pi^2 EI}{L^2}$$

N_{cr}= Π^2*E*I/L^2=3.14^2 * 2.04*10^4*98125/500^2 = 6355276.319 kg = 78945.8 T

λ = √(400*2400/93346.3*10^3)=0.10

Φ = 0.5* [1+0.21(0.10-0.2) +0.1^2]=0.49

X = 1/ (0.49 + √(0.49^2 – 0.1^2)= 1.03 >1

$N_{b,Rd}$ = 1 * 400 cm^2 *2400 kg/cm^2 = 960000 kg

4.6.2.2 $\frac{N_{Ed}}{N_{b,Rd}} \leq 1.0$ = 280427/960000 = 0.29< 1.0   O.K

- **Bending resistance**

The design buckling resistance of a laterally unrestrained element should be taken as:

$$M_{b,Rd} = \chi_{LT} W_y \frac{f_y}{\gamma_{M1}}$$

X_{LT} is the reduction factor for lateral-torsional buckling.

$$\chi_{LT} = \frac{1}{\phi_{LT} + \sqrt{\phi_{LT}^{2} - \beta\bar{\lambda}_{LT}^{2}}} \quad \text{but } \chi_{LT} \leq 1$$

$$\phi_{LT} = 0.5\left[1 + \alpha_{LT}\left(\bar{\lambda}_{LT} - \bar{\lambda}_{LT,0}\right) + \beta\bar{\lambda}_{LT}^{2}\right]$$

$$\bar{\lambda}_{LT,0} = 0.4 \text{ for rolled sections} \quad \beta = 0.75 \text{ for rolled sections}$$

$$\bar{\lambda}_{LT} = \frac{L/i_z}{96}$$

$\bar{\lambda}$ = 500 cm/(17.03cm*96) = 0.30

Φ_{LT} = 0.5* [1+0.21*(0.3-.04)+0.75*.0.3^2] = 1.0465

χ = 1/ [1.0465+ √(1.0465^2-0.75*0.4^2)] = 0.49 <1

$M_{b,Rd}$ = 0.49*6781.25*2400/1 = 7974750 kg.cm

M_{ED}/M_{bRD} = 418083/7974750=0.04 < 1 O.K

4.7 Allowable stress design Method

Gyration Radios r_x=r_y=√(116023.95/400) = 17.03 ƛ = K*L/r

K: is the effective length factor and for the column of both ends fixed

would be 0.5

L: is the length of the column

$ƛ_x$= 0.5*500/17.03 = 14.76

C_c=√ (2∏^2*E/2400) = 6440/√2400=131.5 14.76<131.5

ß= ƛ/C_c = 14.76/131.5 = 0.1111 ƛ<C_c → F_a= (1-.5ß^2)/F.s*Fy

$Fs = 5/3+3\lambda/8C_c-1/8*(\lambda/C_c)$ ^3 = 5/3+3/8*14.76/131.5-1/8* (14.76/131.5)^3 =

1.708

F_a = (1-.5*0.111^2)/Fs = 0.585*2400 = 1407 Kg/cm^2

F_{bx} = 0.6*2400 = 1440 Kg in the case without buckling consideration

- **Existing stresses:**

F_a=P/A=270000/400=675 $Kg/cm^2 < 1400$ Kg/cm^2

S=I/y= 116023.95/20=5801.1958

f_{bx}=M/S=49*10^5 /5801.19 = 844 Kg/cm^2 O.K (safe section)

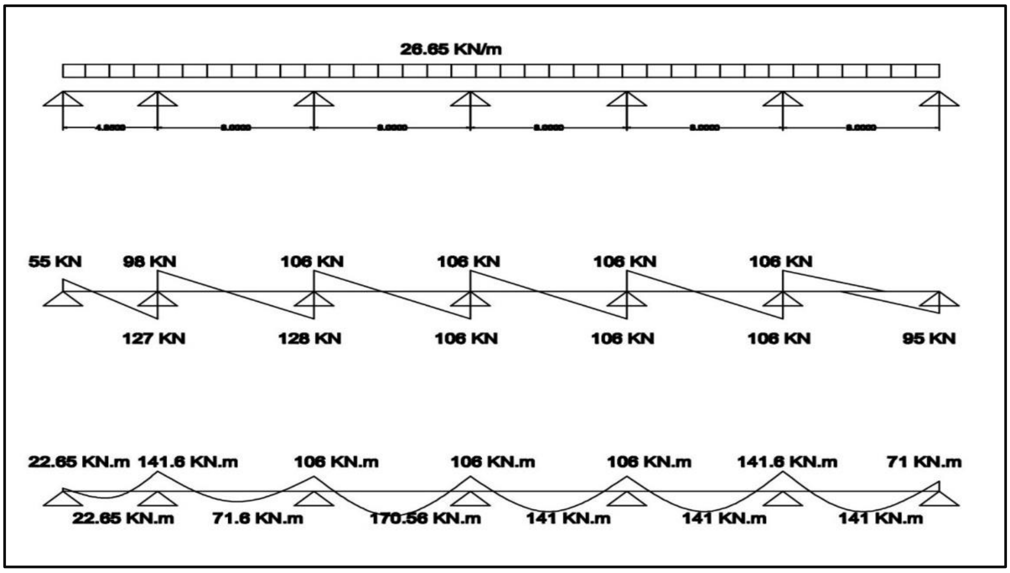


Fig. Beam 2 straining actions

Estimated section : I section 305*165

Straining actions M=170.56

N=11706 kg

Section properties

h=393, b=399 , t_w=22.6 , t_f=36.5 ,

c_f/t_f=4.74 , c_w/t_w=12.8 , I=38677 ,

i=10.3 , A=366 , W_{pl}=2949

$$\alpha = \frac{1}{2}\left(1 + \frac{N_{Ed}}{f_y c\, t_w}\right)$$

$$\psi = \frac{2N_{Ed}}{Af_y} - 1$$

α = 0.5 * (1+ 11726 kg/ (2400 kg/cm2*2.26*39) = 0.53

Ψ = 2*11706 kg/ (366cm2*2400 kg/cm2) -1 = - 0.97

For the steel type S275 the maximum value of C/t for having class number one is obtained by 365/ (13α -1) when the alpha value is more than 0.5. Therefore:

Max C/t = 365/ (13*0.53-1) = 62

For the selected section: C/t = 12.8< 62 → class type one for cross section.

- **Partial factors for resistance**

The partial factors ym should be applied to the various characteristic values of resistance in this section is given as:

Resistance of cross-section whatever the class is: y_{M0} = 1.00
Resistance of members to instability: y_{M1} = 1.00
Resistance of cross-sections in tension to fracture: y_{M2} = 1.10

- **Plastic modulus of the cross section (Wpl)**

W_{pl} = 2949 cm3

- **Buckling resistance**

A compression member should be verified against buckling as follows:

$\frac{N_{Ed}}{N_{b,Rd}} \leq 1.0$ Where:

The design buckling resistance of a compression member should be taken as:

$$N_{b,Rd} = \chi \frac{Af_y}{\gamma_{M1}}$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} \quad \text{but } \chi \leq 1$$

$$\phi = 0.5\left[1 + \alpha\left(\overline{\lambda} - 0.2\right) + \overline{\lambda}^2\right]$$

α is the imperfection factor and could be found from table. For the cross section of

C 40*40   α=a=0.21

Table 23 Imperfection Factor section properties

Buckling curve	a	b	c	d
Imperfection factor α	0.21	0.34	0.49	0.76

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \overline{\lambda}^2}} \text{ but } \chi \leq 1$$

The non-dimensional slenderness λ is given by:

$$\overline{\lambda} = \sqrt{\frac{Af_y}{N_{cr}}}$$

Ncr is the elastic critical force for the relevant buckling mode For flexural, or strut buckling, Ncr is the Euler load, i.e.

$$N_{cr} = \frac{\pi^2 EI}{L^2}$$

Ncr= Π2*E*I/L2=3.142 * 2.04*104*38677/8002 = 12155 Kg

λ = √(366*2400/12155)=8.5

Φ = 0.5* [1+0.21(8.5-0.2) +8.52]=36

X = 0.014<1

Nb,Rd = 0.014 * 400 cm2 *2400 kg/cm2 = 12297.6 kg

$\frac{N_{Ed}}{N_{b,Rd}} \leq 1.0$ ***= 11706/12297.6 = 0.95 < 1.0***   ***O.K***

- **Bending resistance**

MEd=170.56 KN.m= 1739228 Kg.cm

The design buckling resistance of a laterally unrestrained element should be taken as:

$$M_{b,Rd} = \chi_{LT} W_y \frac{f_y}{\gamma_{M1}}$$

X LT is the reduction factor for lateral-torsional buckling.

$$\chi_{LT} = \frac{1}{\phi_{LT} + \sqrt{\phi_{LT}^2 - \beta\bar{\lambda}_{LT}^2}} \quad \text{but } \chi_{LT} \leq 1$$

$$\phi_{LT} = 0.5\left[1 + \alpha_{LT}\left(\bar{\lambda}_{LT} - \bar{\lambda}_{LT,0}\right) + \beta\bar{\lambda}_{LT}^2\right]$$

$$\bar{\lambda}_{LT,0} = 0.4 \text{ for rolled sections} \quad \beta = 0.75 \text{ for rolled sections}$$

$$\bar{\lambda}_{LT} = \frac{L/i_z}{96}$$

ƛ = 0.40

ΦLT = 0.5* [1+0.21*(0.8-.04)+0.75*.0.82] = 0.78

χ = 1/ [0.78+ √(0.78-0.75*0.42)] = 0.62 <1

Mb,Rd = 0.62*2949*2400/1 = 44444601 kg.cm

$M_{ED}/M_{b,RD}$ = 1739228/44444601=0.04 < 1 O.K

- **Allowable stress design Method**

Gyration Radios r_x=r_y= 10.3 ƛ = K*L/r

K: is the effective length factor and for the column of both ends fixed would be 0.5

L: is the length of the column

$ƛ_x$= 0.5*800/10.3 = 38.83

C_c=√ (2∏^2*E/2400) = 6440/√2400=131.5 38.83<131.5

ß= ƛ/Cc = 38.83/131.5 = 0.29 ƛ<Cc → Fa= (1-0.5ß2)/F.s*F_y

F_s = 5/3+3ƛ/8Cc-1/8*(ƛ/Cc) 3= 5/3+3/8*38.83/131.5-1/8* (38.83/131.5)3 = 1.77

F_a = (1-0.5*0.292)/Fs = 531 Kg/cm^2

F_{bx} = 0.6*2400 = 1440 Kg in the case without buckling consideration

Existing stresses:

F_a=P/A=11706/366=32 Kg/cm2 < 530 Kg/cm^2

S=I/y= 38677/19.6=1973 cm^3

f_{bx}=M/S=1739228/1973 = 881.51 Kg/cm^2 O.K (safe section)

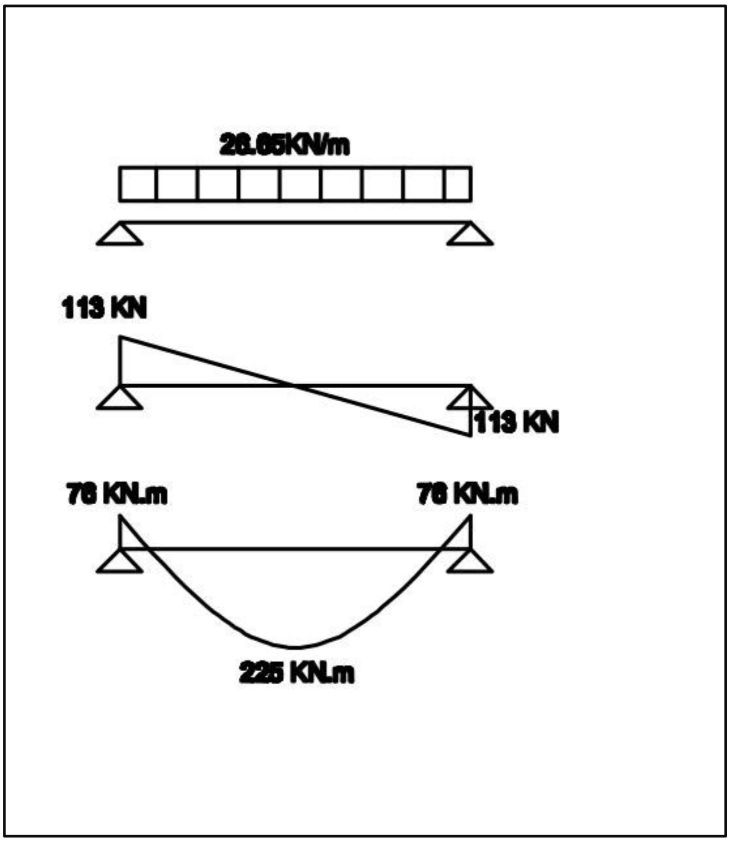


Figure 4-5: Beam 1 straining actions

Estimated section : I section 305*165

Straining actions M=225KN.m = 2294360Kg.cm

N=113 kN= 11530 Kg

α = 0.53

Ψ =- 0.97

$(C/t)_{max}$= 62

Section properties
h=393, b=399 , $t_{w=}$22.6 , t_f=36.5 , c_f/t_f=4.74 , c_w/t_w=12.8 , I=38677 , i=10.3 , A=366 , W_{pl}=2949

For the selected section: C/t = 12.8< 62 → class type one for cross section.

- **Partial factors for resistance**

y_{M0} = 1.00

y_{M1} = 1.00

y_{M2} = 1.10

- **Plastic modulus of the cross section (Wpl)**

W_{pl} = 2949 cm3

- **Buckling resistance**

A compression member should be verified against buckling as follows:

N_{cr}= Π2*E*I/L2=3.142 * 2.04*104*38677/8002 = 12155 Kg

λ = √(366*2400/12155)=8.5

Φ = 0.5* [1+0.21(8.5-0.2) +8.52]=36

X = 0.014<1

$N_{b,Rd}$ = 0.014 * 400 cm^2 *2400 kg/cm^2 = 12297.6 kg

$\frac{N_{Ed}}{N_{b,Rd}} \leq 1.0$ ***= 11530/12297.6 = 0.93 < 1.0*** ***O.K***

4.7.1.3

- **Bending resistance**

M_{Ed}=225KN.m = 2294360Kg.cm

The design buckling resistance of a laterally unrestrained element should be taken as:

ƛ = 0.40

Φ_{LT} = 0.5* [1+0.21*(0.8-.04)+0.75*.0.82] = 0.78

χ = 1/ [0.78+ √(0.78-0.75*0.42)] = 0.62 <1

$M_{b,Rd}$ = 0.62*2949*2400/1 = 4444601 kg.cm

M_{Ed}/M_{bRD} = 2294360/4444601=0.51 < 1 O.K

- **Allowable stress design Method**

Gyration Radios rx=ry= 10.3 ƛ = K*L/r

K: is the effective length factor and for the column of both ends fixed would be 0.5

L: is the length of the column

$ƛ_x$= 0.5*800/10.3 = 38.83

C_c=√ (2∏^2*E/2400) = 6440/√2400=131.5 38.83<131.5

ß= ƛ/C_c = 38.83/131.5 = 0.29 ƛ<Cc → Fa= (1-0.5ß2)/F.s*Fy

F_s = 5/3+3ƛ/8Cc-1/8*(ƛ/Cc) 3= 5/3+3/8*38.83/131.5-1/8* (38.83/131.5)3 = 1.77

F_a = (1-0.5*0.292)/Fs = 531 Kg/cm^2

F_{bx} = 0.6*2400 = 1440 Kg in the case without buckling consideration

Existing stresses:

F_a=P/A=11530/366=31.50 Kg/cm^2 < 530 Kg/cm^2

S=I/y= 38677/19.6=1973 cm^3

f_{bx}=M/S=2294360/1973 = 1162 Kg/cm^2 O.K (safe section)

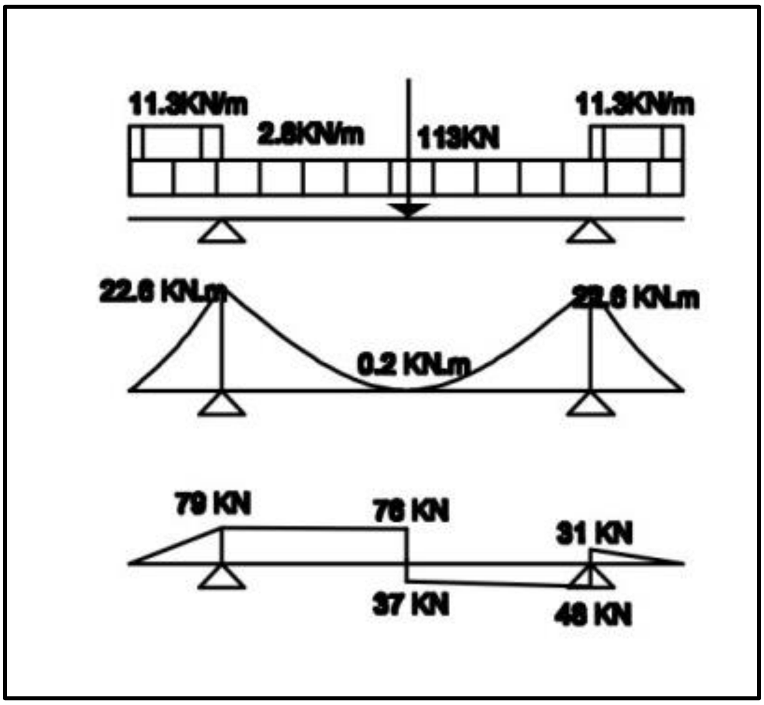


Figure 4-6: Beam 3 straining actions

It was clear that the loads carried by this beam is less than the main beams (beam 1 and beam 2) , but regarding connection details between the beams and the slab, it was decided to use the same section of the main beam to provide a safe connection

4.8 Slab design

Introduction

A composite floor slab is used provided by the manufacturer kingspan with a concrete slab thickness of 140 mm supported by the previously designed steel beams.

Verification is carried on two stages which are composite and non-composite stages

Material properties

Total depth of slab	h = 140 mm
Thickness of steel deck	h_p = 80.5 mm
Span	L = 4 m
Effective cross sectional area	A_{pe} = 1705 mm^2/m
Second moment of area of the profile	I_p = 208 cm^4/m

Yield strength of the profile deck f_{yp} = 350 N/mm^2

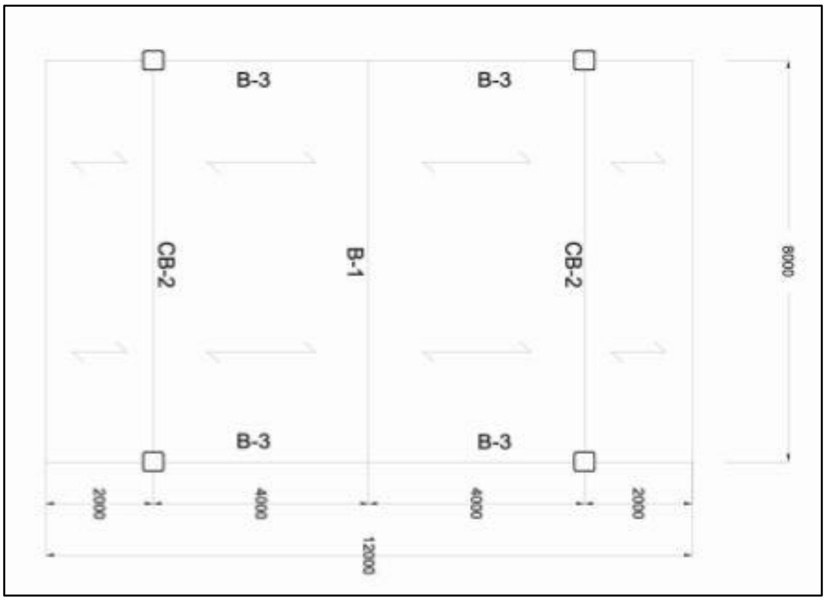


Figure 4-7: Slab Design

- **Cracking of concrete**

To prevent slab cracking , anti-crack reinforcement is needed of cross sectional area of A_s which should not be less than 0.4% of cross sectional area of unproped concrete over the steel deck which finally gets one layer of a steel mesh consists of eight steel bars of 10mm diameter in each direction

- **Deflection**

For an internal span of a continuous slab the vertical deflection maybe determined using the following approximations:

• the second moment of area may be taken as the average of the values for the cracked and un-cracked section;

• for concrete, an average value of the modular ratio, n, for both long-term and short-term effects may be used.

The slabs in the projects are considered as a one way slabs, hence it transferring the load in one direction to the main beam

From another perspective regarding our sustainable approach in design, traditional concrete slabs were prevented and multideck slab were used to provide

- Concrete volume savings
- Quicker installation
- Value for money
- Small thickness

Due to its profile it requires less concrete than normal traditional solutions, it has a wider standard cover width requiring fewer panels and side laps so it provides no temporary supports before casting as well as ensuring a lower prices slab regarding the low amount of concrete and steel required

On the other hand the multideck slab is not providing wide spans which was considered during applying the steel beams grid, so the grid applied achieves a span less than 5.4 m which was the maximum span for the section used.

- **Specification and design**

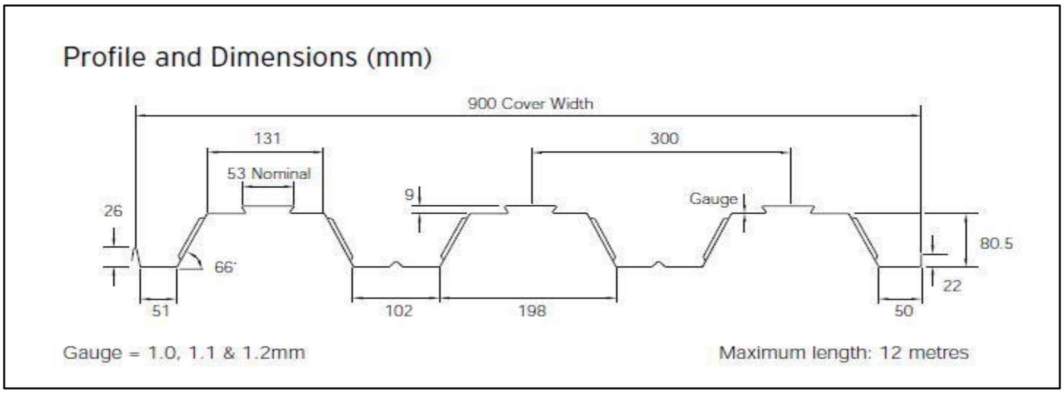


Figure 4-8: Specification of steel deck

Section Properties per Metre Width

Normal Thickness (mm)	Self Weight		Height to Neutral Axis	Second Moment of Area (cm⁴/m)	Steel Area (mm²/m)	Ultimate Moment Capacity (kNm/m)	
	(kg/m²)	(kN/m²)	Sagging			Sagging	Hogging
1.00	11.49	0.113	42.50 mm	171.3	1413.00	12.62	9.94
1.10	12.64	0.124	43.10 mm	190.6	1560.00	14.39	11.33
1.20	13.83	0.136	45.00 mm	208.6	1705.33	16.42	12.73

Figure 4-9: section properties

Load/Span Table (Steel - 350N/mm²)

Span Type (Support Condition)	Slab Depth (mm)	Min Mesh Size	Gauge = 1.0 Total Applied Load (kN/m²) SLS 4.0	6.0	8.0	10.0	12.0	14.0
	130	A142	4.03	3.90	3.70	3.28	2.98	2.75
	140	A142	3.93	3.93	3.92 3.93	3.48 3.86	3.16 3.51	2.91 3.24
	150	A142	3.84	3.84	3.84	3.66 3.84	3.32 3.70	3.06 3.41
	160	A142	3.75	3.75	3.75	3.75	3.49 3.75	3.21 3.58
	175	A142	3.65	3.65	3.65	3.65	3.65	3.42 3.65
	200	A193	3.45	3.45	3.45	3.45	3.45	3.45
	250	A252	3.16	3.16	3.16	3.16	3.16	3.16
	130	A142	4.53	4.31	3.70	3.28	2.98	2.75
	140	A142	4.39	4.39	3.92 4.29	3.48 3.86	3.16 3.51	2.91 3.24
	150	A142	4.26	4.26	4.13 4.26	3.66 4.08	3.32 3.70	3.06 3.41
	160	A142	4.15	4.15	4.15	3.84 4.15	3.49 3.89	3.21 3.58
	175	A142	3.99	3.99	3.99	3.99	3.72 3.99	3.42 3.82
	200	A193	3.76	3.76	3.76	3.76	3.76	3.75 3.76
	250	A252	3.40	3.40	3.40	3.40	3.40	3.40

Figure 4-10: Load/span Table

Design value of sagging bending resistance M_{Rd} = 16.42 KNm/m

Height to neutral axis = 45 mm

Normal concrete strength class C25/30

Density of normal weight , reinforced 26 KN/m^3 (wet)

25 KN/m^3 (dry)

Self-weight of concrete slab = 0.136 * 26 = 3.536 KN/m^2

= 0.136 * 25 = 3.4 KN/m^2

Permanent actions

Composite stage : the load is: concrete slab(3.4 KN/m^2)+ steel deck(0.18 KN/m^2) = 3.58 KN/m^2

Variable actions

Imposed floor load = 2.64 KN/m^2

Ultimate Limit State (ULS)

Partial factor for permanent actions y_G = 1.35

Partial factor for variable actions y_Q = 1.5

Reduction factor ξ = 0.925

Combinations of actions at ULS

Design value of combined actions = (ξ * y_G*g_k) +(y_Q*q_k)

(0.925*1.35*3.58) + (1.5*2.64) = 8.43 KN/m2

Design moment and shear force

M_{ed} = F_d*L2 / 8 = 8.43*42/8 = 16.86 KNm/m width

V_{Ed} = F_d* L / 2 = 8.43*4/2 = 16.86 KN/m

Partial factors for resistance

Structural steel	y_{MO} = 1.0
Concrete	y_C = 1.5
Reinforcement	y_S = 1.25
Longitudinal shear	y_{VS} = 1.25

Design values of material strengths

Steel deck

Design yeild strength $f_{YP,d}$ = 350 N/mm^2

Concrete

Design value of concrete compressive strength $f_{cd} = \alpha_{cc} * f_{ck} / y_C$

α_{cc} = 0.85

f_{cd} = 0.85 * 25 / 1.5 = 14.2 N/mm2

Verification of composite slab

Ultimate Limit State (ULS)

Bending resistance – location of plastic neutral axis (pna)

Maximum compressive design force per meter in the concrete above the steel deck assuming the location of plastic neutral axis is below the solid part of the slab is determined as:

$N_c = f_{cd}A_c$ = 14.2 * 105 * 1000 * 10-3 = 1491 KN/m

Maximum tensile resistance per meter of the profiled steel sheet is determined as:

$N_p = f_{YP,d}A_p$ = 350 * 1705 * 10-3 = 596.75 KN/m

Since Np < Nc , therefore neutral axis lies above the profiled steel deck

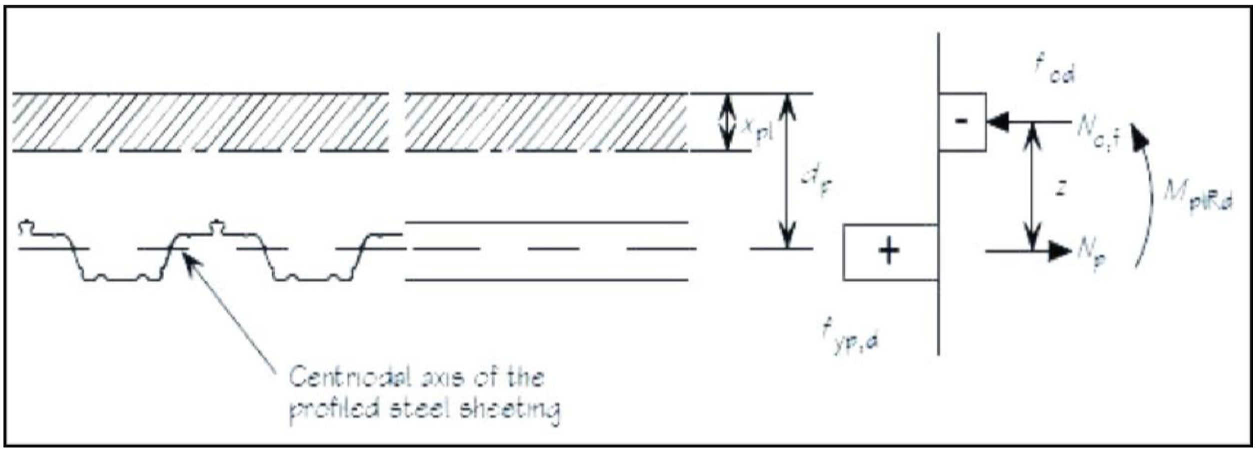


Figure 4-11: neutral axe calculation

The depth of concrete in compression is:

$$x_{pl} = \frac{A_{pe} f_{yp,d}}{b f_{cd}}$$

where:

b is the width of the floor slab being considered, here;

$b =$ 1000 mm

X_{pl} = 1701 * 350 / 1000 * 14.2 = 41.9 mm

Bending resistance – full shear connection

For full shear connection, the design moment resistance is:

$M_{pl,Rd} = A_p F_{yd}(d_p - x_{pl}/2)$

d_p = 140-60 = 80 mm

The plastic bending resistance per metre width of the slab is:

$M_{pl,Rd}$ = 1701*350*(80-41.9/2) = 35.37 KNm/m

M_{Ed} / $M_{pl,Rd}$ = 16.86/35.37 = 0.48 < 1.0 (OK)

Longitudinal shear resistance:

Design resistance to longitudinal shear ($V_{l,Rd}$) is given by

$$V_{l,Rd} = \frac{b d_p}{\gamma_{vs}} \left(\frac{m A_p}{b L_s} + k \right)$$

m = 160 N/mm^2

k = 0.125 N/mm^2

L_s = 4000/4 = 1000 mm

$V_{l,Rd}$ = (1000*80/1.25) * (160*1701/1000*1000 + 0.125)*10-3 = 25.42 KN/m

V_{Ed} = 16.86 KN/m

V_{Ed}/ $V_{l,Rd}$ = 16.86/25.42 = 0.66 < 1 OK

Longitudinal shear resistance:

Vertical shear resistance Vv,Rd is given by

$$V_{v,Rd} = \left(v_{min} + k_1 \sigma_{cp} \right) b_s d_p$$

For simplicity of calculations, assume Ϭcp = 0

$V_{v,Rd}$=V_{min}.*b_s*d_p

$$v_{min} = 0.035 k^{3/2} f_{ck}^{1/2}$$

$$\text{where } k = 1 + \sqrt{200/d_p} \le 2.0$$

V_{min}=0.49 N/mm2

$V_{v,Rd}$= 0.49*80 = 39.2 KN/m > 16.86 KN/m OK

4.9 Design of beam to column end plate bolted-welded connection

Categories of bolted connections

Shear connections

(1) -Bolted connections loaded in shear should be designed as one of the following:

a) Category A: Bearing type

In this category bolts from class 4.6 up to and including class 10.9 should be used. No preloading and special provisions for contact surfaces are required. The design ultimate shear load should not exceed the design shear resistance, obtained from 3.6, nor the design bearing resistance, obtained from 3.6 and 3.7.

b) Category B: Slip-resistant at serviceability limit state

In this category preloaded bolts should be used. Slip should not occur at the serviceability limit state. The design serviceability shear load should not exceed the design slip resistance, obtained from 3.9. The design ultimate shear load should not exceed the design shear resistance, obtained from 3.6, nor the design bearing resistance, obtained from 3.6 and 3.7.

c) Category C: Slip-resistant at ultimate limit state

In this category preloaded bolts should be used. Slip should not occur at the ultimate limit state. The design ultimate shear load should not exceed the design slip obtained from nor the design bearing resistance, obtained from 3.6 and 3.7. In addition for a connection in tension, the design plastic resistance of the net cross-section at bolt holes 6.2 of EN 1993-1-1), should be checked, at the ultimate limit state.

The design checks for these connections are summarized in Table 3.2.

Tension connections

(1)-Bolted connection loaded in tension should be designed as one of the following:

a) Category D: non-preloaded

In this category bolts fro111 class 4.6 up to and including class 10.9 should be used. No preloading is required. This category should not be used where the connections are frequently subjected to variations of tensile loading. However, they may be used in connections designed to resist normal wind loads.

b) Category E: preloaded

In this category preloaded 8.8 and 10.9 bolts with controlled tightening in conformity with 1.2.7

Reference Standards: Group 7 should be used.

Table 24 Bolts categories

Category	Criteria	Remarks
Shear connections		
A bearing type	$F_{v,Ed} \leq F_{v,Rd}$ $F_{v,Ed} \leq F_{b,Rd}$	No preloading required. Bolt classes from 4.6 to 10.9 may be used.
B slip-resistant at serviceability	$F_{v,Ed,ser} \leq F_{s,Rd,ser}$ $F_{v,Ed} \leq F_{v,Rd}$ $F_{v,Ed} \leq F_{b,Rd}$	Preloaded 8.8 or 10.9 bolts should be used. For slip resistance at serviceability see 3.9.
C slip-resistant at ultimate	$F_{v,Ed} \leq F_{s,Rd}$ $F_{v,Ed} \leq F_{b,Rd}$ AC2 $\sum F_{v,Ed} \leq N_{net,Rd}$ AC2	Preloaded 8.8 or 10.9 bolts should be used. For slip resistance at ultimate see 3.9. $N_{net,Rd}$ see 3.4.1(1) c).
Tension connections		
D non-preloaded	$F_{t,Ed} \leq F_{t,Rd}$ $F_{t,Ed} \leq B_{p,Rd}$	No preloading required. Bolt classes from 4.6 to 10.9 may be used. $B_{p,Rd}$ see Table 3.4.
E preloaded	$F_{t,Ed} \leq F_{t,Rd}$ $F_{t,Ed} \leq B_{p,Rd}$	Preloaded 8.8 or 10.9 bolts should be used. $B_{p,Rd}$ see Table 3.4.
The design tensile force $F_{t,Ed}$ should include any force due to prying action, see 3.11. Bolts subjected to both shear force and tensile force should also satisfy the criteria given in Table 3.4.		

- **Components of the connection**

Column: Box section 400*400*25 mm

Beam I-beam section 305*165*22.6 mm S275 steel

F_y=275 N/mm^2 Fu=410 N/mm^2

h_o=399 mm t_w=22.6 mm t_f=36.5mm

for the plate F_u=410 N/mm^2

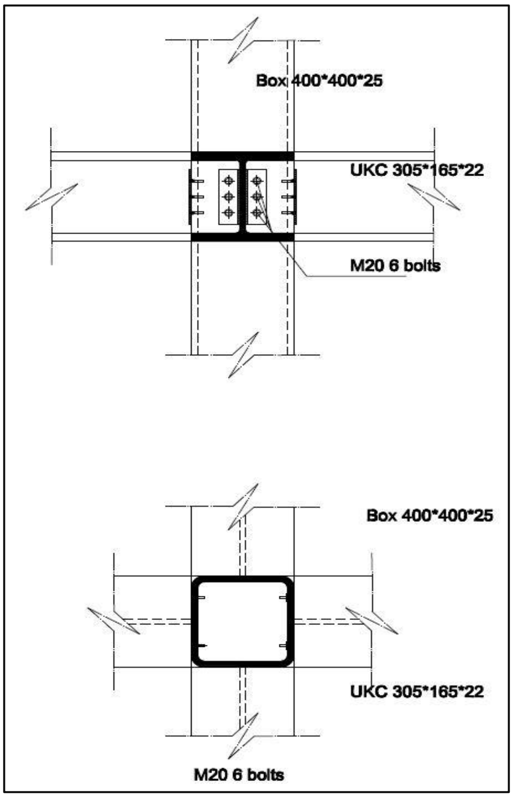


Figure 4-12: connection details

$$V_{cRd} \approx \frac{h_b \times t_w \times \left(f_y / \sqrt{3} \right)}{\gamma_{MO}}$$

V_{crd}=(399*22.6*275/√3)/1*10^{-3} = 1431 KN

Design shear force at ULS V_{ed}= 128 KN

V_{ed}<0.75* V_{crd}

Hence; partial end plate is proposed

Hb<500 mm   Therefore 8 mm end plate is proposed

End plate depth= 0.6*h_b= 240 mm

Assuming six M20 bolts

- **Bolt Details**

Bolts are Anchor bolts M20 grade 5.8 60mm long.

Tensile stress area of bolt	$A_s = 245\ mm^2$
Diameter of the holes	$d_0 = 22\ mm$
Diameter of the washer	$d_w = 37\ mm$
Yield strength	$f_{yb} = 400\ N/mm^2$
Ultimate tensile strength	$f_{ub} = 500\ N/mm^2$

Table 25 bolt spacing allowable

Distances and spacings, see Figure 3.1	Minimum	Maximum[1) 2) 3)]		
		Structures made from steels conforming to EN 10025 except steels conforming to EN 10025-5		Structures made from steels conforming to EN 10025-5
		Steel exposed to the weather or other corrosive influences	Steel not exposed to the weather or other corrosive influences	Steel used unprotected
End distance e_1	$1{,}2d_0$	$4t + 40$ mm		The larger of $8t$ or 125 mm
Edge distance e_2	$1{,}2d_0$	$4t + 40$ mm		The larger of $8t$ or 125 mm
Distance e_3 in slotted holes	$1{,}5d_0$ [4)]			
Distance e_4 in slotted holes	$1{,}5d_0$ [4)]			
Spacing p_1	$2{,}2d_0$	The smaller of $14t$ or 200 mm	The smaller of $14t$ or 200 mm	The smaller of $14t_{min}$ or 175 mm
Spacing $p_{1,0}$		The smaller of $14t$ or 200 mm		
Spacing $p_{1,i}$		The smaller of $28t$ or 400 mm		
Spacing p_2 [5)]	$2{,}4d_0$	The smaller of $14t$ or 200 mm	The smaller of $14t$ or 200 mm	The smaller of $14t_{min}$ or 175 mm

1) Maximum values for spacings, edge and end distances are unlimited, except in the following cases:
- for compression members in order to avoid local buckling and to prevent corrosion in [AC2) exposed members (the limiting values are given in the table) and; (AC2]
- for exposed tension members [AC2) to prevent corrosion (the limiting values are given in the table). (AC2]

2) The local buckling resistance of the plate in compression between the fasteners should be calculated according to EN 1993-1-1 using $0{,}6\ p_1$ as buckling length. Local buckling between the fasteners need not to be checked if p_1/t is smaller than $9\,\varepsilon$. The edge distance should not exceed the local buckling requirements for an outstand element in the compression members, see EN 1993-1-1. The end distance is not affected by this requirement.

3) t is the thickness of the thinner outer connected part.

4) The dimensional limits for slotted holes are given in 1.2.7 Reference Standards: Group 7.

5) For staggered rows of fasteners a minimum line spacing of $p_2 = 1{,}2d_0$ may be used, provided that the minimum distance, L, between any two fasteners is greater or equal than $2{,}4d_0$, see Figure 3.1b).

Minimum end distance e_1=1.2*22.6= 27.12 mm = 30 mm

Minimum edge distance e_2=1.2*22.6= 27.12 mm =30 mm

Maximum edge and end distance = 4t+40 mm = 4*22.6 + 40 = 130.4 mm

Minimum spacing = 2.2 do= 2.2*22.6= 50 mm

Maximum spacing 14t = 316.4 mm or 200 mm

e_1= e_2 = 50 mm P = 70 mm

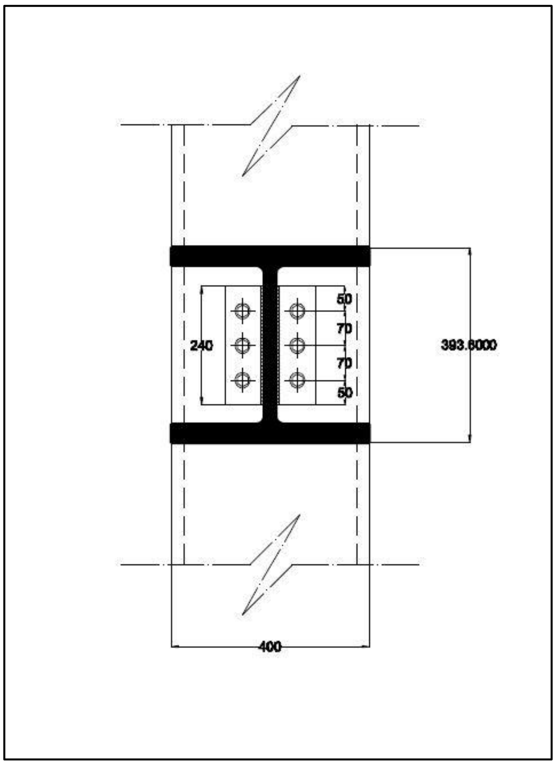


Figure 4-13: bolts spacing

- **Weld design**

For full strength side welds.

a>= 0.39 tw 0.39*22.6= 8.814 mm

a=0.7*Leg length a= 9mm Leg = 13 mm

Partial factors of resistance

yM0 = 1.00

yM1 = 1.25 (for shear)

yM2 = 1.10 (for bolts in tension)

The connection detail must be ductile to meet the design requirement that it behaves as nominally pinned. For the UK, and based on SN014, the ductility requirement is satisfied if the supporting element (column flange in this case) or the end plate,

$$t_p \le \frac{d}{2.8}\sqrt{\frac{f_{u,b}}{f_{y,p}}} \quad \text{or} \quad t_{f,c} \le \frac{d}{2.8}\sqrt{\frac{f_{u,b}}{f_{y,c}}}$$

Tp=25/2.8*√500/275 = 12 mm.

Therefore : ductility is ensured , use plate of 8 mm thickness

- **Joint shear resistance**

The following table gives the complete list of design resistances that need to be determined for the joint shear resistance. Only the critical checks are shown in this example. The critical checks are denoted with an * in the table. Because a full strength weld has been provided, no calculations for the weld are required.

Table 26 modes of failure

Mode of failure	
Bolts in shear*	$V_{Rd,1}$
End plate in bearing*	$V_{Rd,2}$
Supporting member (column) in bearing	$V_{Rd,3}$
End plate in shear (gross section)	$V_{Rd,4}$
End plate in shear (net section)	$V_{Rd,5}$
End plate in block shear	$V_{Rd,6}$
End plate in bending	$V_{Rd,7}$
Beam web in shear*	$V_{Rd,8}$

- **Bolts in shear**

Assuming the shear plane passes through the threaded portion of the bolt, the shear resistance Fv,Rd of a single bolt is given by:

$$F_{v,Rd} = \frac{\alpha_v f_{ub} A}{\gamma_{M2}}$$

Fv,Rd=0.6*500*245*10^{-3}/1.25 = 58.8 KN

For 6 bolts V_{Rd1} = 6*58.8 = 352.8 KN

- **End plate in bearing**

The bearing resistance of a single bolt, Fb,Rd is given by:

$$F_{b,Rd} = \frac{k_1 \alpha_b f_{u,p} d t_p}{\gamma_{M2}}$$

$$k_1 = \min\left(2.8\frac{e_2}{d_o} - 1.7; 2.5\right)$$

K = 2.8*50/25 – 1.7 = 3.9 > 2.5

Therefore k = 2.5

$$\alpha_b = \min\left(\alpha_d; \frac{f_{u,b}}{f_{u,p}}; 1.0\right)$$

α_b = 500/410 = 1.21

For calculation simplifying α = 1

Fb.Rd = 2.5*1*410*25*8*10^{-3}/1.25 = 164 KN

For inner and end bolts , Fb.Rd is the same = 164 KN

for 6 bolts = 6*164 = 984 KN

- **Beam web in shear**

Shear resistance is checked only for the area of the beam web connected to the end plate

The design plastic shear resistance is given by:

$$V_{pl,Rd} = V_{Rd,8} = \frac{A_v(f_{y,b}/\sqrt{3})}{\gamma_{M0}}$$

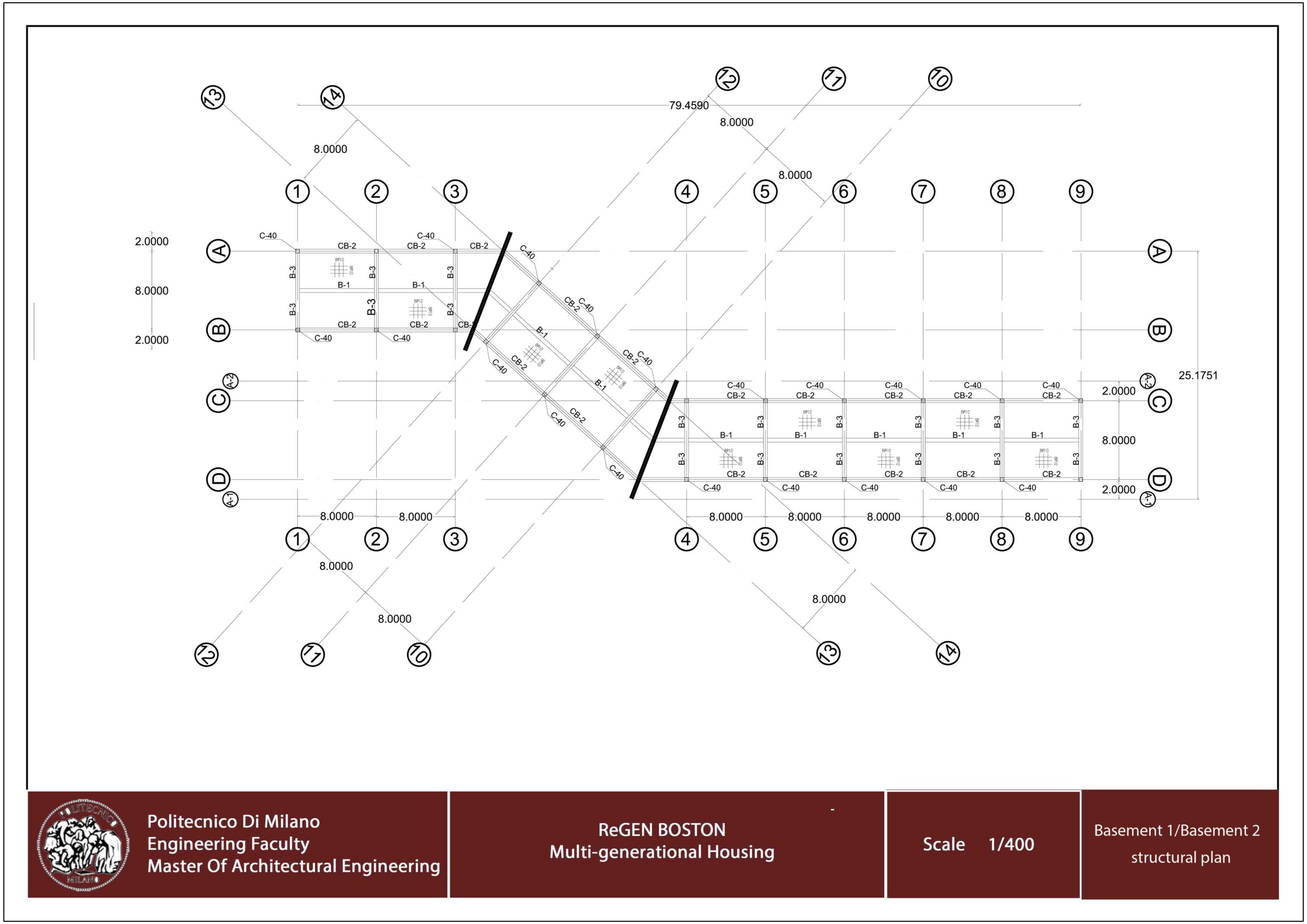
$V_{pl,Rd} = V_{Rd3} = 260*22.6*275/\sqrt{3} *10^{-3} = 932$ KN

The governing value among V_{Rd} values , is the least one which must exceed $V_{Ed} = 128$ KN which is the value of V_{Rd1} bolts in shear = 352.8 KN > 128 KN

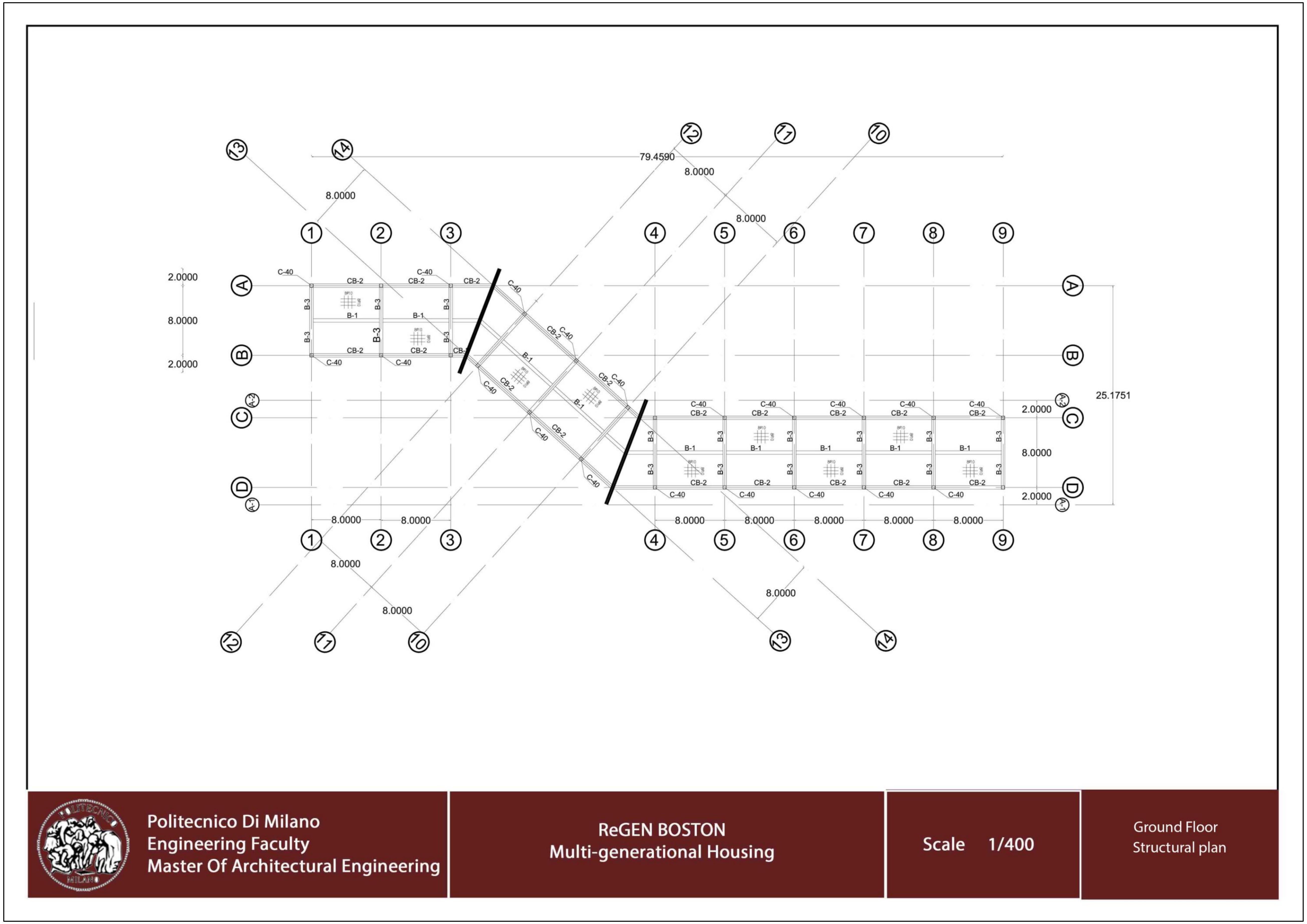
(Safe connection).

4.10 STRUCTURAL DRAWINGS:

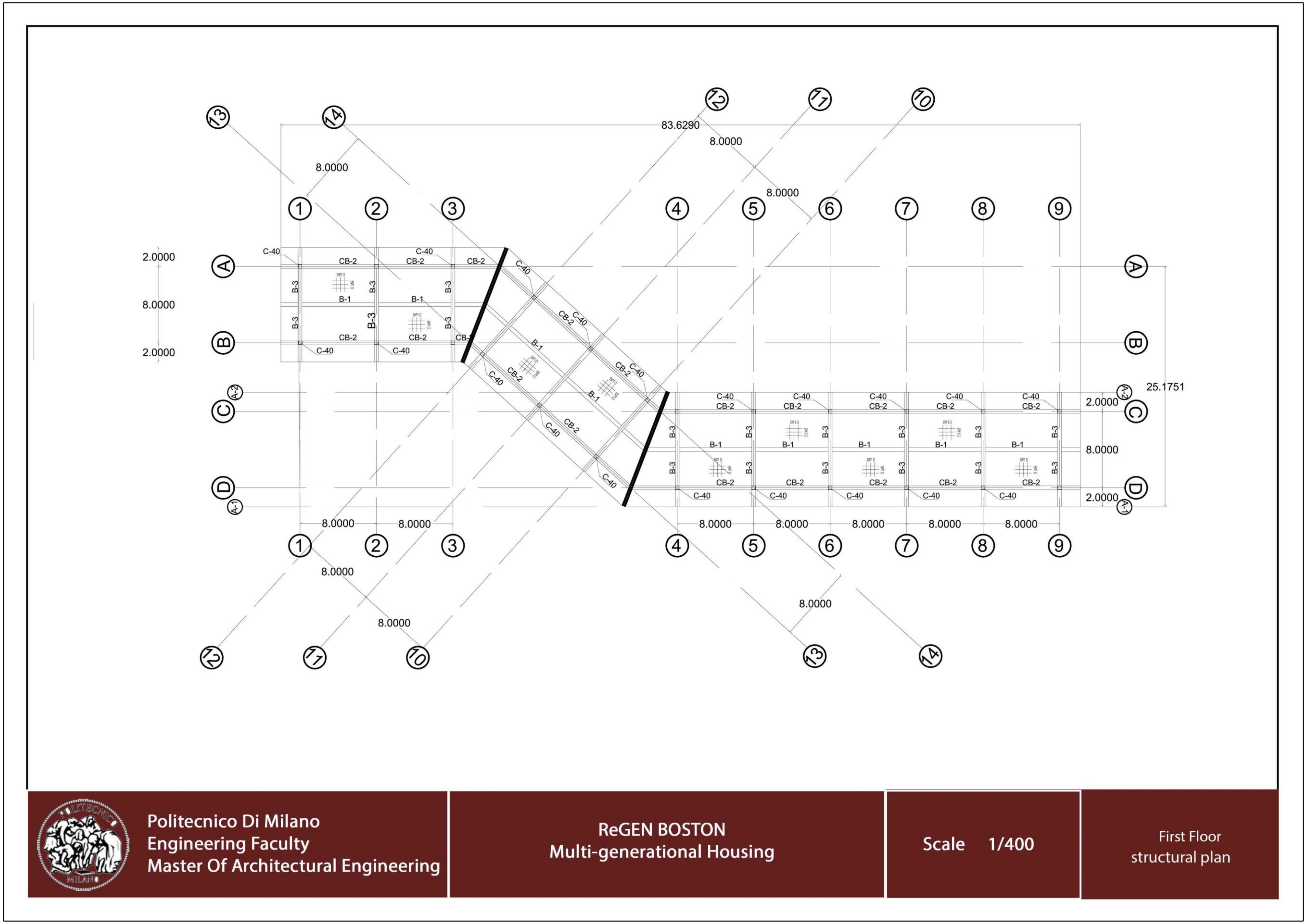
Note: Refer to the following pages for all the detailed structural drawings.



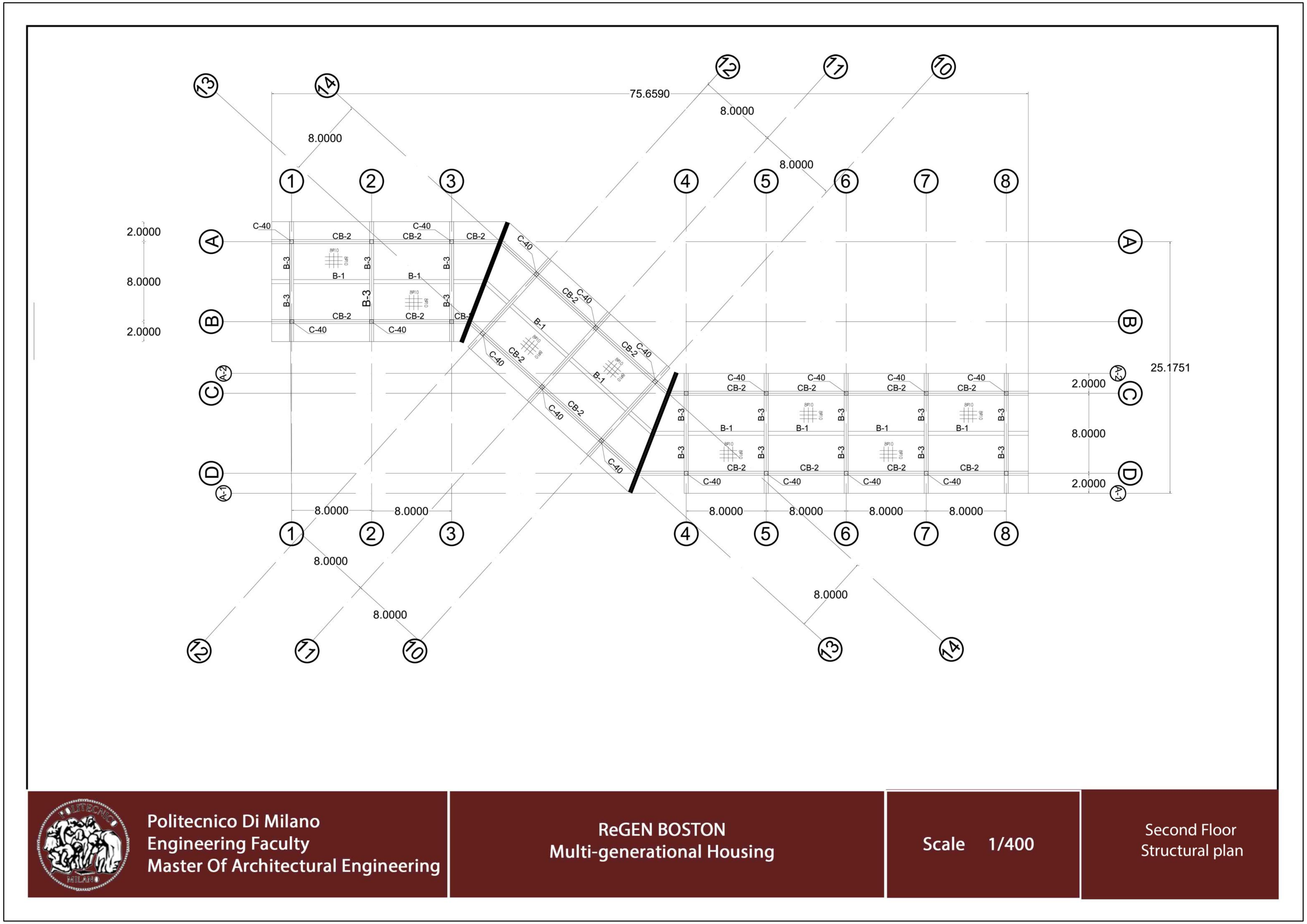
STR-DRAWING 1 BASEMENT1/2



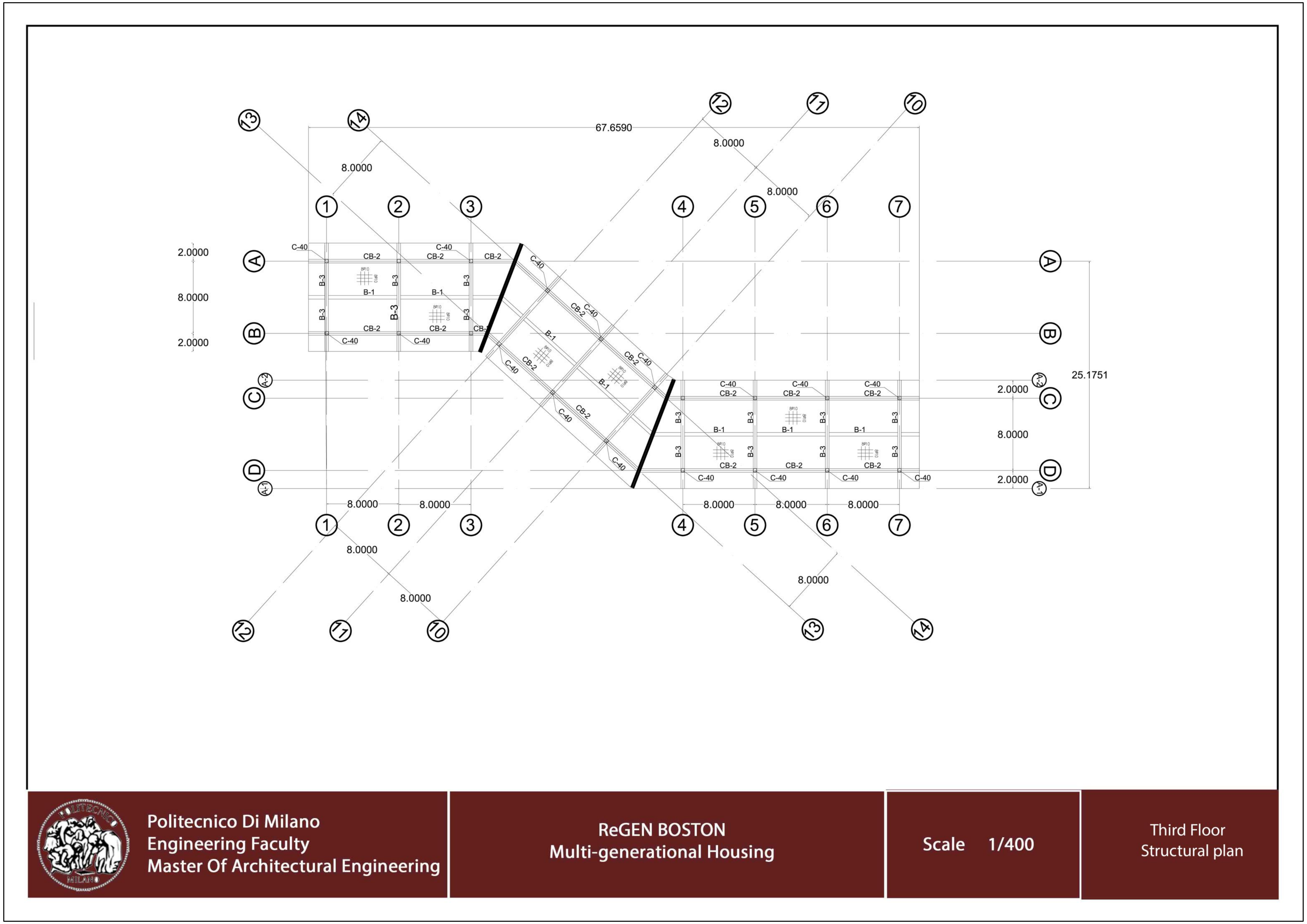
STR-DRAWING 2: GROUND FLOOR



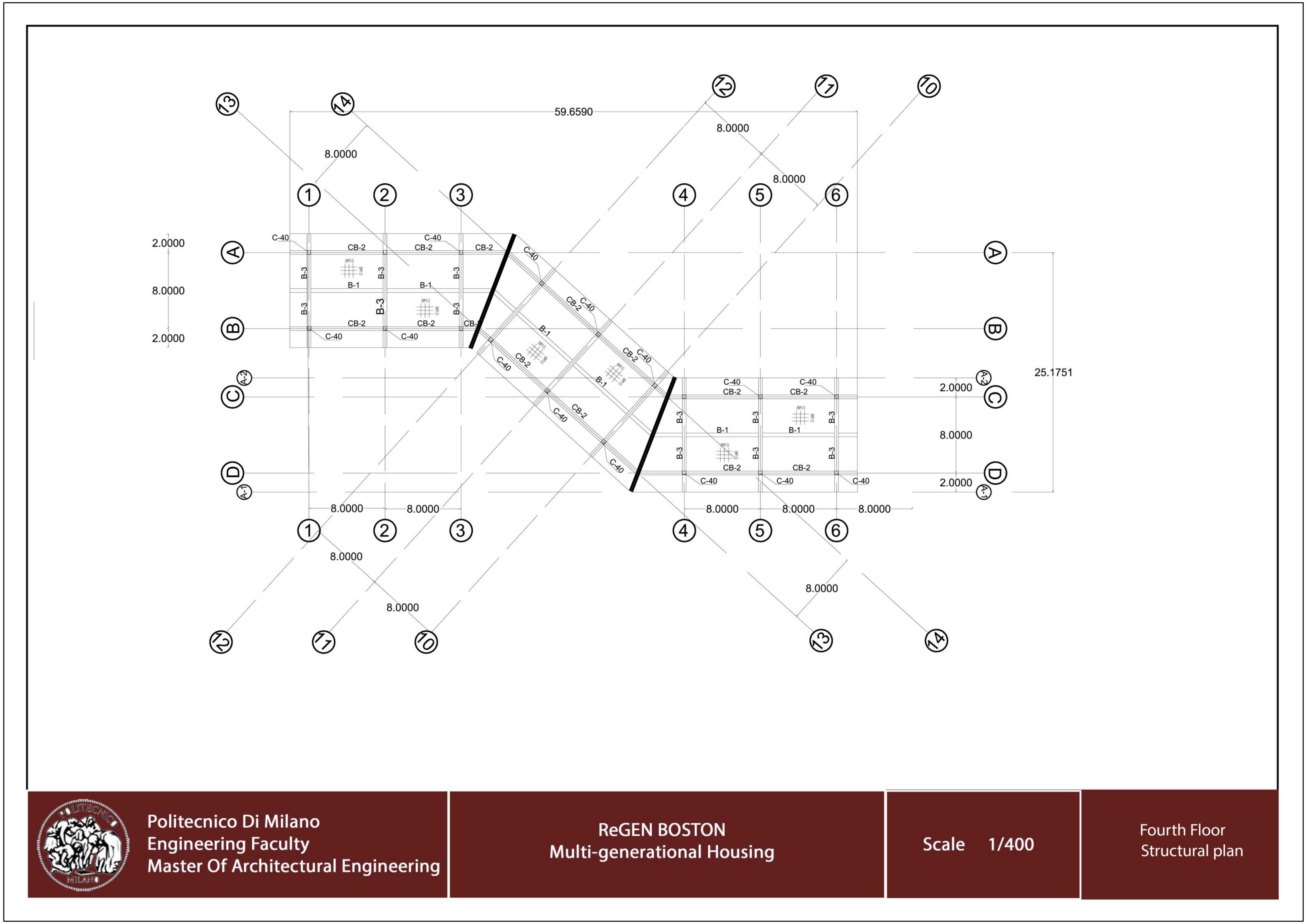
STR-DRAWING 3 : FIRST FLOOR



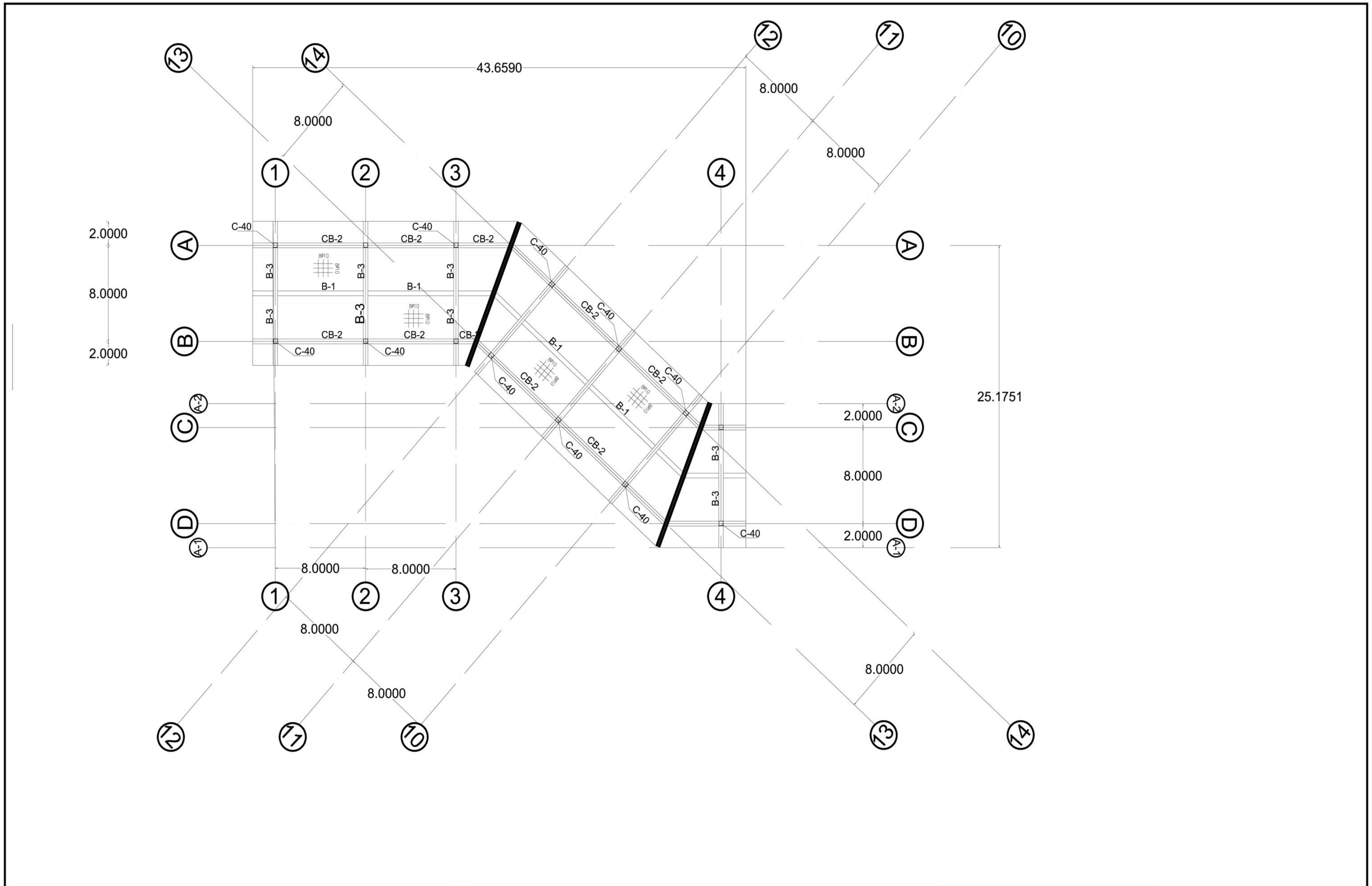
STR-DRAWING 4: SECOND FLOOR



STR-DRAWING 5: THIRD FLOOR



STR-DRAWING 6: FOURTH FLOOR



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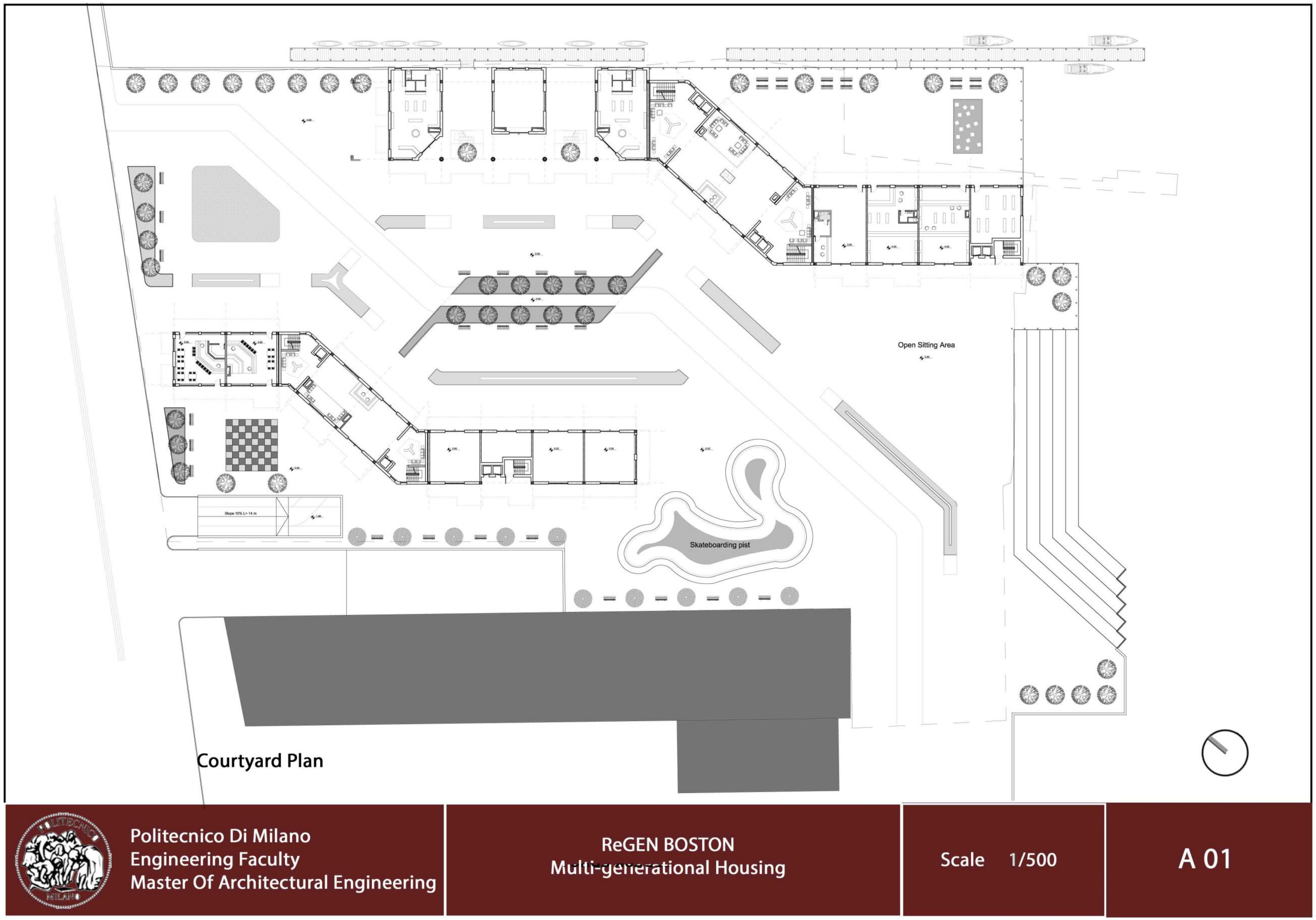
Fifth Floor
Structural plan

STR-DRAWING 7: FIFTH FLOOR

ARCHITECTURAL DRAWINGS

Back to Chapter 2: ARCHITECTURAL DESIGN



ARCH. DRAWING 1: Courtyard Plan

First Basement Level

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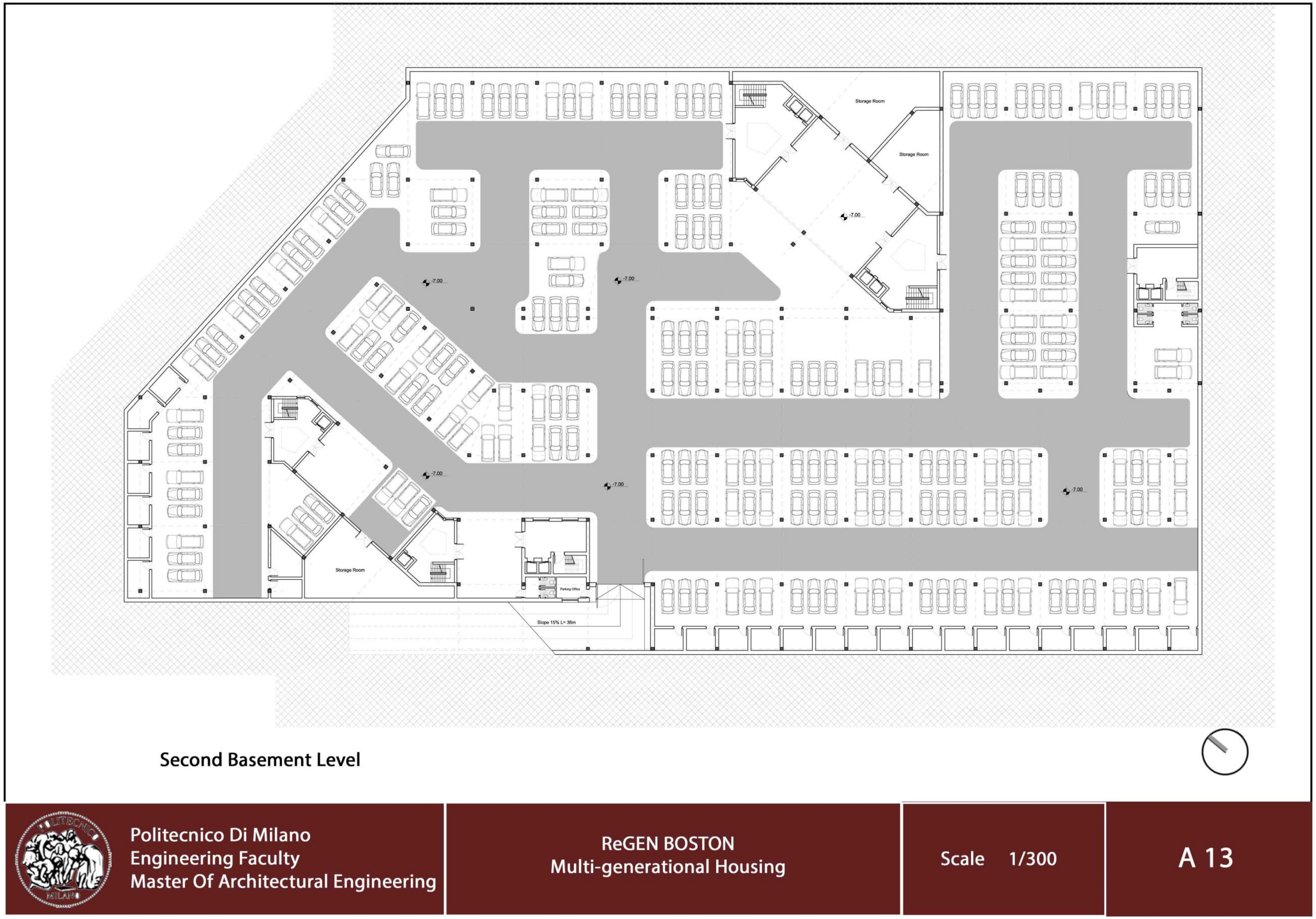
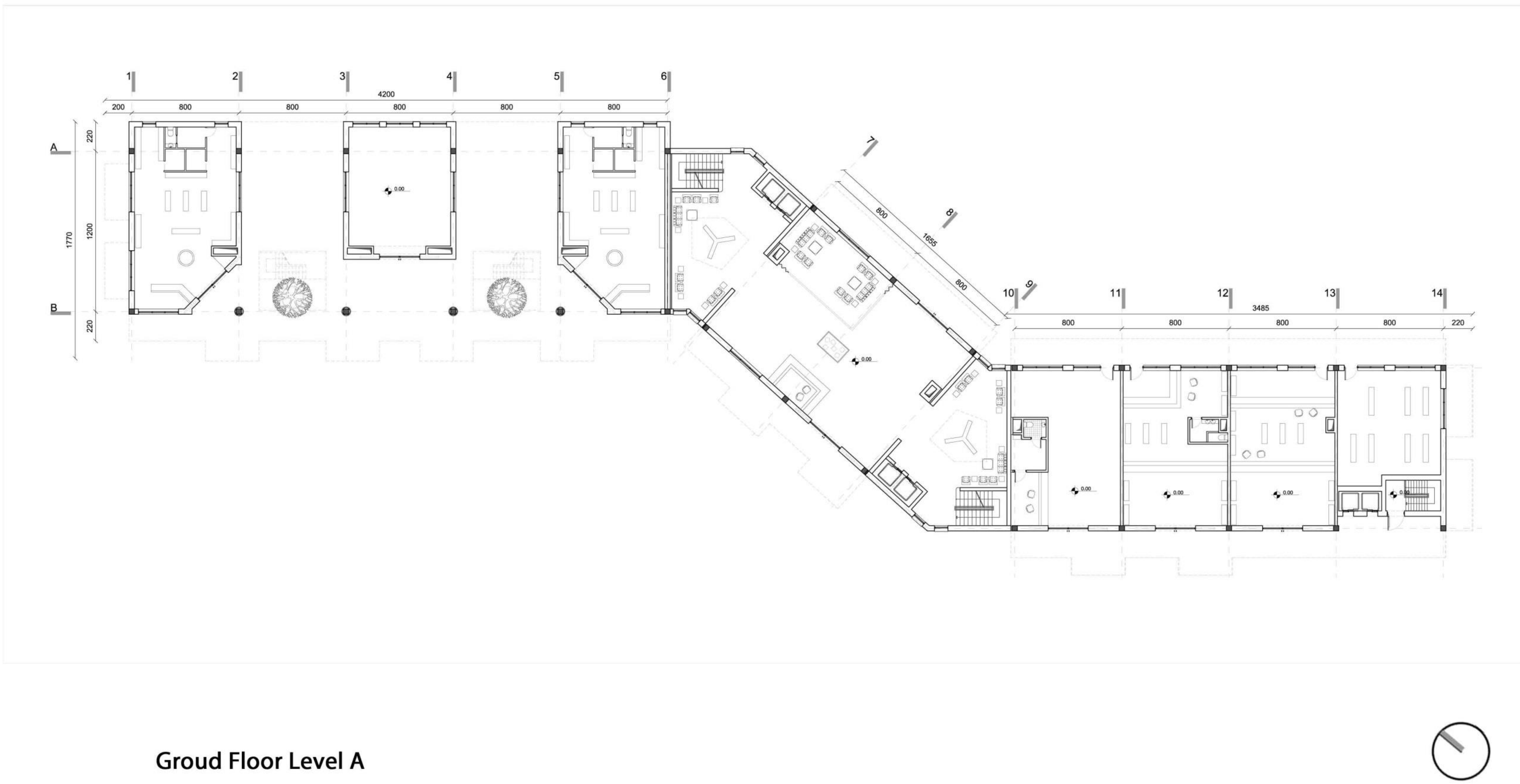
ARCH. DRAWING 2: First Basement Level



ARCH. DRAWING 3: Second Basement Level



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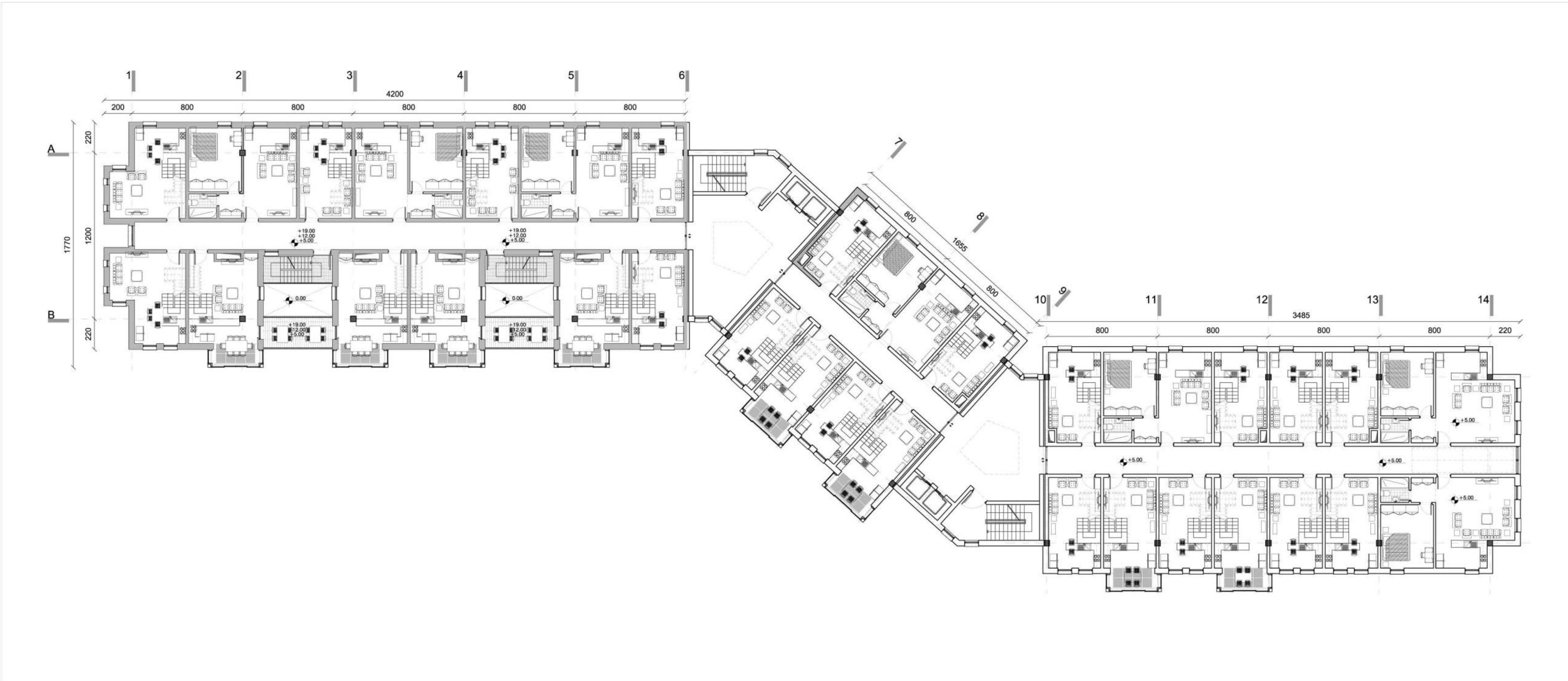
Scale 1/300

A 02

ARCH. DRAWING 4: Ground Floor Level A



First Floor Plan A

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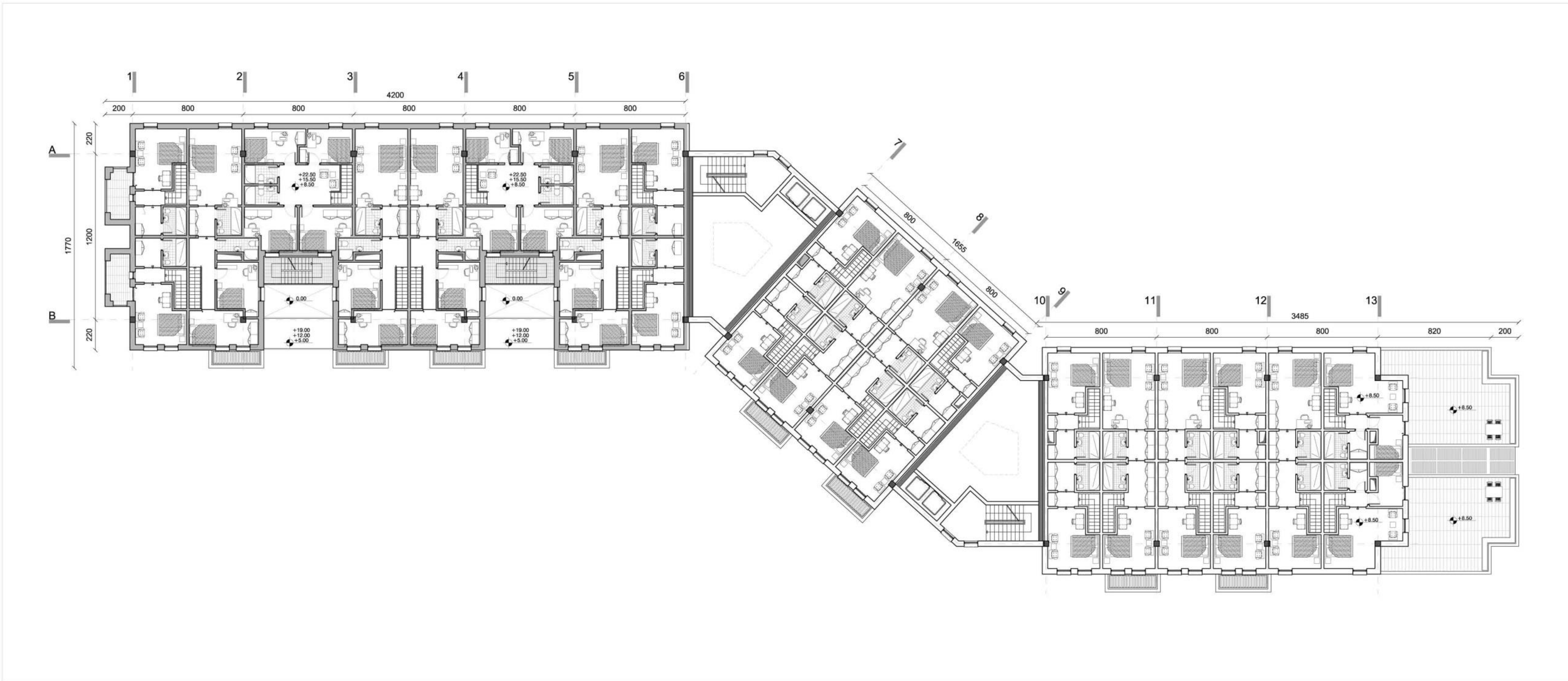
A 03

ARCH. DRAWING 5: First Floor Plan A



Second Floor Plan A

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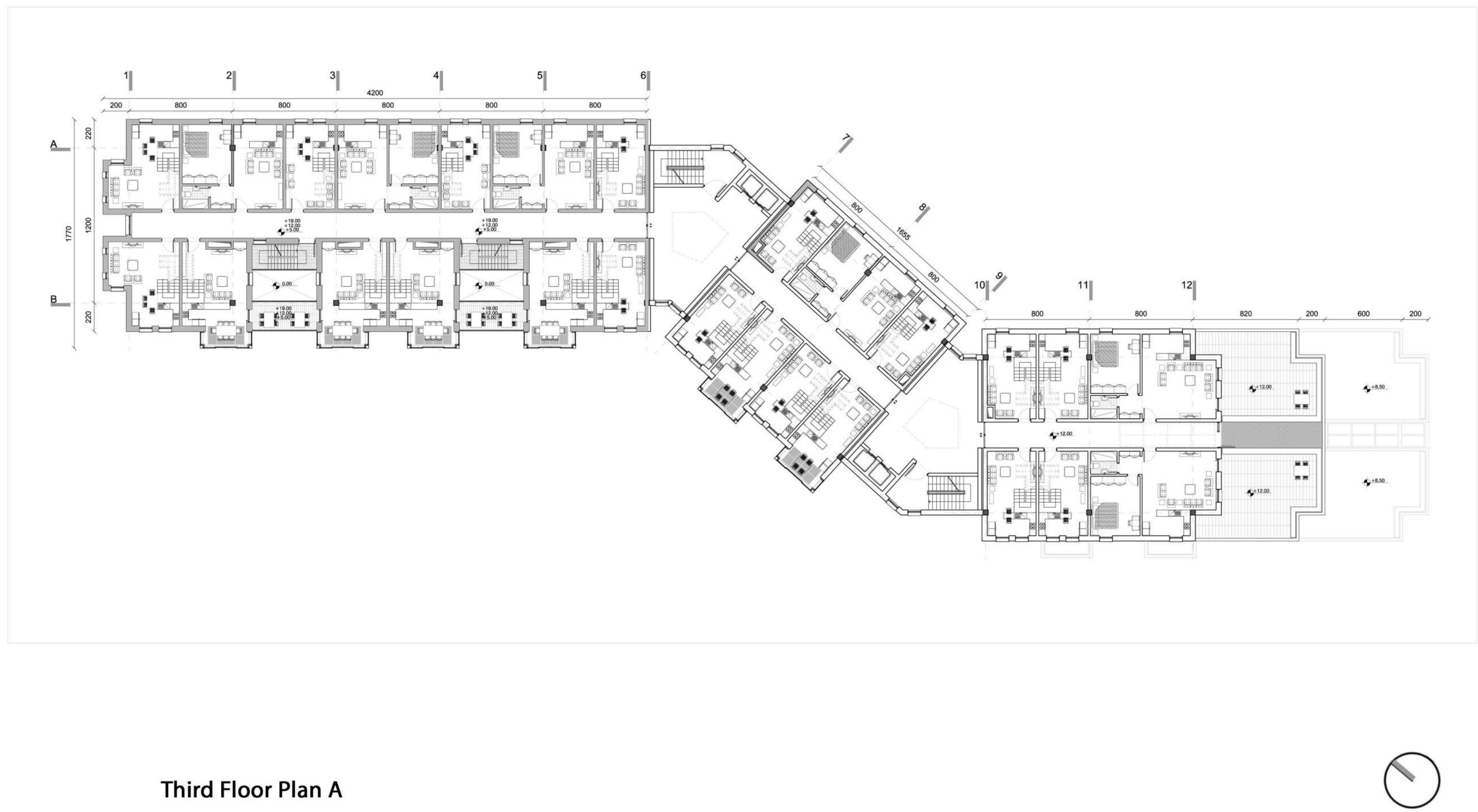
A 04

ARCH. DRAWING 6: Second Floor Plan A



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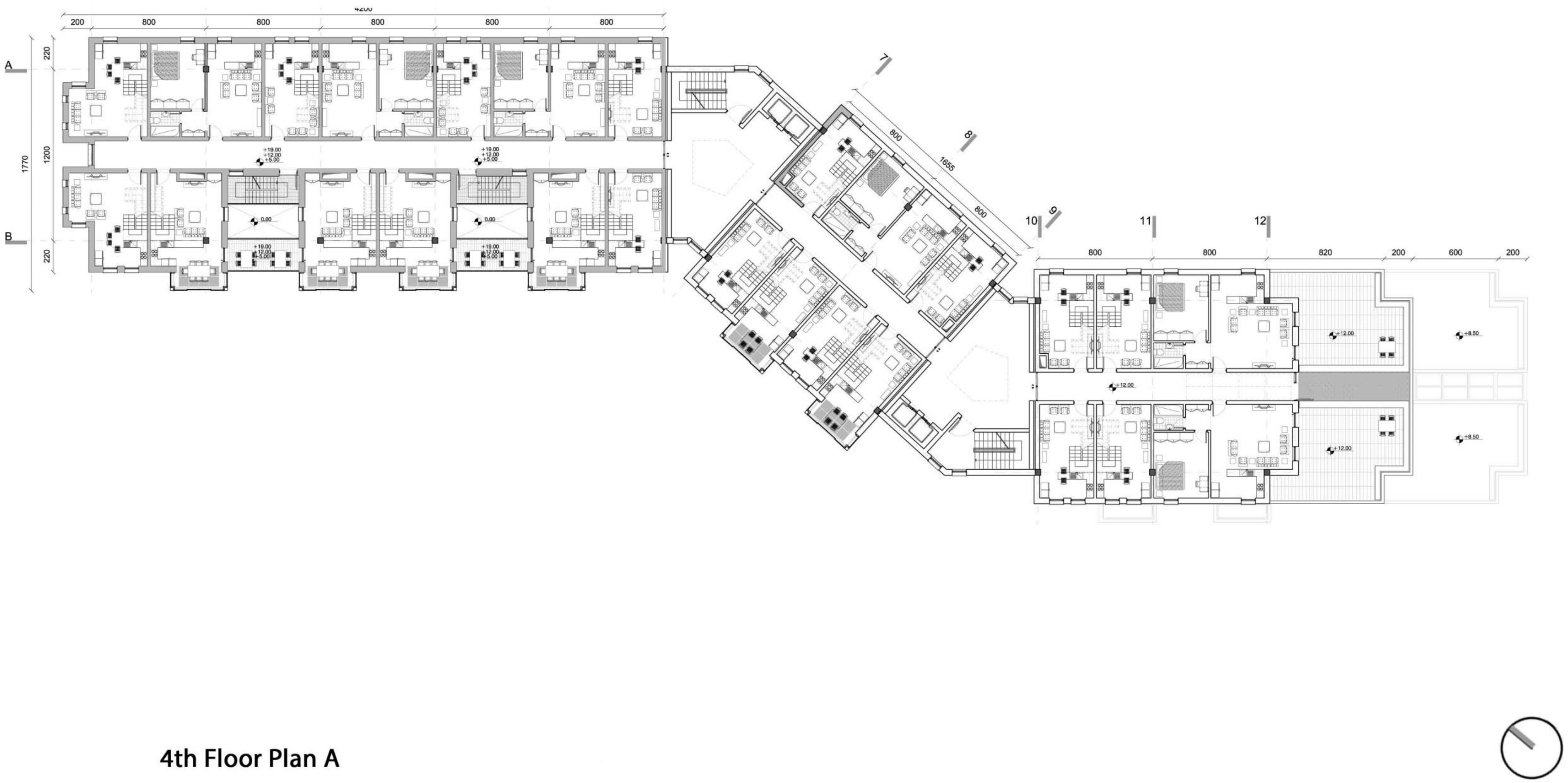
A 05

ARCH. DRAWING 7: Third Floor Plan A



4th Floor Plan A

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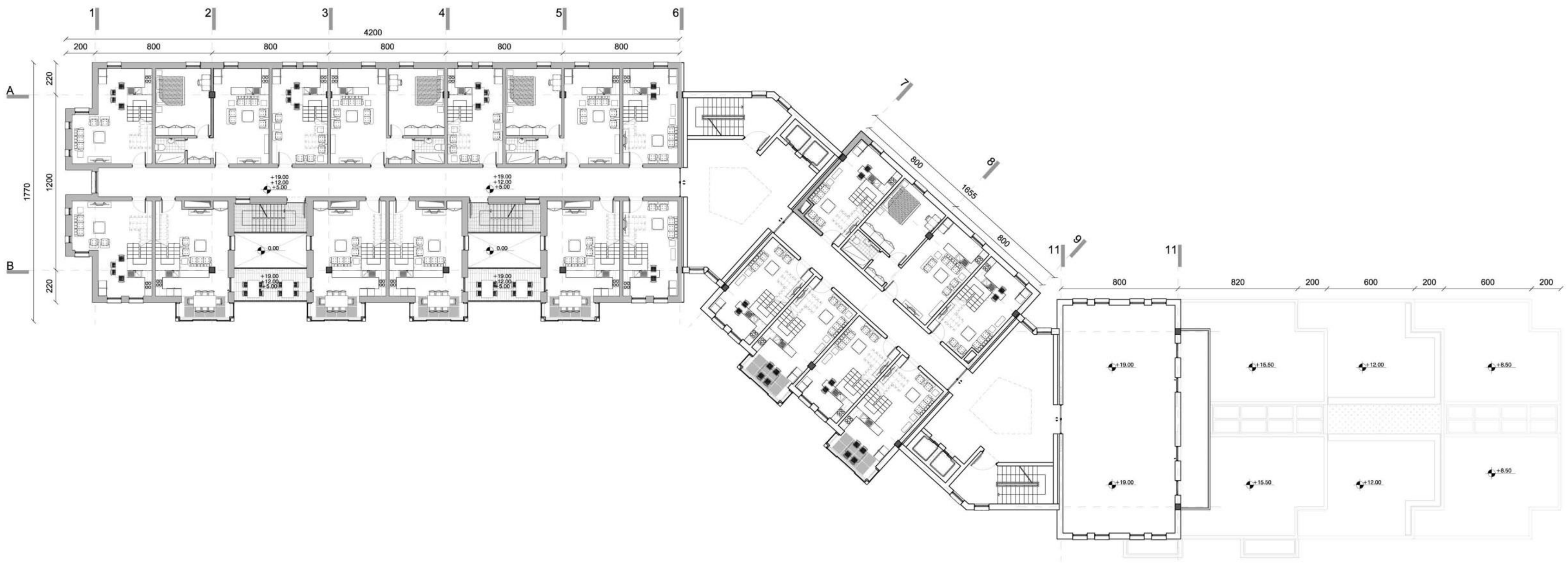
ARCH. DRAWING 8: 4th Floor Plan A



5th Floor Plan A

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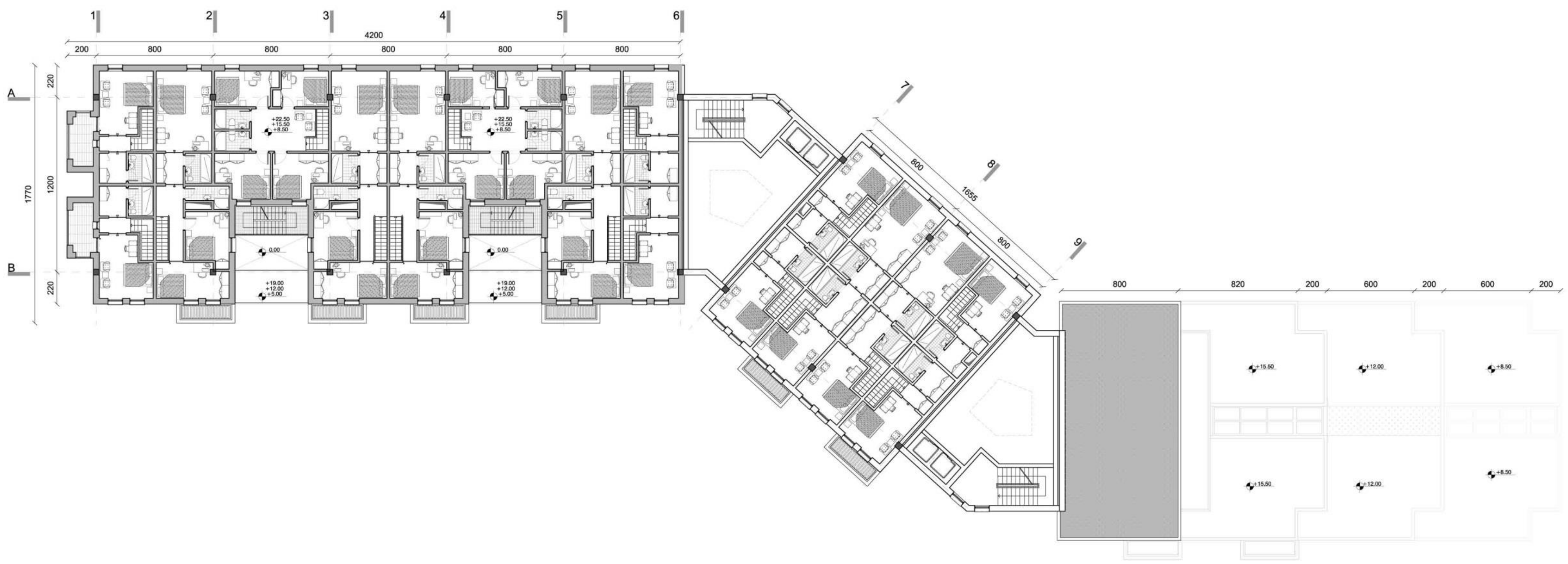
Scale 1/300

A 07

ARCH. DRAWING 9: 5th Floor Plan A



6th Floor Plan A

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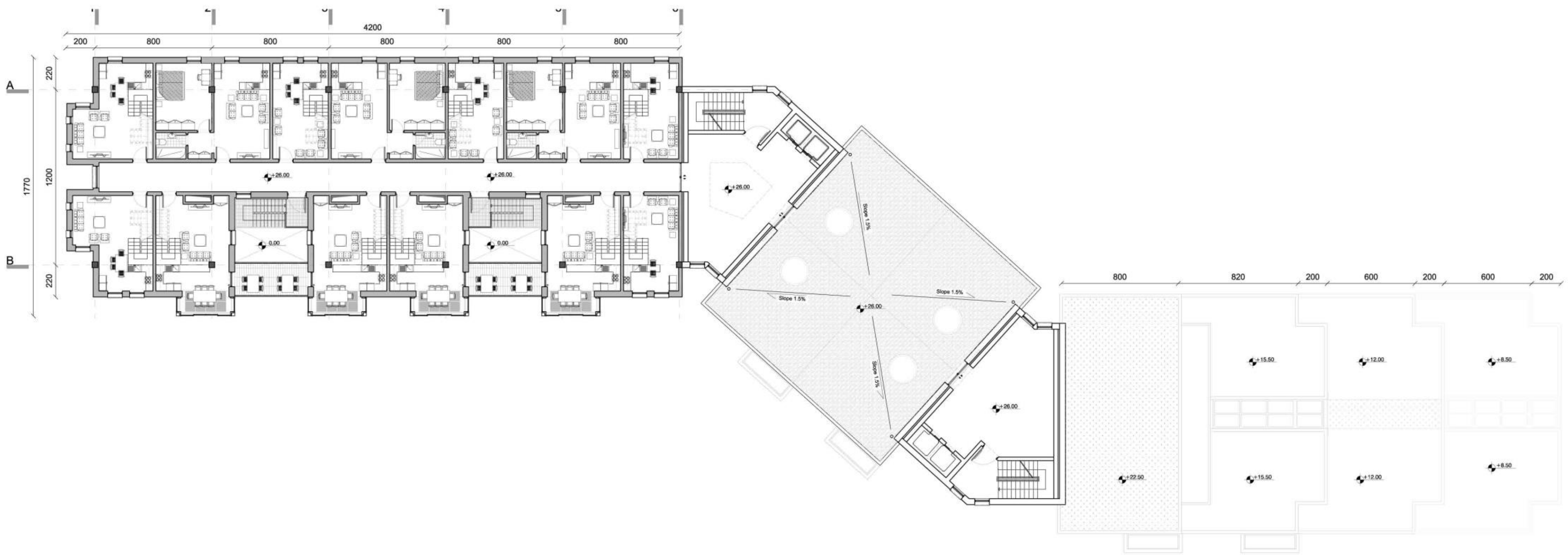
Scale 1/300

A 08

ARCH. DRAWING 10: 6th Floor Plan A



7th Floor Plan A

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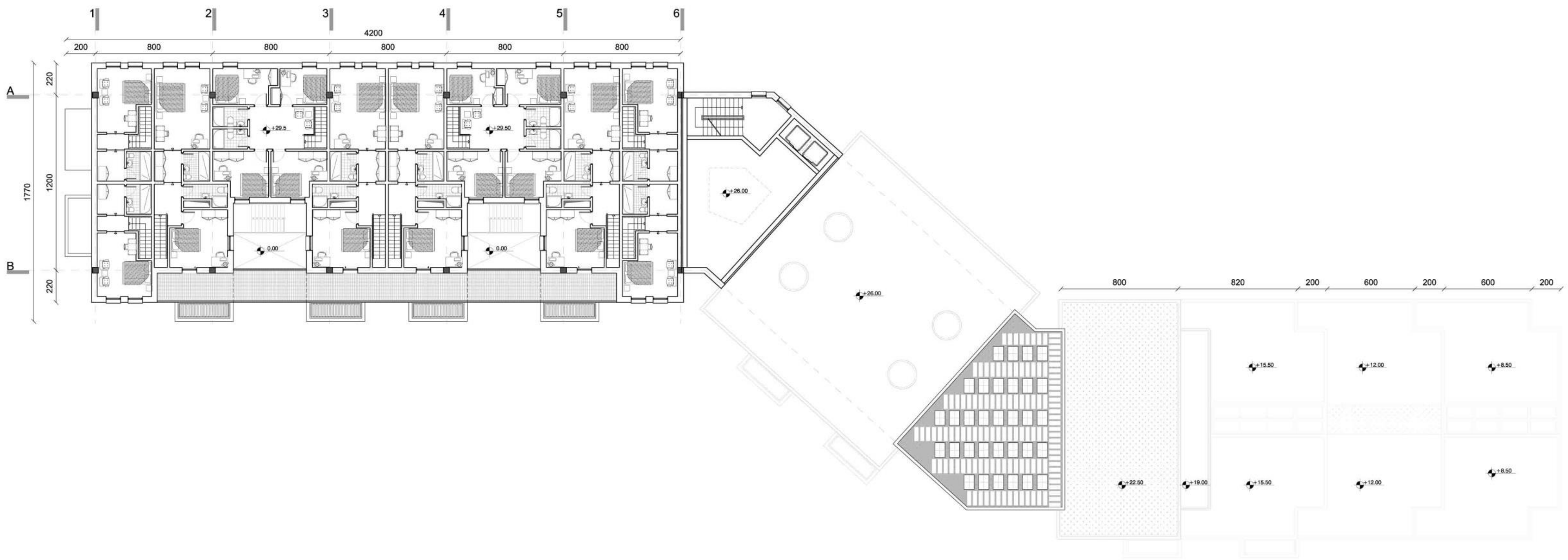
A 16

ARCH. DRAWING 11: 7th Floor Plan A



8th Floor Plan A

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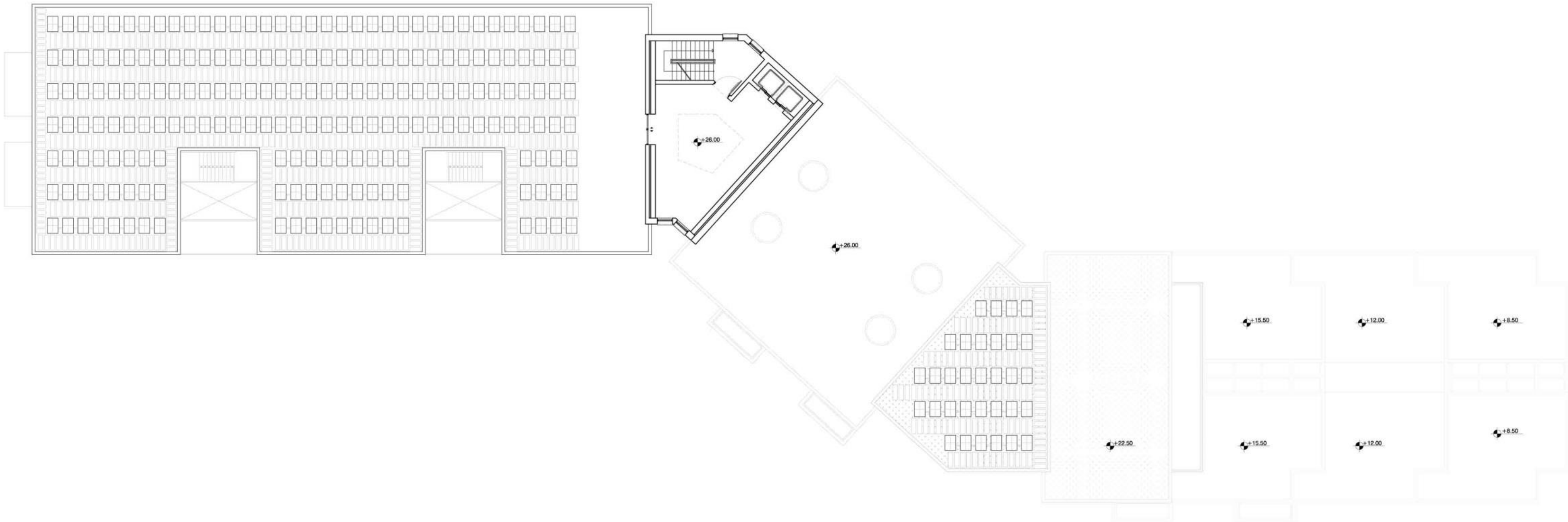
A 10

ARCH. DRAWING 12: 8th Floor Plan A



Roof Floor Plan A

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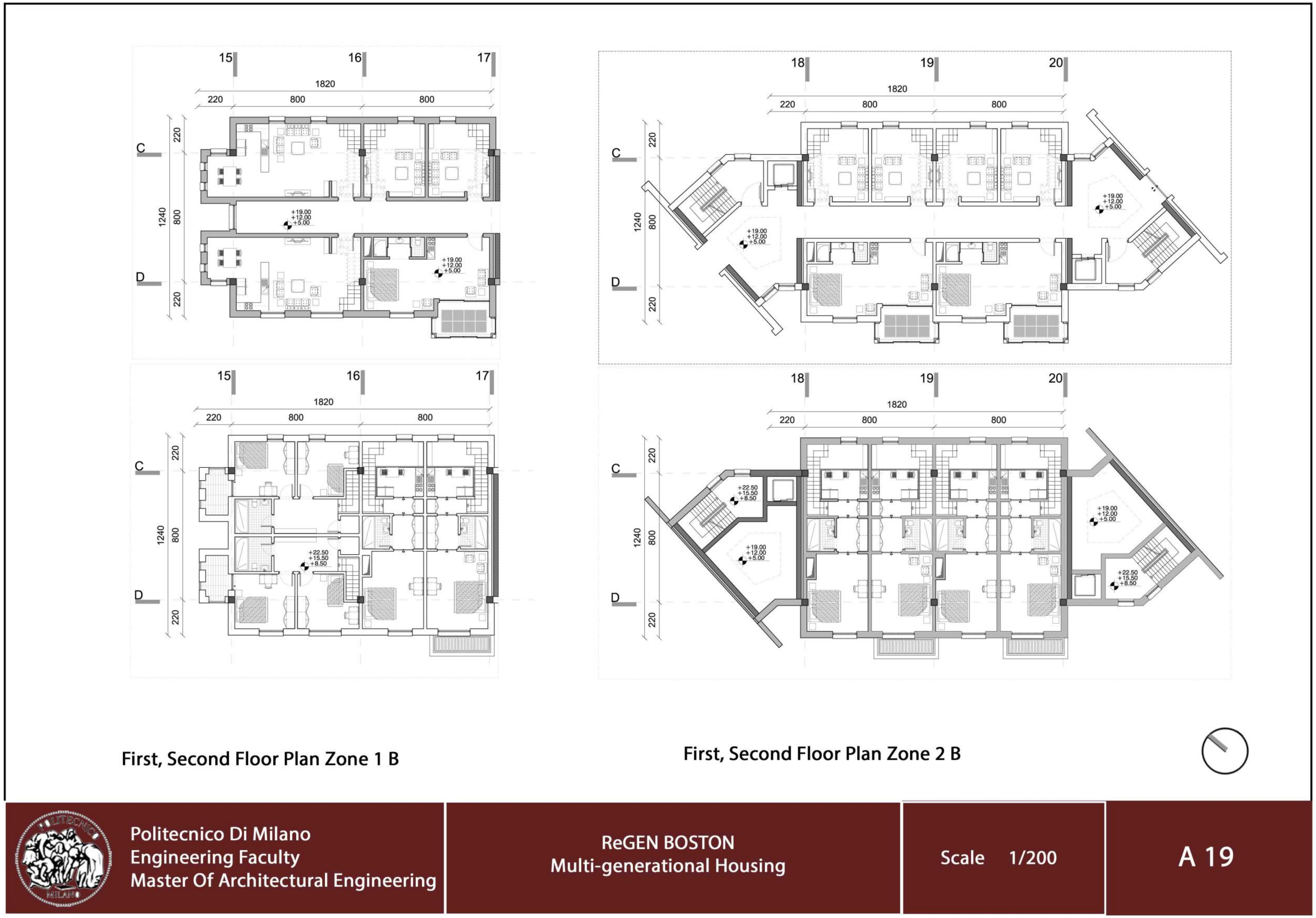
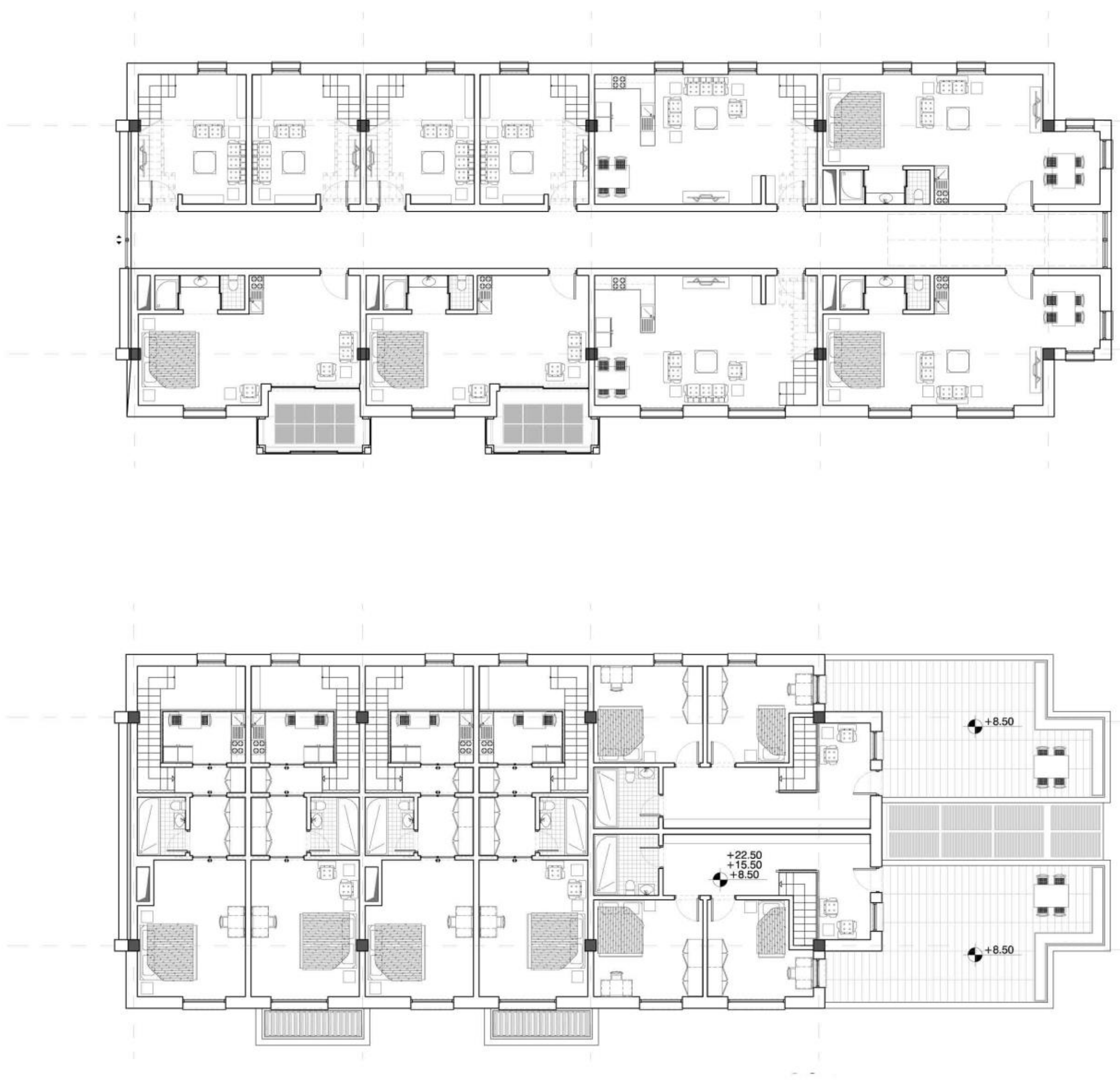
A 11

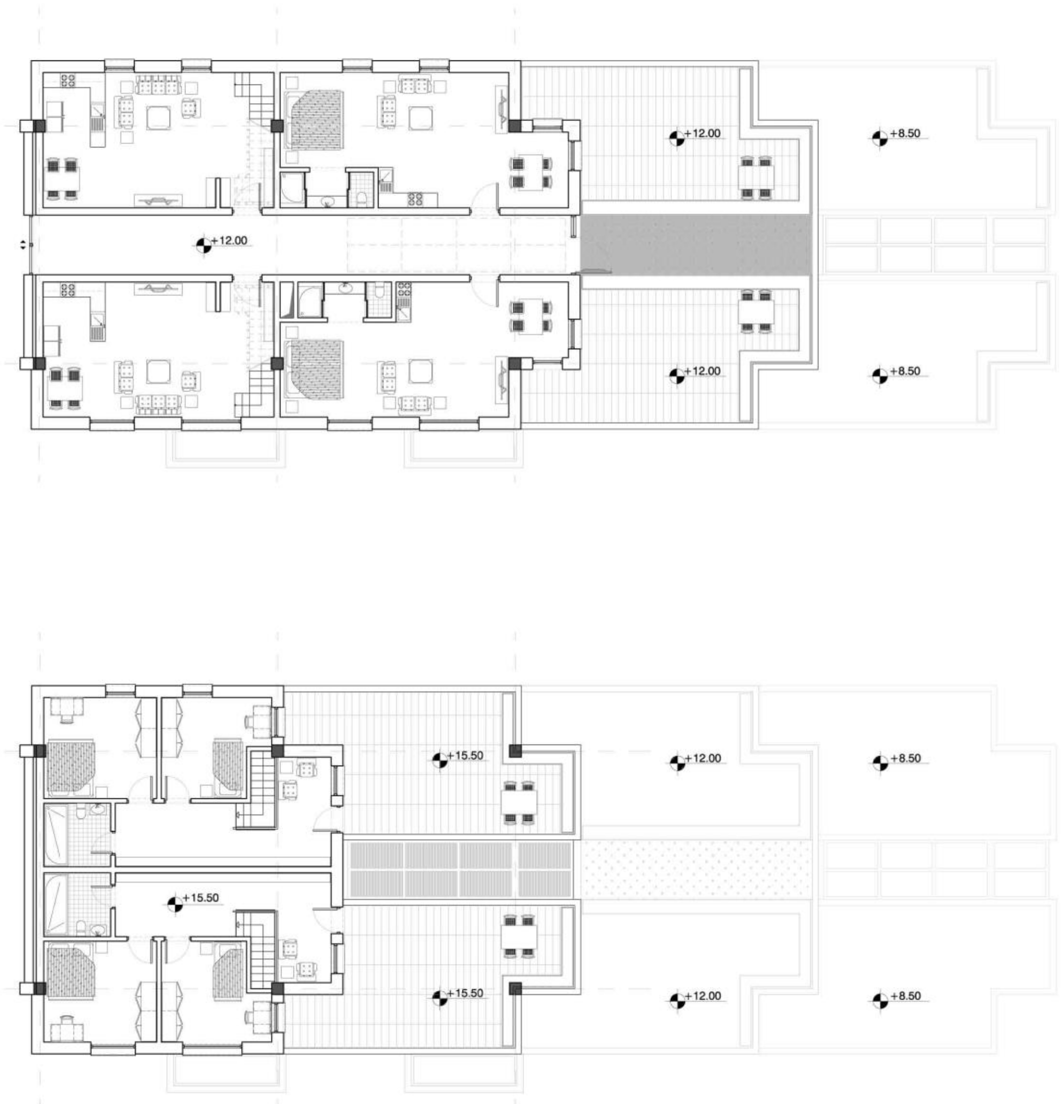
ARCH. DRAWING 13: Roof Floor Plan A



ARCH. DRAWING 14: First, second Floor Plan Zone 1B/2B



First, Second Floor Plan Zone 3 B



3rd, 4th Floor Plan Zone 3 B

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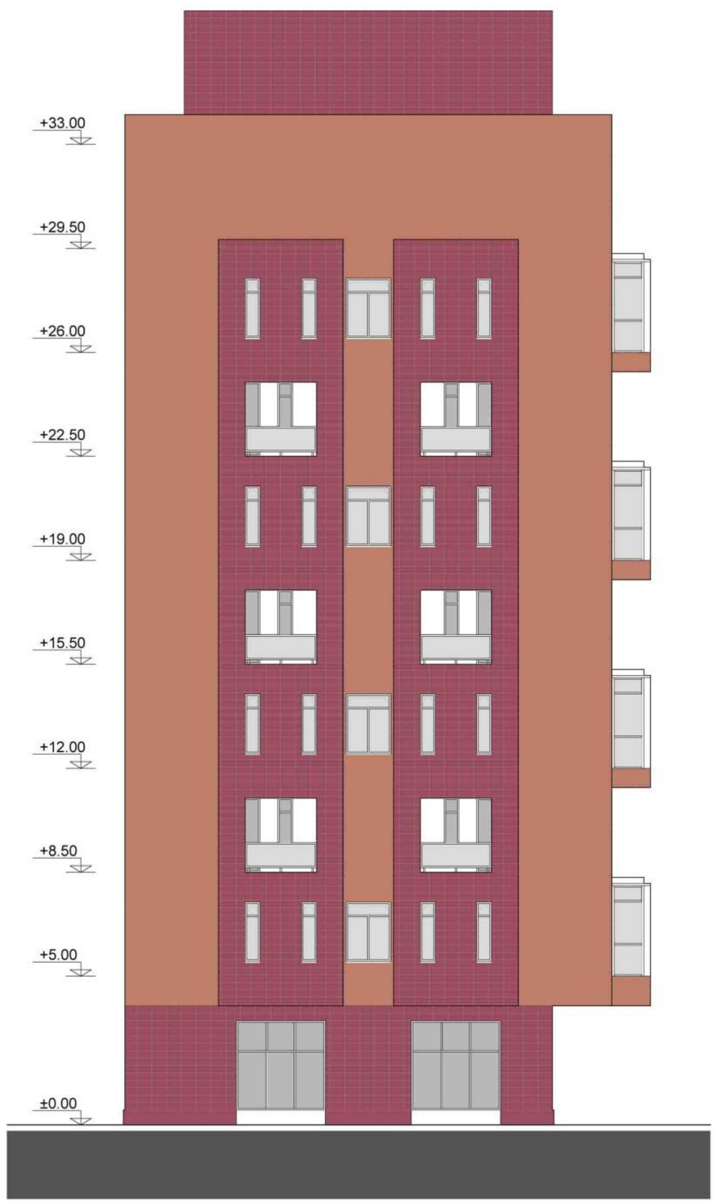
ARCH. DRAWING 15: First, Second, Third, fourth floor Plan Zone 3B

ARCH. DRAWING 16: South Facade



West Facade

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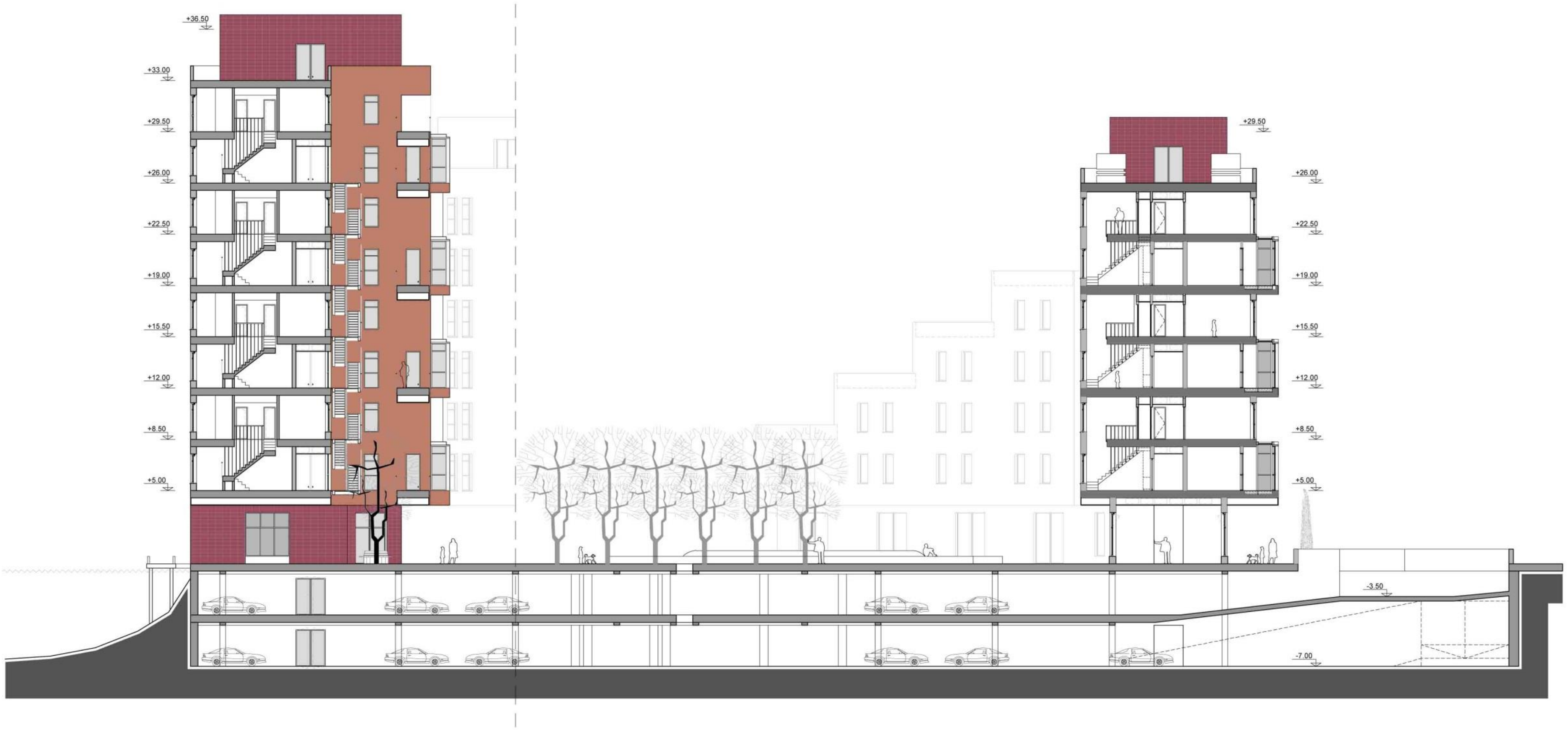
Scale 1/200

A 15

ARCH. DRAWING 17: West Facade



Cross Section

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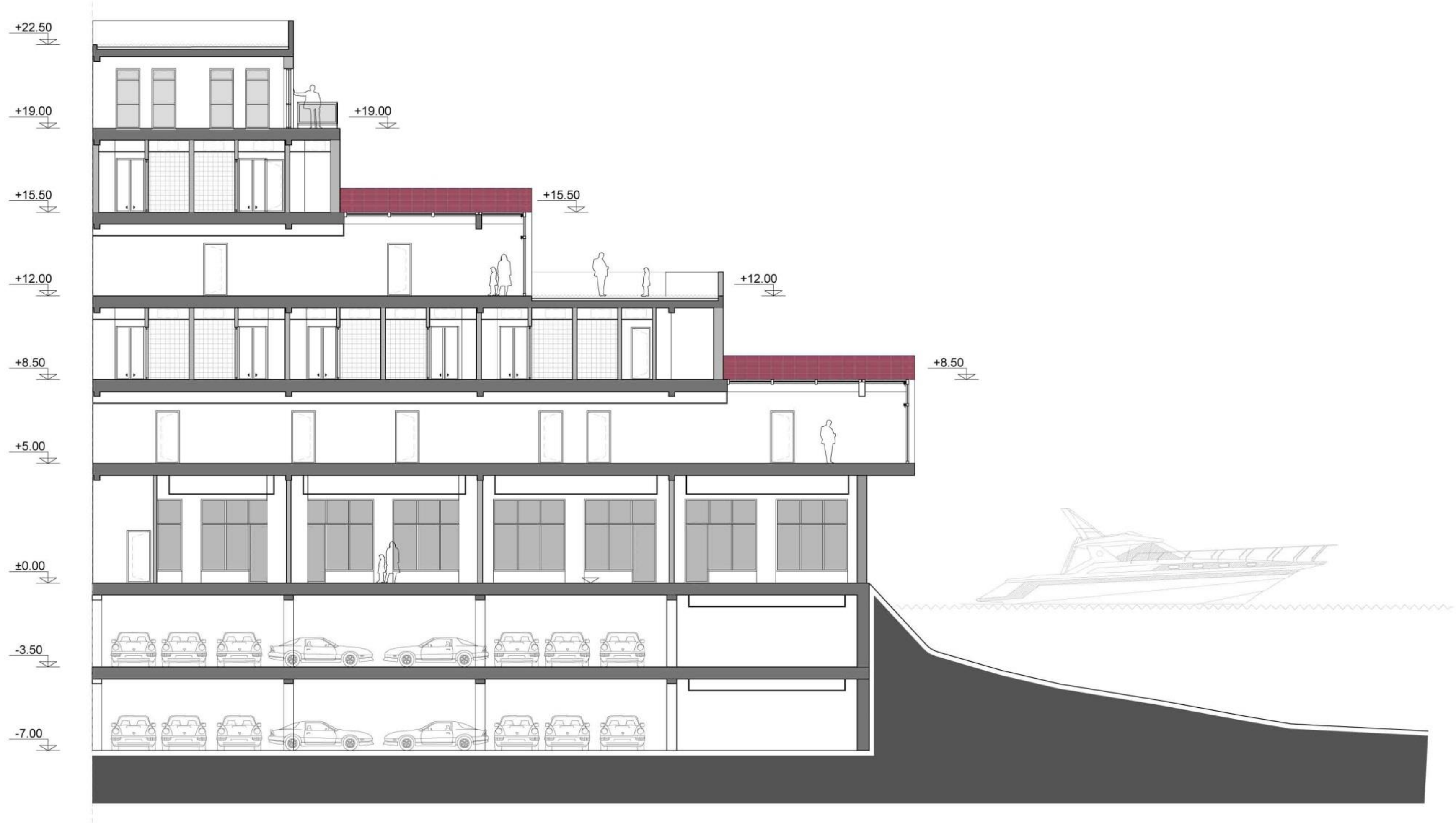
ARCH. DRAWING 18:Cross Section



Corridor Section

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A 18

ARCH. DRAWING 19: Corridor Section

North Elevation

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A 16

ARCH. DRAWING 20: North Facade

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39. http://www.deathbyarchitecture.com

LIST OF FIGURES

LIST OF TABLES:

LIST OF ARCHITECTURAL DRAWINGS

LIST OF SCHEMATICS

LIST OF STRUCTURAL DRAWINGS

LIST OF TECHNICAL DRAWINGS