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Building Refurbishment and Reuse of The Old Industrial Building Within the Context of Modularity Case Study: Bombelli, Milano

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1. Abstract

Il riutilizzo di edifici esistenti è importante sia per non interrompere il contesto del luogo sia per mantenere la sua integrità con quella zona piuttosto che demolire edifici inutilizzati e costruire un altro edificio. In casi di studio, quando gli spazi interni degli edifici sono stati rivalutati, è stato visto che la situazione attuale è stata valutata e sono state progettate scatole prefabbricate al posto delle pareti interne e delle partizioni. Questo studio mira a rendere disponibili a lungo gli edifici inutilizzati con le unità prefabbricate dopo i lavori di ristrutturazione, al fine di portarli a un nuovo utilizzo con piccoli interventi per le loro funzioni future senza alcuna demolizione. Inoltre, le trasformazioni ottimizzano anche le prestazioni energetiche in quanto l'edificio migliora sotto molti aspetti. Mentre l'analisi energetica è stata osservata nei campioni di ristrutturazione, non è stata trovata alcuna informazione relativa alle condizioni fisiche degli interni valutate con unità prefabbricate. Sulla base di questo ambito, il case study è stato analizzato per vedere in che misura questi metodi contribuiscono a migliorare le prestazioni energetiche e se le unità prefabbricate possono essere utilizzate per uffici e abitazioni per garantire condizioni di comfort. Infine, se il pannello fotovoltaico è progettato per soddisfare questo fabbisogno energetico, viene esaminato il contributo delle unità prefabbricate. Considerando che l'uso di unità e uffici prefabbricati aumenta il funzionamento delle attrezzature e dei servizi, in caso di elevato fabbisogno energetico, i pannelli fotovoltaici vengono progettati e discussi sulla quantità di servizi e attrezzature che possono essere forniti.

Parole chiave: ristrutturazione edilizia, riutilizzo degli edifici, modellizzazione energetica, flessibilità, modularità, unità prefabbricate.

The reuse of existing buildings is important both in order not to disrupt the context of place and to maintain its integrity with that area rather than demolishing unused buildings and constructing another building. In case studies, when the internal spaces of the buildings were re-evaluated, it was seen that the current situation was evaluated, and prefabricated boxes were designed instead of the interior walls and partitions. This study aims to make unused buildings available for a long time with the prefabricated units after refurbishment, in order to bring them to new usage with little interventions for their future functions without any demolition. In addition, transformations also optimize energy performance as the building improves in many respects. While energy analysis was observed in the refurbishment samples, no information related to the physical conditions of the interiors evaluated with prefabricated units could be found. Based on this scope, the case study has been analysed to see how much these methods contribute to improving energy performance, and whether the prefabricated units can be used for office and housing to ensure comfort conditions. Finally, if the PV panel is designed to meet this energy requirement, the contribution of prefabricated units is examined. Considering that the use of prefabricated units and offices increases the equipment and service operation, in case of high energy requirement, PV panels are designed and discussed how much service and equipment can be supplied.

Keywords: building refurbishment, building reuse, energy modelling, flexibility, modularity, prefabricated units.

2. Introduction

Refurbishment strategy is occurred by result of that high amount of historical buildings is unused. This is shown by the analysis that construction of new buildings is decreased by 28% in Europe from 20th to 21st century (Lisitano, et al., 2018). Changes of building envelope and service systems to make buildings reusable will help the building have a new function, but if this same function is not intended to be used in the future, it will need to be improved according to its intended use. This means that the physical structure and systems of the building are constantly changing. This doesn’t only cause excessive costs for the building owner, but also reduces the time of usability (Slaughter, 2001: Sadafi et al. 2014). The flexible design makes the buildings adaptable to transformation of functions or capacity that enables to divide into categories and prioritised (Sadafi, Zain, & Jamil, 2014).

In consideration to environmental and ecological awareness and economic situations, many companies aim sustainability. This is one of the reasons to increase tendency of modular design. In modular construction, the modules are prefabricated in a manufacturing facility that means away from construction and shipped to site. In the study of modelling same building in BIM to compare modular and traditional methods in terms of duration, the results show that the modular lasts 28 days while the traditional is completed on 67 days. This also effects on construction costs and the BIM model calculates $97000 for modular and $120000 for traditional (Hammada & Akbarnezhada, 2017).

The study focuses on the flexible designs in the buildings with controlling energy consumption and costs by shaping spaces easily. For this reason, all designs and analysis are collected on the BIM platform after energy after energy analysis in IESVE. The flexibility is designed with prefabricated systems and modular units to control and change functions easily. By considering lifespan of building, the modularity is a solution of rethinking about inner spaces and redesigning for future scenarios.

In this project, different types of changes were considered as a building envelope including main components as wall, roof, slab, building services such as heating, cooling and ventilation, building functions that are decided in program demands. As a result, refurbishment strategy is tackled into three main processes. First one is refurbishment of building including thermal mass and loads improvement with new occupant profile, second one is reuse of inner space with prefabricated modules, last one is reconditioning of roof with PV panels to decrease energy demand.

2.1 Issues and Relevance

What makes the space defined is how people experiences that space. Therefore, with the changing conditions (economic, technological, communication, etc.), the areas in which people maintain their activity in the city are also changing. The place is no longer in communication with the city as before. And as a result, some places lose their effectiveness within the city. Within the dynamic city life, the use and usability of building is also changing. Those buildings, which cannot keep up with the pace of change in the city, find themselves pushed out of life. The aim of the study is to reveal the potential of the inefficient or abandoned places.

While assessing this potential, the cost can be minimized with the minimum intervention to the existing building. The new functions are programmed with also considering maximize building life span that are also flexible to adopt to the conditions of today and the building is aimed at increasing sustainability by reducing energy consumption.

2.2 Current Systems

Today refurbishment strategies and building reuse methods are generally separated from each other. The retaining of building values was considered by refurbishment works which are generally applied on building envelopes. These interventions on the envelope are resulted in high-cost and long-lasting traditional refurbishment applications that cause difficulties to adapt of occupant requirements today and future. Most conversions are preferred because of their low budget; however, due to environmental factors or the capacity of the building (Gillot & Spataru, 2010).

The transformation of buildings varies according to the type of it. In the examples of refurbishment, it is seen that the old industrial buildings have uses such as the library, exhibition area or museum which are open to the public after they are re-used. In addition, when a more modular design is applied with prefabricated units, it has been found that the buildings can be converted from industrial to office or residential uses regardless of the type of building. The reason for this is that the modular units have a flexible design and are able to transform the service systems.

2.3 Future Tendency

It becomes common trend that each living spaces have specific character for human use. The redesign of existing building stocks is more important for conservation and reuse of the buildings. The re-architecture method is a result of changing needs of occupants. The adaption of the changes is observed as an outcome when the built environment is transformed by design process. The ability is called as flexibility, which is an adaptation to transition of functions, cooperation with new technologies, varying of demographics. The future of the building is evaluated regarding the flexibility that they may be easily adjusted in terms of requirements.

Nowadays, the concept of flexibility in architecture becomes preferable by manufacturers, contractors or public institutions in the situation that the needs of the society, the observed shortcomings or a dynamic design are desired. The combination of flexibility and functionality maximizes the use of the intended areas. Design strategies are shaped by the determination of changing systems and making changes easily. Design strategies should help the concept of sustainability, which means reducing materials and energy consumption.

3. Research Objectives

3.1 Questions and Brainstorm

Before starting research, many questions were defined to guide a way of literature review with our supervisors. In accordance to the facts mentioned on the previous parts, the research was shaped with those questions:

- What are the ways to minimize building intervention when the energy performance is enhanced?
- How is it possible to minimize building costs for building refurbishment?
- How should be functions designed in the system?
- How can be the future situation controlled in this system?

As a result of those questions, the research was developed with the keywords to progress literature reviews and enlarge content of the project. During the brainstorm, one of the main goals of the project was stated as designing new system inside existing building. The aim should be provided with minimum intervention of the building. Therefore, this considers other goals of the project as energy performance and minimum costs. When these aims to lead the research, flexibility as a keyword is one of the guidance in the literature review and case studies. Flexibility can be named as the best way of retaining value of building. In the other side, the flexible designs in the buildings can control energy consumption and costs by shaping spaces easily. The flexibility is designed with prefabricated systems and modular units to control and change functions easily. By considering lifespan of building, the modularity is a solution of rethinking about inner spaces and redesigning for future scenarios.

3.2 Literature Review

Following the research question, literature review was started on defined general topics such as zero energy buildings, refurbishment and building energy modelling. Afterwards, keywords were customized according to the area decided to work, and research on prefabrication and flexibility, cost effective energy refurbishment, climate adaptive building shell and energy efficiency was concentrated upon. In this section, the articles that are taken from the literature and which can guide the study are summarized.

First paper was found with keywords as BEM, ZEB, renewable energy, climate changing. According to this paper, the best energy is the energy that is never used. In this context, the construction sector constitutes the most important area to be examined in the field of energy consumption as it has a large share in primary and final energy consumption. Buildings are held accountable for 40% of the worldwide consumption of energy, considering the energy consumed for construction phase (Cao, Dai, & Liu, 2016). For this reason, reducing the energy consumed in buildings and increasing their efficiency has great importance in terms of protecting energy resources and reducing CO2 emissions.

Second paper was “Strategy for Low-E mission Refurbishment” stated that environmental impacts resulting from the renovation of buildings are less than when they are demolished and rebuilt because all materials have a certain formation energy and the regeneration of materials leads to new carbon emissions. In addition, the waste produced during and after the destruction process constitutes carbon emission (Baker, 2009).

Third input was the topic as “Energy Performance of Buildings” published a research by European Commission of Energy. Today, in Europe, more than 35% of buildings are constructed 50 years ago or more and around 75% of them are energy inefficient. However, every year, only about 1% of the total building count is refurbished. The refurbishment of existing buildings can result in significant energy savings and can reduce CO2 emissions by around 5%, as well as reducing EU total energy consumption by 5-6% (European Commission, 2019).

Even if tend towards to renewable energy sources helps to save energy, it is unfortunately low in old buildings. The objectives of the European Union in 2020 are mainly related to the design of new buildings that are close to zero energy buildings. However, some national energy agencies and academic institutions are interested in the energy efficient refurbishment of existing buildings for the 2050 objectives of the European Union. In regions with Mediterranean climate and oceanic climate, effective energy refurbishment to be applied to old buildings are more effective in terms of heating energy costs compared to solar energy (Eicker, Demir, & Gurlich, 2017). Considering that 60% of the buildings were built between the 2nd World War and 1976 in Italy with these climates (Malacarne, 2016), it makes more sense to investigate refurbishment of old buildings rather than to renewable energies.

The final source was about the evaluation of industrial buildings in Italy that was issued by Corriere Newspaper. This focuses on the evaluation of more than 20 thousand abandoned industrial buildings (Millucci, 2016). In this context, a refurbishment method that can be easily applied in all industrial buildings with enough volume has been investigated.

3.3 Case Studies

In this part, as literature review and research questions were considered, 3 different case studies were examined in terms of refurbishment of industrial buildings. For the analyzes of these case studies, structural improvement, changes of their plans, functions of new designed building, and renovation of building envelope.

The refurbishment projects were provided by location, information of year, costs and responsible groups such as design, structural, mechanical and construction teams. All case studies were chosen from different countries as orderly France, Netherlands and Italy as seen in *Figure 1*.

Figure 1. Location of the case studies

Case 1: FRAC Dunkerque

Figure 2. Location of FRAC and picture from outside (source: Archdaily)

The building FRAC Dunkerque is placed on port in France as seen in *Figure 2*. The building, called Halle AP2, is one of symbolic warehouse buildings to produce boats. Its location provides the building has much brightness while the volume is immense due to old function of the building. In the project, the halle was protected and made double with same dimensions under envelope. One of them is located to seaside while the other one included the program needs.

- **Structure:** The building has rectangular form and structure was aligned straight through vertical and horizontal axis. The FRAC including functions of exhibition hall was supported with more columns because of dense of functions and floors.

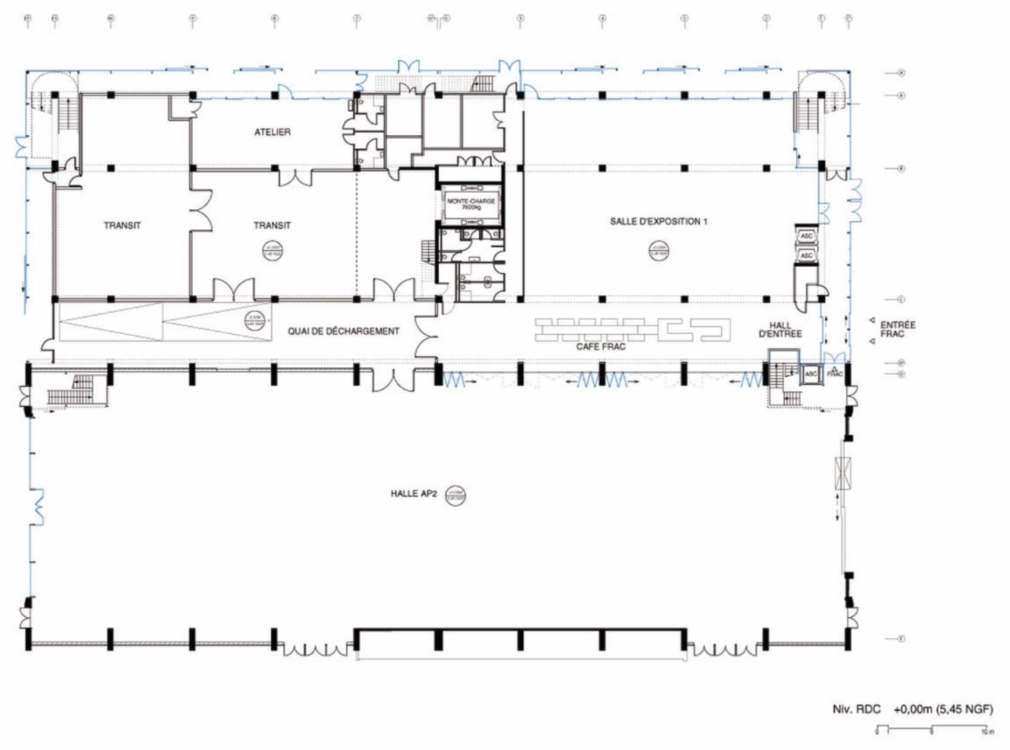


Figure 3. FRAC - Ground Floor (source: Archdaily)

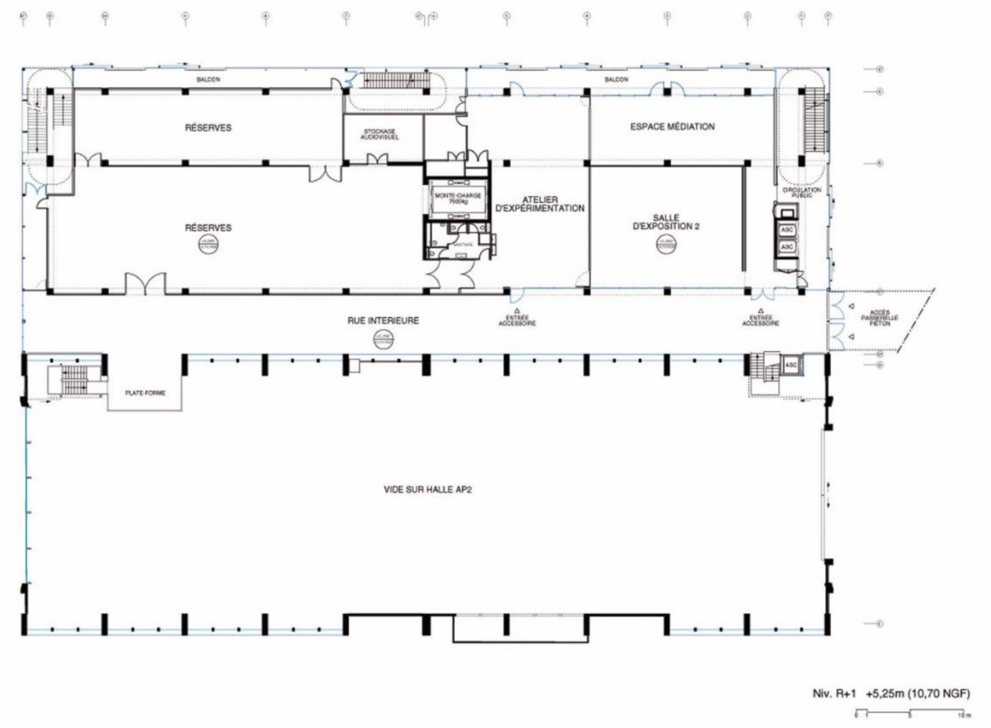


Figure 4. FRAC – 1st Floor (source: Archdaily)

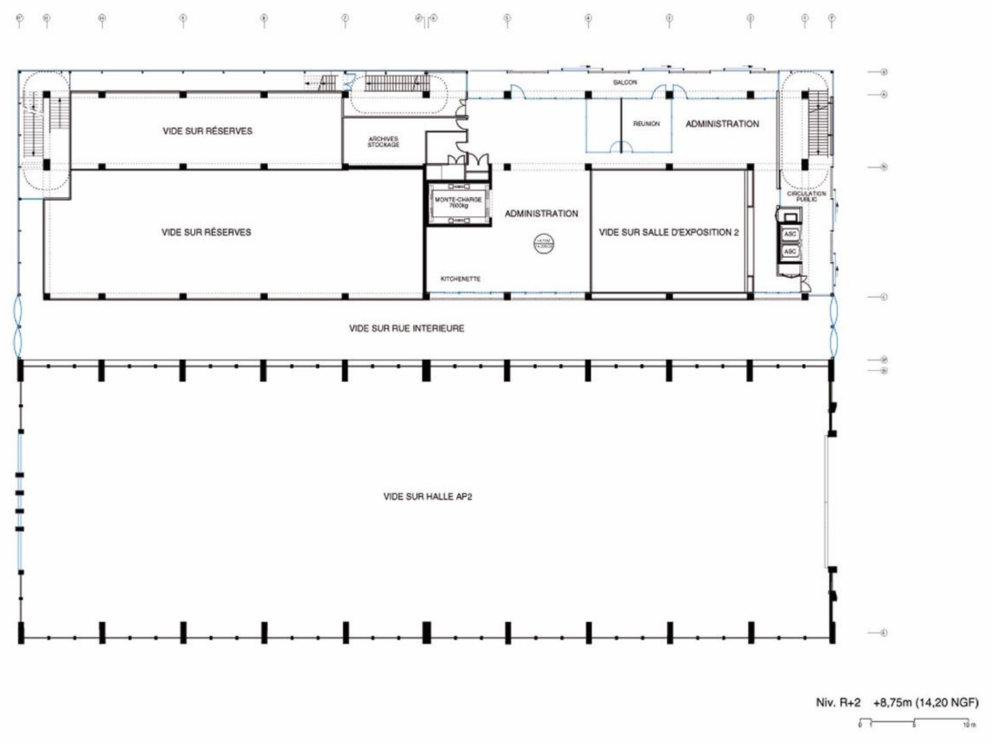


Figure 5. FRAC – 2nd Floor (source: Archdaily)

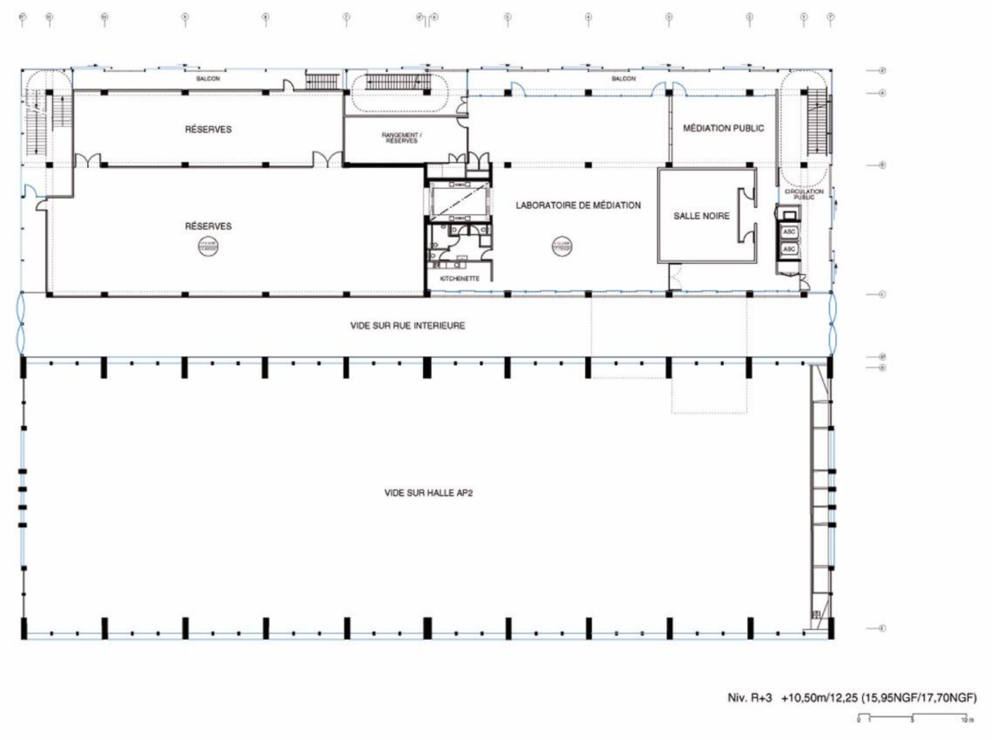


Figure 6. FRAC – 3d Floor (source: Archdaily)

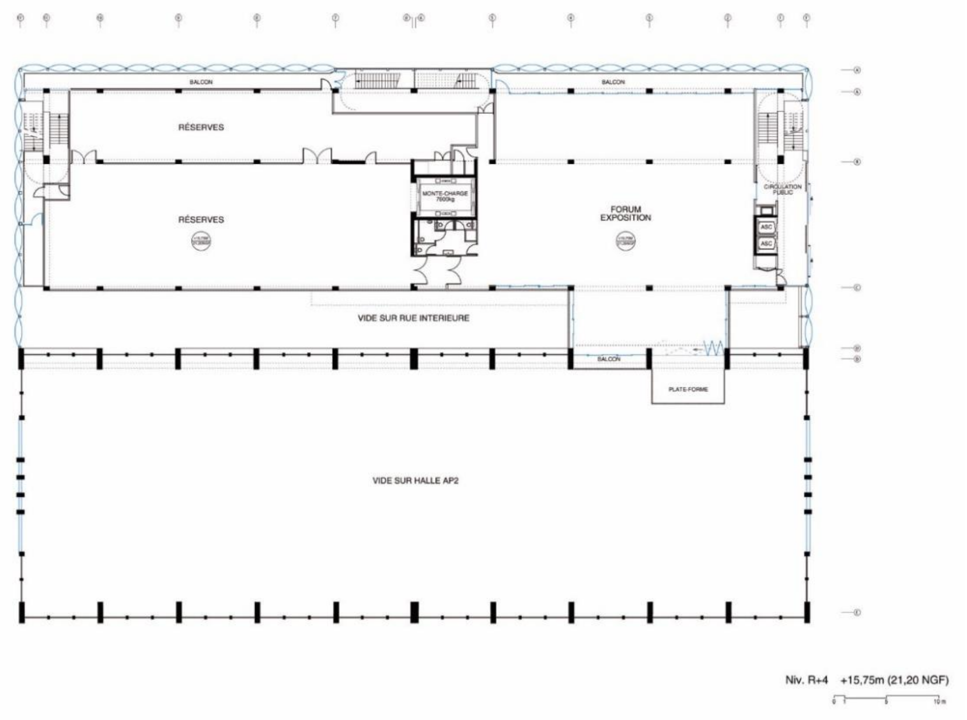


Figure 7. FRAC – 4th Floor (source: Archdaily)

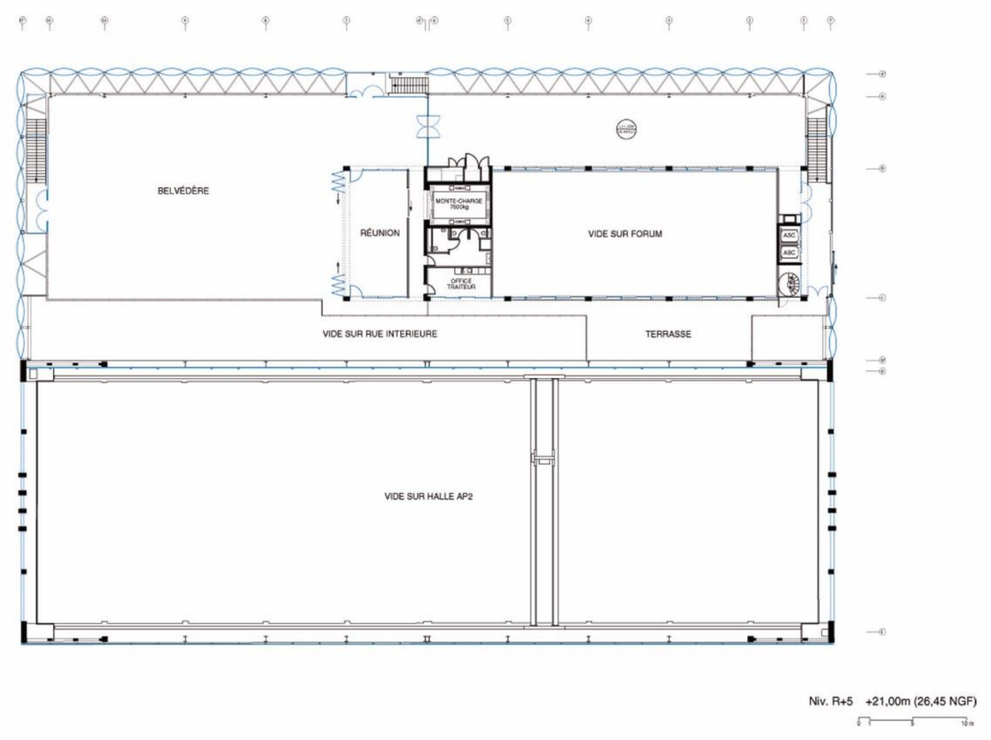


Figure 8. FRAC – 5th Plan (source: Archdaily)

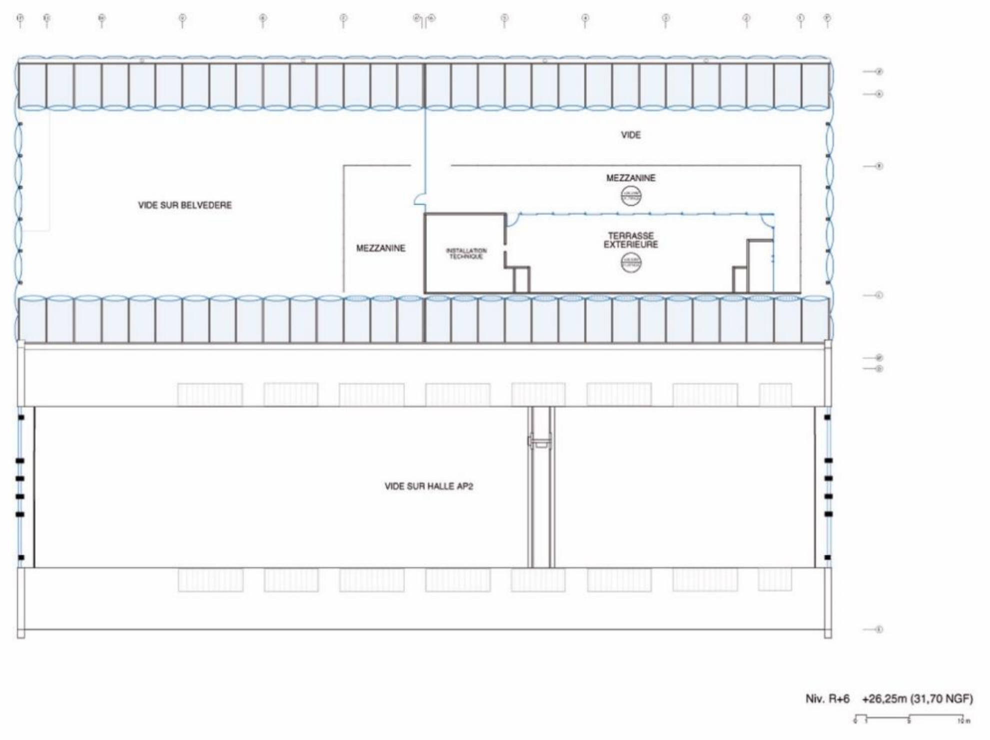


Figure 9. FRAC – Top (source: Archdaily)

- **Changes of functions and floor plans:** The building has seven floors with 11129.0 sqm. Old industrial building has changed to main function of building is exhibition hall differentiated uses to public and private. The FRAC houses, by loans to both galleries and museum, archived and presented collections of contemporary art to the public. There are three main expositions in ground floor, first floor, and fifth floor, studio and salons are in first floor, and laboratory and cinema in third floor, forum in fourth floor. There is also terrace view on the top of the building.

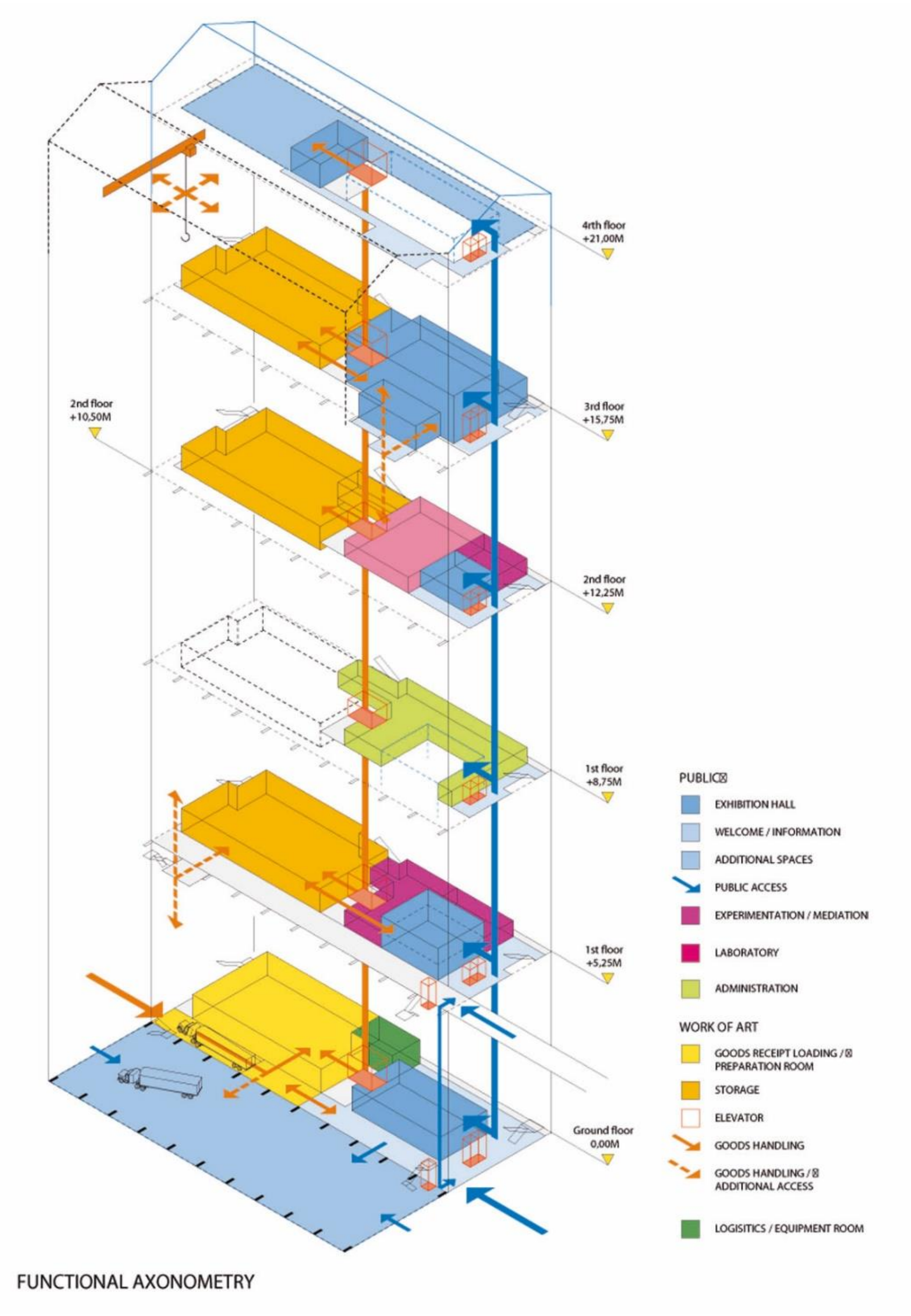


Figure 10. Building functions in axonometric view of FRAC (source: Archdaily)

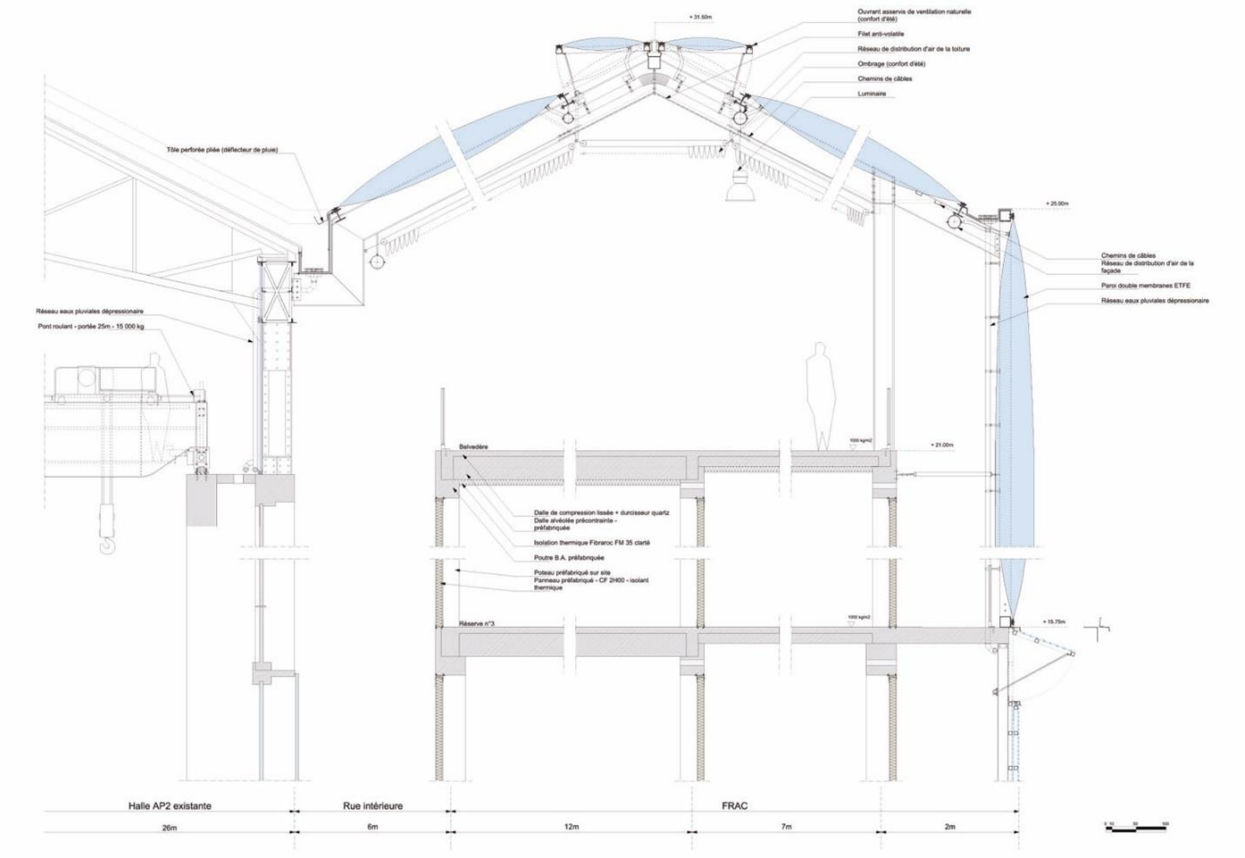


Figure 11. Building envelope and section of FRAC (source: Archdaily)

- **Improvement of Building Envelope:** FRAC, with its bioclimatic and transparent layer, slim structure, has both flexibility and easy convertibility. Due to this aspect, the visibility of the art products exhibited on the floors has been provided in order to be seen. This makes more flexible and transformative platforms enabling program requirements. Since the building consists of two parts, it is combined with pedestrian bridge in some parts along front of building that is connected to halle. The AP2 has been designed to host important art activities such as exhibitions and extensive works, as well as concerts, fairs and other public events.

Case 2: LocHal Library

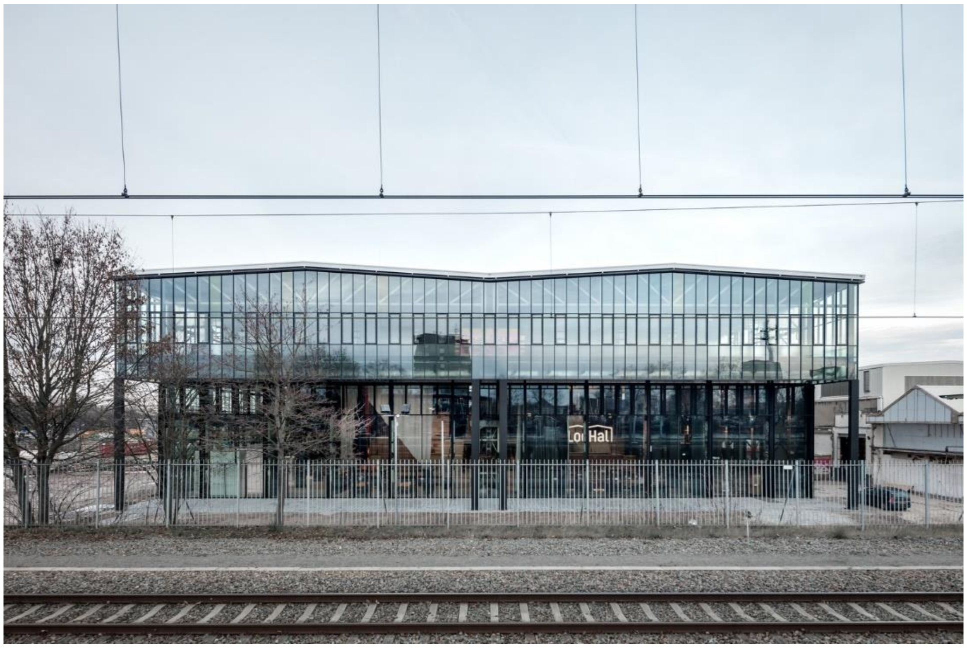


Figure 12. Location of LocHal Library and picture from outside (source: Archdaily)

The LocHal is a building that was transformed from a dormant building of a former railway station with a central location to modern library.

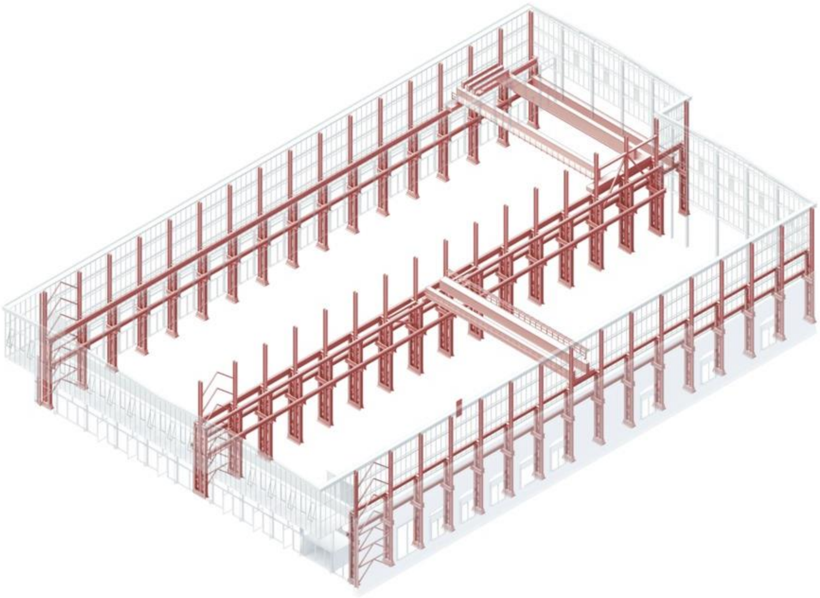


Figure 13. Structure of LocHal Library (source: Archdaily)

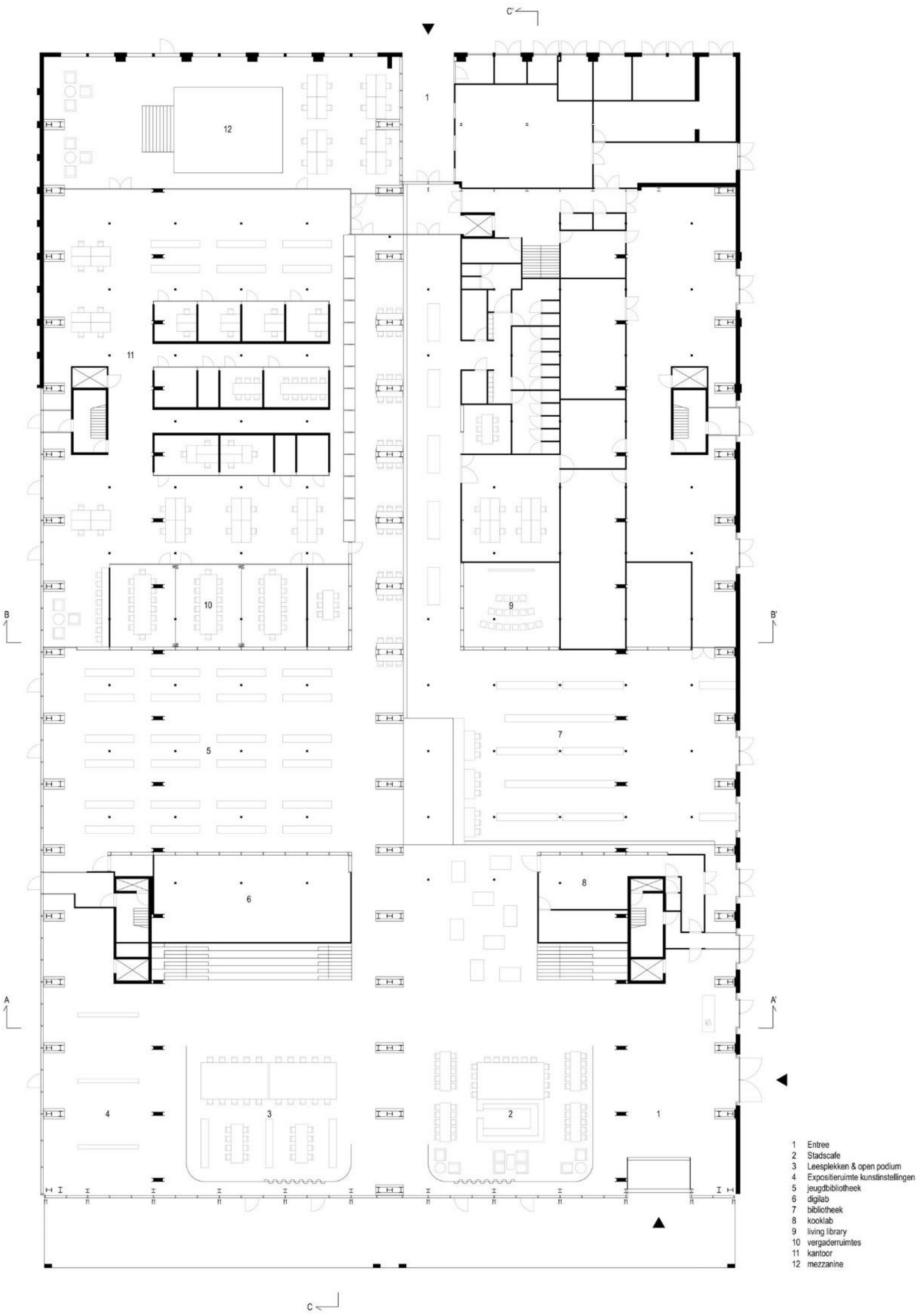


Figure 14. Ground floor of LocHal Library (source: Civic Architects)

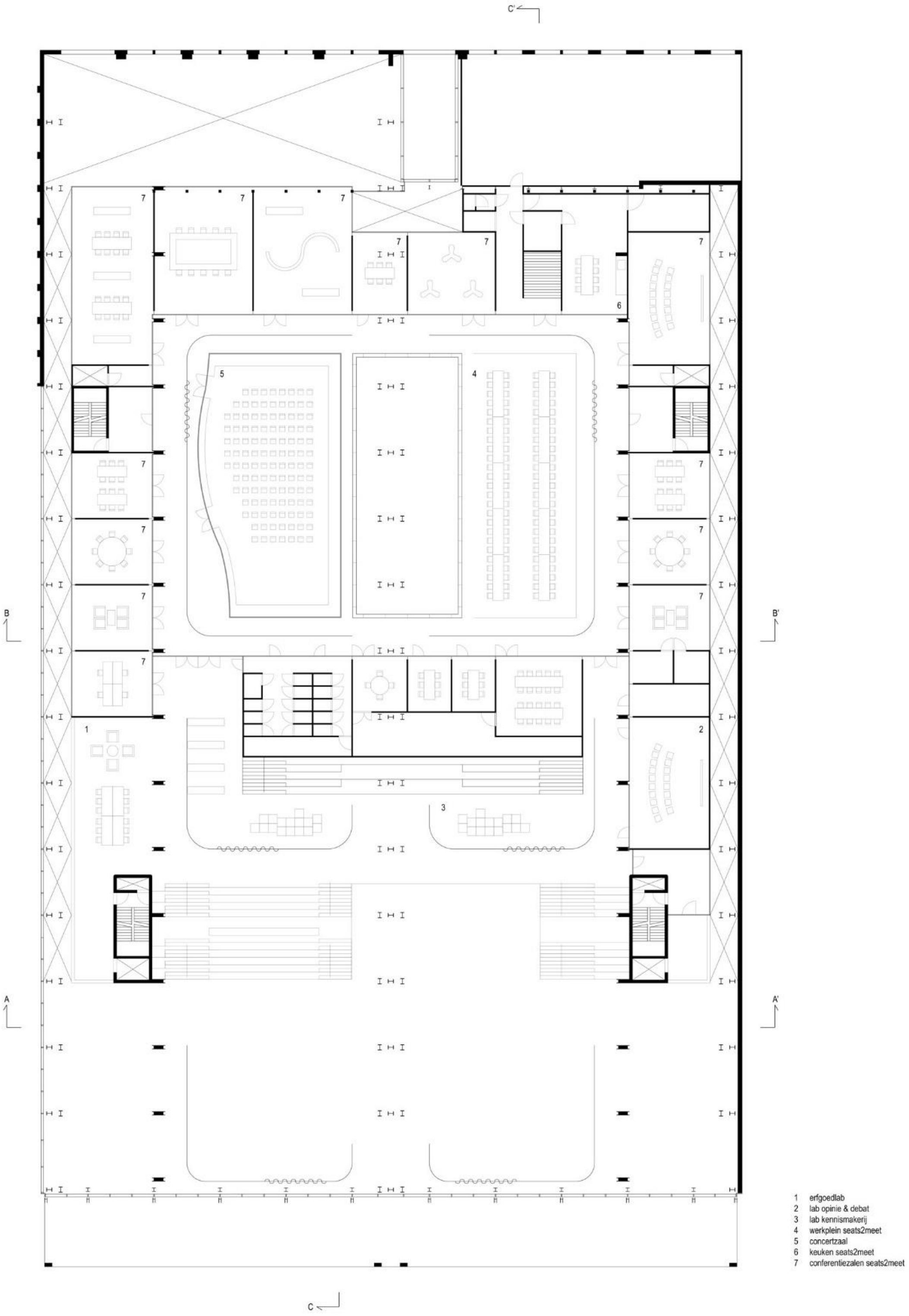


Figure 15. First floor of LocHal Library (source: Civic Architects)

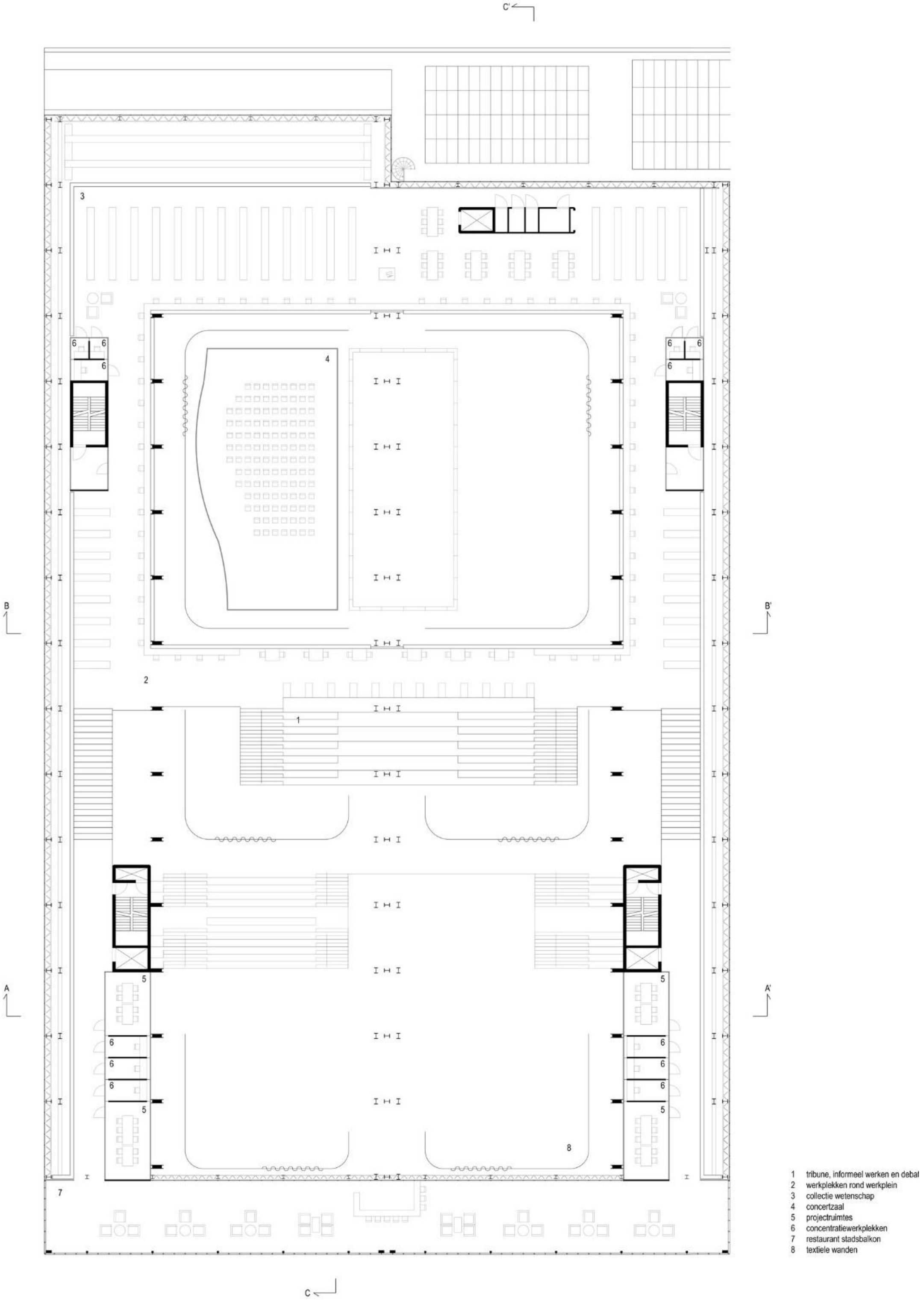


Figure 16. Second floor of LocHal Library (source: Civic Architects)

- **Changes of functions and floor plans:** The open library divided into many zones. First one is a large central hall which meets visitors after entering, second one is the courtyard which was designed with stairs and terraces for reading, working, talking and discussing. Also, visitors arrived at co-working place surrounded with meeting spaces. Finally, the last floor consists of large corridors which provides cosier workplaces for groups that was connected to winter garden with view of city.

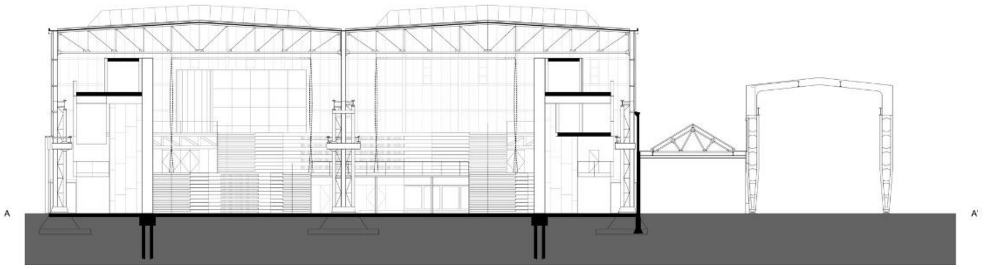


Figure 17. A-A' Section of LocHal Library (source: Civic Architects)

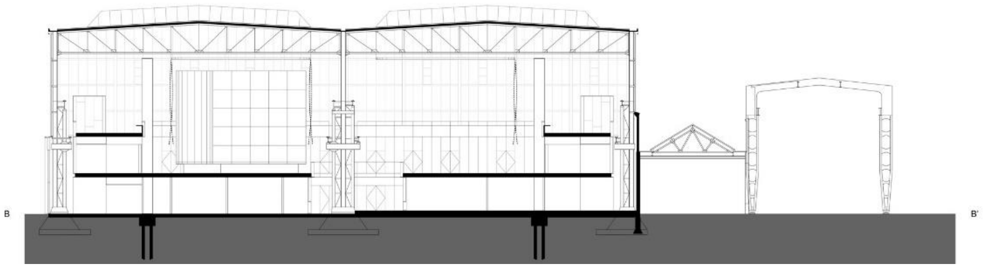


Figure 18. B-B' Section of LocHal Library (source: Civic Architects)

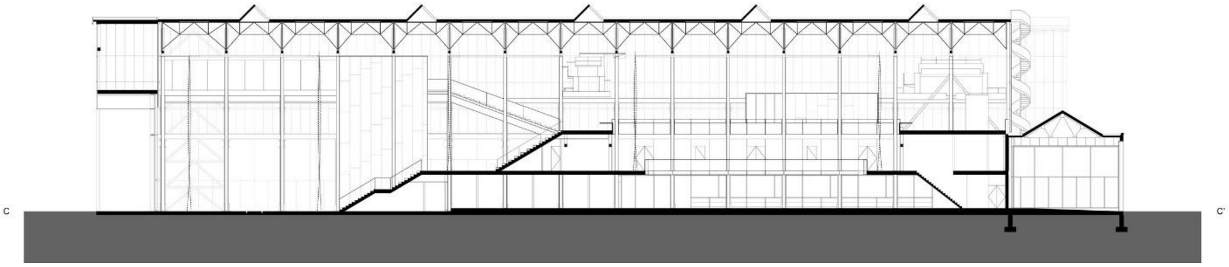


Figure 19. C-C' Section of LocHal Library (source: Civic Architects)

- **Structure:** The library capitalized the existing structure. Comfort of interior was improved with diagonal visions and new structural elements were designed as minimized amount. The zones preserve the openness of the building to preserve the LocHal building as one large usable volume, rather than designing closed volumes or replacing it.

Case 3: Technopole for Industrial Research Shed #19

Figure 20. The building of Technopole Shed #19 picture from outside (source: Archdaily)

Officine Reggiane is a remarkable structure of old industrial city Reggio Emilia. Research and investigation are used to identify possible future transformations. The building is located on the Santa Croce suburban area where was planned industrial settlement in 1901. The building was used to produce rolling stock, and the production was converted to weapons and war materials because of First World War.

- **Structure and Improvement of Building Envelope:** The deterioration of area was considered at first, the original composition and the structure are preserved. The architecture was shaped by the memory which was described by an essential part of industrial sites such as by labour sounds, smells, machines, process waste and people.

New building has large roofing to shape and figure the vacant and enclosed space with typological features. With corresponding to the original structure, space subdivision was designed with structural and thermal modules.

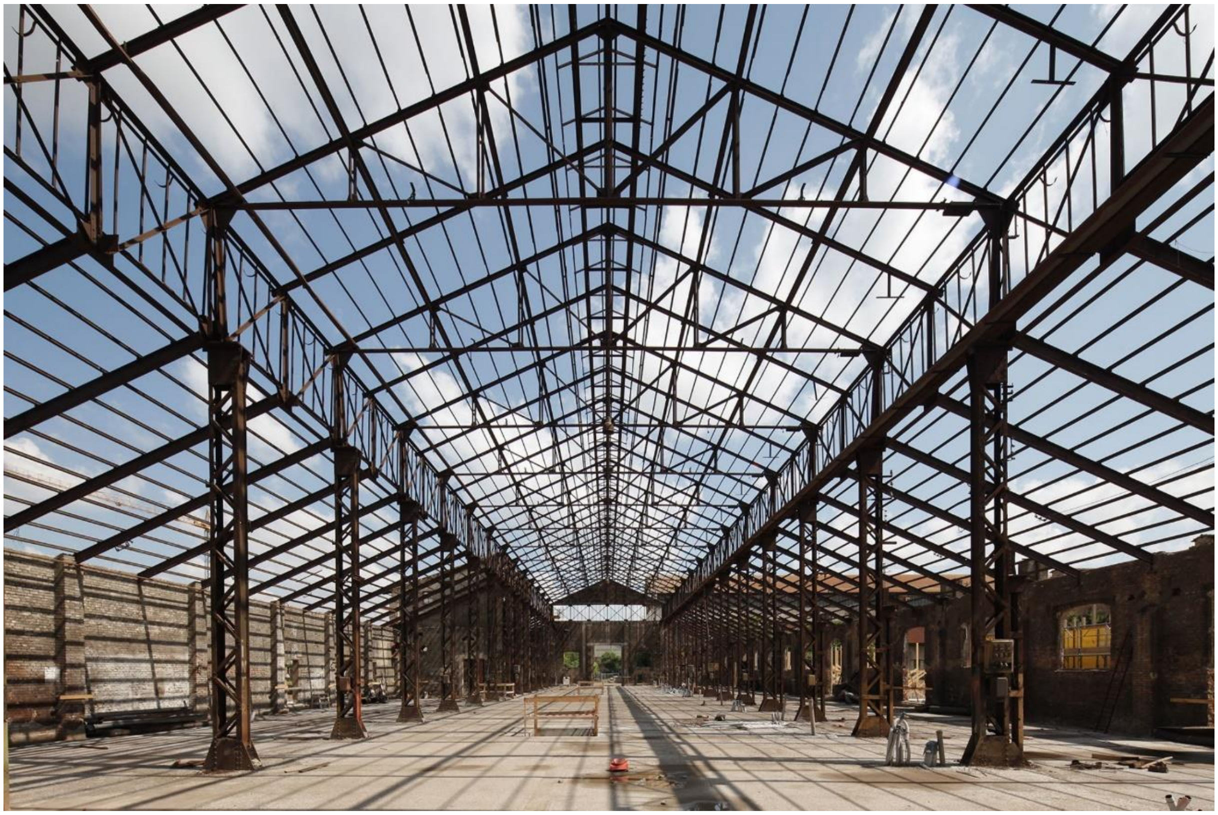


Figure 21. The building of Technopole Shed #19 with structure (source: Archdaily)

- **Changes of functions and floor plans:** Officine Reggiane was imagined as theatrical scene by architects. The old industrial building has lack of dynamic components of the place exampled by production and movement of operators and in new design. The architectural memory of factory included many components such as empty volumes, tracks, and machines constituted by time and labour. The building was replaced with many dynamic components such as research function and users as research students.

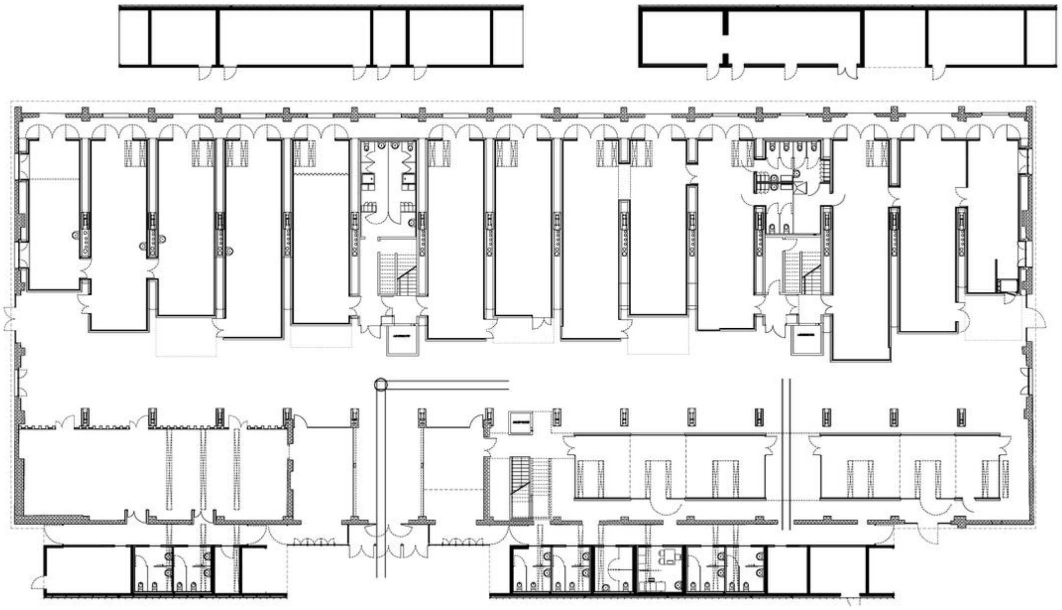


Figure 22. Technopole Shed #19 - Ground floor (source: Archdaily)

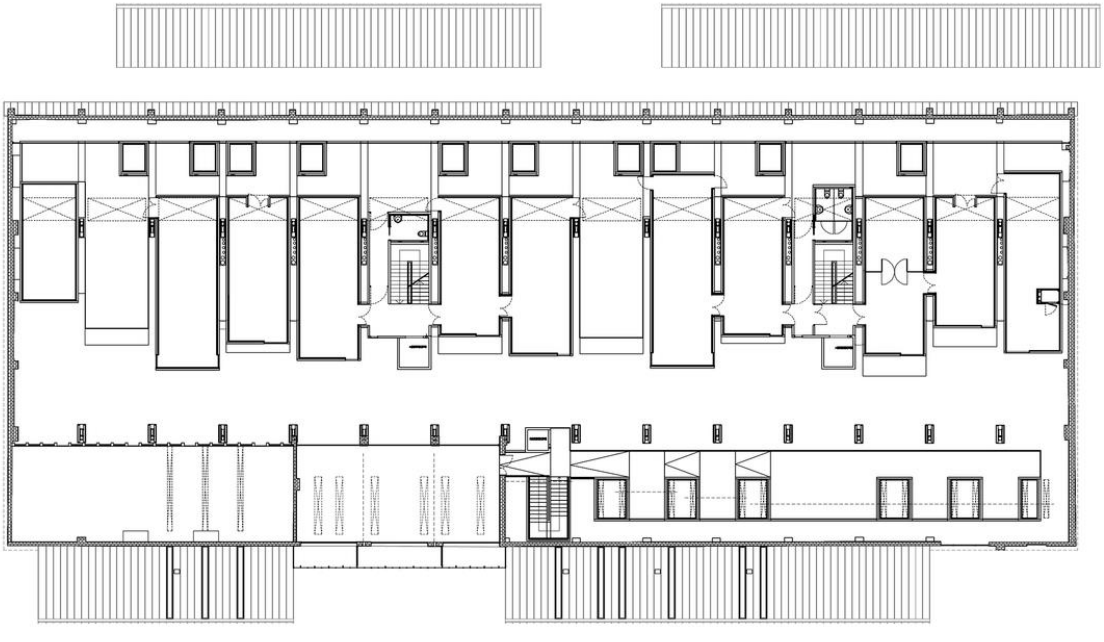


Figure 23. Technopole Shed #19 – 1st floor (source: Archdaily)

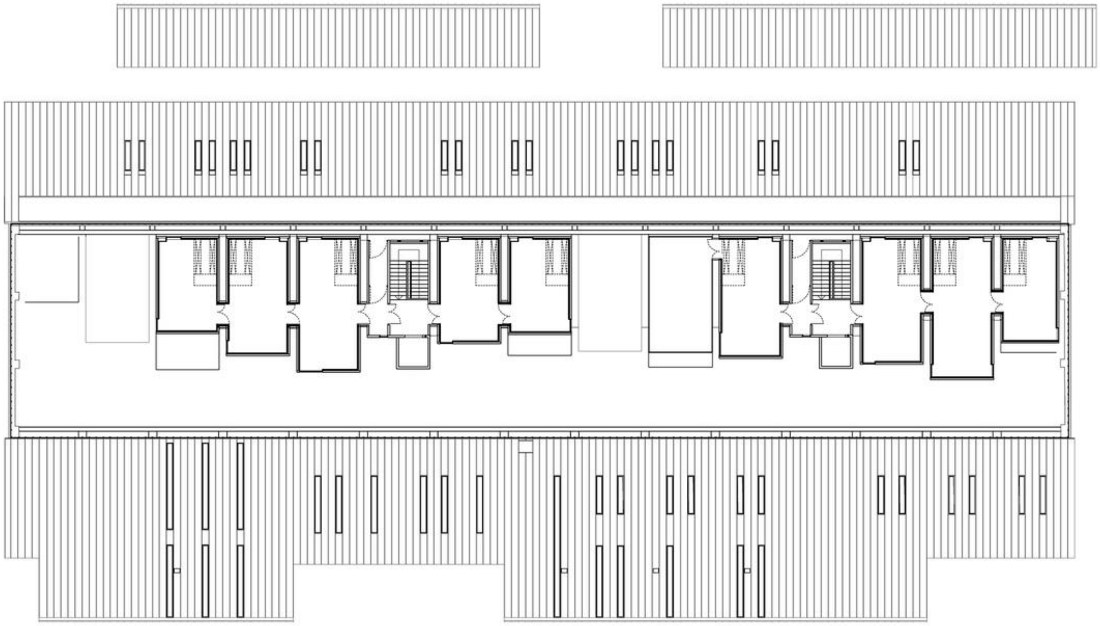


Figure 24. Technopole Shed #19 - Top view (source: Archdaily)

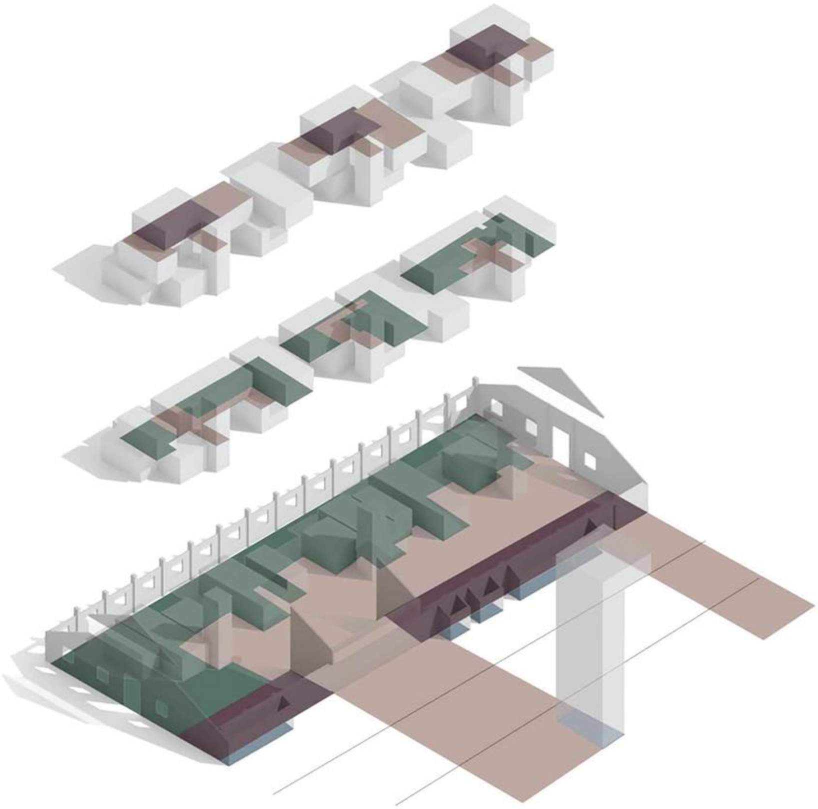


Figure 25. Axonometric perspective (source: Archdaily)

Evaluation of case studies:

The refurbishment of old industrial buildings was examined into structural, functional, architectural ways. The refurbishment methods were started with the preservation of the building shapes and its structures generally to remain the spirit and history of the building. Some steel structures were added inside of buildings to improve strength and to support newly designed roofs. The building functions were imagined with the scenarios which were occurred by the memory of the spaces, people and other components. Since the old industrial buildings have large volumes and wide confined spaces, the new functions were considered to conserve the feeling of commodiousness and were designed by public functions such as a library, exhibition halls, and offices. When the real case study is examined in terms of structure and inner volume, the changes in these industrial buildings enlighten the way of refurbishment and reuse.

4. Prefabricated Units

4.1 Prefab Units

Prefabrication is a building process where some elements are built off-site and, shipped to a construction area for installing after completion. Prefabricated units providing short construction time and predictable pricing. It uniquely benefits from the worldwide infrastructure built to transport shipping containers. It is useful for emergency shelters that can be easily and quickly moved. The major advantage of container transport is versatility.

Pros

- *Prefabrication or modularity:* Most of the units are produced and reachable as prefabricated modular containers, which makes construction time shorter. The delivering and building of these prefabricated modular units are faster that varies from 4 weeks to 10 weeks by considering details or demands. They also have building directions of these units and this makes simpler and quicker for everyone. They can be customized as the office or home with different shapes, panels or materials that are converted to do it yourself project.

- *Easy transportation and placing:* The prefabricated units are generally made of shipping containers as understood from its name that can move around and ship worldwide. The preparation and placing of the foundation are easy and fast.

Figure 26. Transportation of shipping containers (source:Prefab.net)

- *Predictable cost:* The prefabricated units are generally presented by fixed price including all operations and labour times. They can be resulted by some changes because of shipping and building units. In general, containers are relatively low-cost choices except for some luxury homes or extraordinary structures. In this case, containers are not always less expensive.
- *Recycling:* The use of shipping containers is the environmental choice for prefabricated units that is provided by redundant components of the shipping industry. Prefabricated units are environment-friendly due to preserving metal sources that are gathered from many old containers that are not used.

Although many pros of prefab units are listed above, there are also numerous cons which are mentioned below.

Cons

- *Not effective recycling:* Most prefabricated containers are aimed to be in aesthetical shape, and it results to be made of single-use containers. It may be good to prevent damages from years of use and to lose services and functions. As a stated by Hunter (2019), that multiple used containers are not suitable for continuous conversion and use in new constructions. Building a container house requires a lot of steel and needs to be attached to each other with studs.
- *Structural facts:* There are standards of shipping containers such as ISO 1496-1:2013. The standards limited its dimensions and weights. The shipping containers are lifted by pulling from their corners: however, containers should be very strong at the corners. Also, the walls are crucial to provide strength thanks to their support for openings. If large opening is designed, new reinforcements are required to create balance. In order to design larger buildings, the prefabricated units are stacked together seen in *figure 27* and it can need to be welded reinforcement and it results in expensive way. The welding should not be in a corner, should be in a spot wherever two containers join that requires significant engineering and more proficiency.

Figure 27. Stacked Container Islands (source: Sunnyda Company)

- *Unknown materials:* Used containers are manufactured with unknown materials, from harmless consumer goods to hazardous industrial materials. And the paints and surfaces used in the containers are industrial; they may contain lead and toxic pesticides.
- *Limited space:* The dimensions are limited by the standard ISO 668: 2013. These limited spaces can be covered easily by plumbing, HVAC, insulation and other systems. The problem is generally solved by designing technical rooms in a different container unit.
- *Insulation problems:* In case of exterior use of prefabricated units, the extra insulation is also needed for the shipping containers. A thin insulating layer with high resistance, such as PUR spray foam, is preferred. To design well-insulated wall, the wall thickness should be increased and is made of more environmental and sustainable insulation materials.

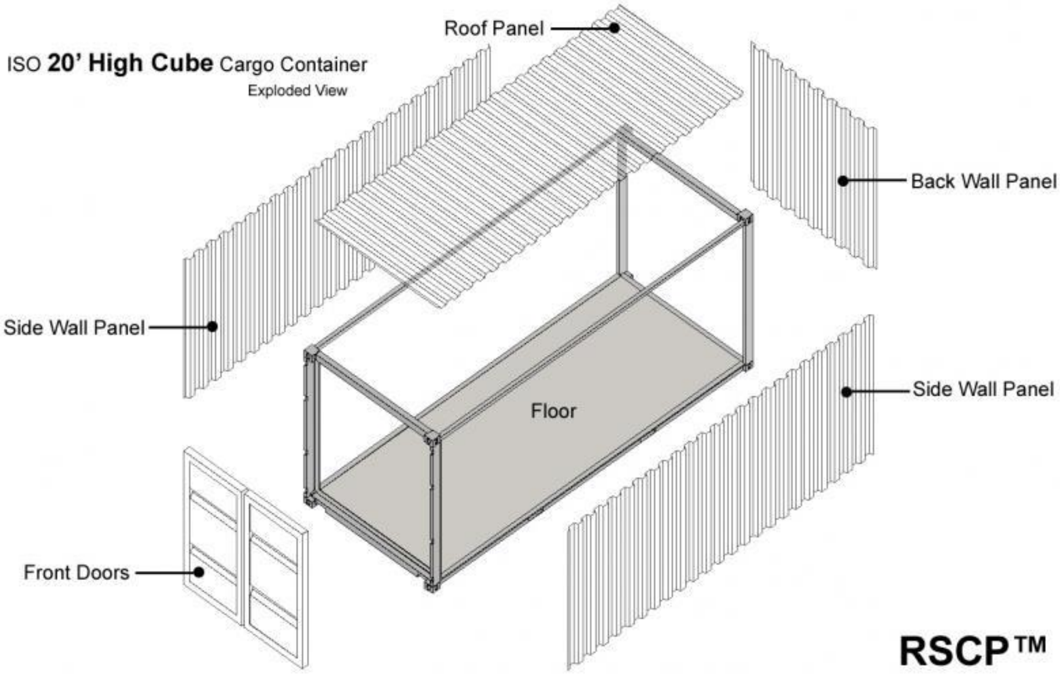


Figure 28. Basic layers (source: Residential Shipping Container Primer)

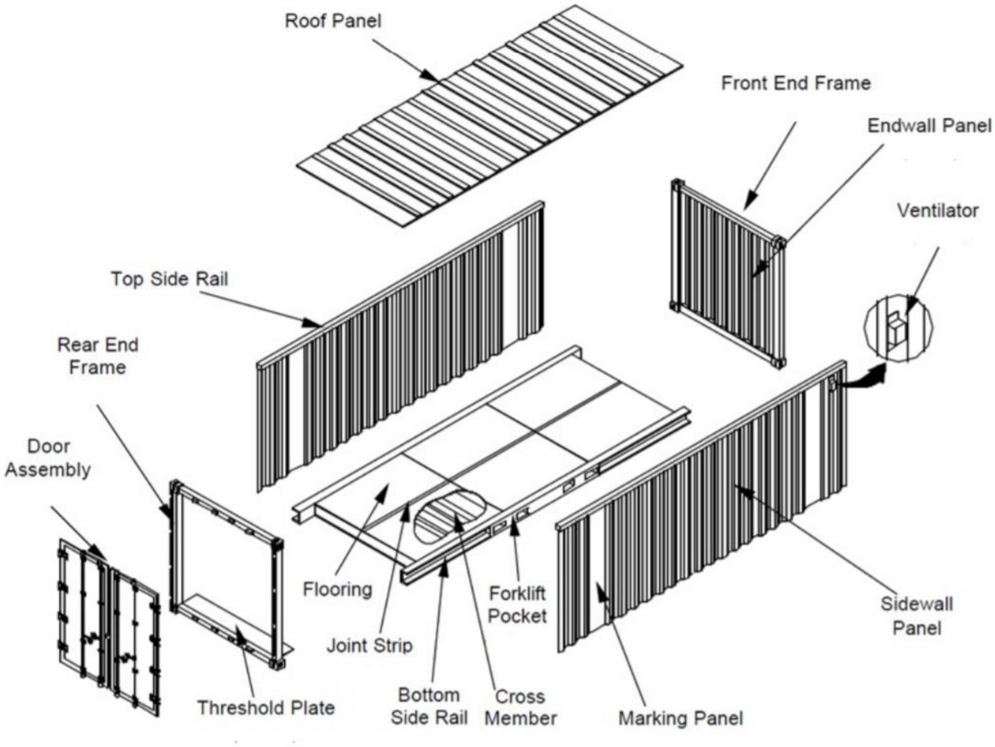
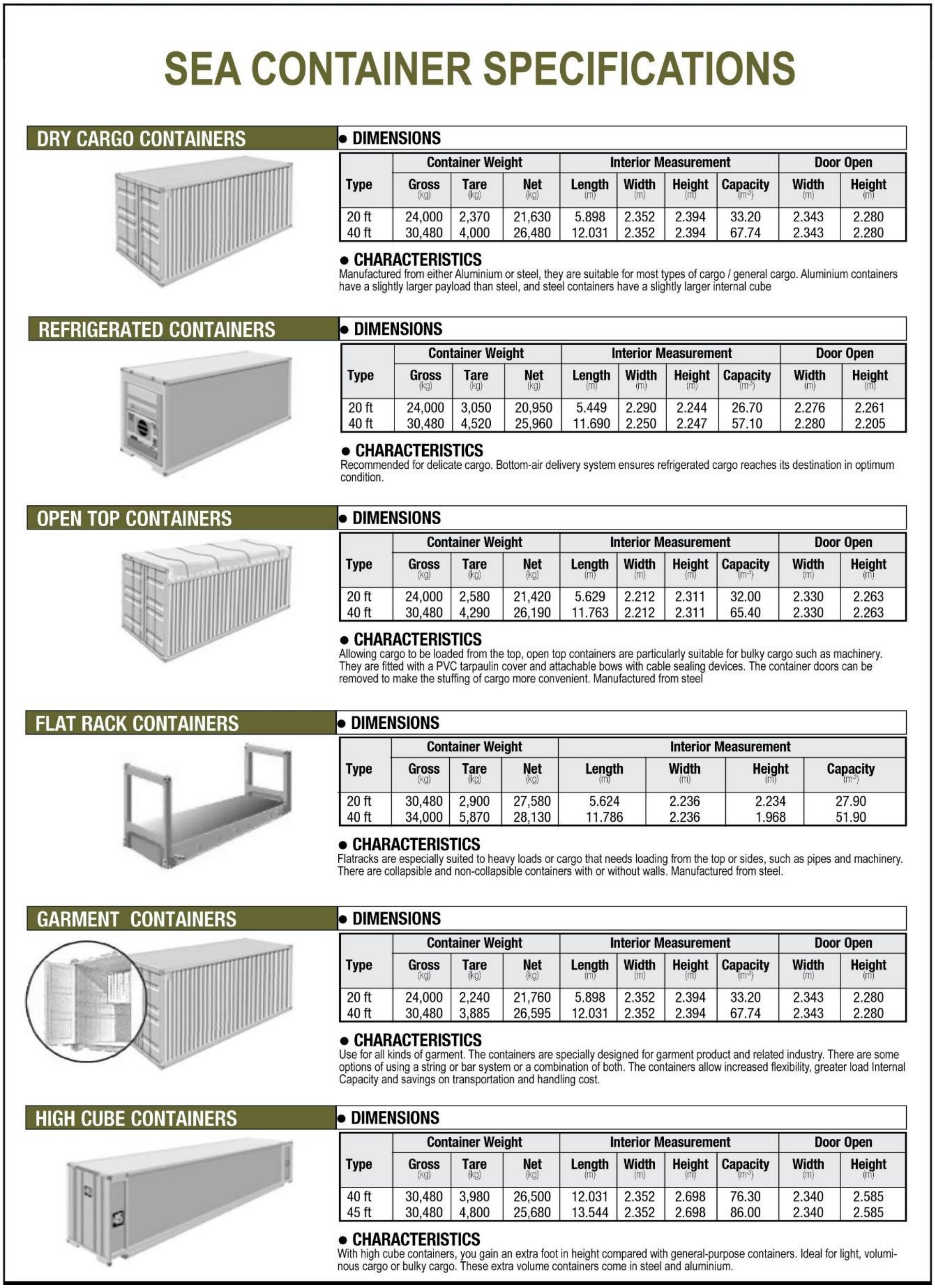


Figure 29. Detailed layers (source: Residential Shipping Container Primer)



SEA CONTAINER SPECIFICATIONS

DRY CARGO CONTAINERS

● DIMENSIONS

Type	Container Weight			Interior Measurement				Door Open	
	Gross (kg)	Tare (kg)	Net (kg)	Length (m)	Width (m)	Height (m)	Capacity (m^3)	Width (m)	Height (m)
20 ft	24,000	2,370	21,630	5.898	2.352	2.394	33.20	2.343	2.280
40 ft	30,480	4,000	26,480	12.031	2.352	2.394	67.74	2.343	2.280

● CHARACTERISTICS

Manufactured from either Aluminium or steel, they are suitable for most types of cargo / general cargo. Aluminium containers have a slightly larger payload than steel, and steel containers have a slightly larger internal cube

REFRIGERATED CONTAINERS

● DIMENSIONS

Type	Container Weight			Interior Measurement				Door Open	
	Gross (kg)	Tare (kg)	Net (kg)	Length (m)	Width (m)	Height (m)	Capacity (m^3)	Width (m)	Height (m)
20 ft	24,000	3,050	20,950	5.449	2.290	2.244	26.70	2.276	2.261
40 ft	30,480	4,520	25,960	11.690	2.250	2.247	57.10	2.280	2.205

● CHARACTERISTICS

Recommended for delicate cargo. Bottom-air delivery system ensures refrigerated cargo reaches its destination in optimum condition.

OPEN TOP CONTAINERS

● DIMENSIONS

Type	Container Weight			Interior Measurement				Door Open	
	Gross (kg)	Tare (kg)	Net (kg)	Length (m)	Width (m)	Height (m)	Capacity (m^3)	Width (m)	Height (m)
20 ft	24,000	2,580	21,420	5.629	2.212	2.311	32.00	2.330	2.263
40 ft	30,480	4,290	26,190	11.763	2.212	2.311	65.40	2.330	2.263

● CHARACTERISTICS

Allowing cargo to be loaded from the top, open top containers are particularly suitable for bulky cargo such as machinery. They are fitted with a PVC tarpaulin cover and attachable bows with cable sealing devices. The container doors can be removed to make the stuffing of cargo more convenient. Manufactured from steel

FLAT RACK CONTAINERS

● DIMENSIONS

Type	Container Weight			Interior Measurement			
	Gross (kg)	Tare (kg)	Net (kg)	Length (m)	Width (m)	Height (m)	Capacity (m^3)
20 ft	30,480	2,900	27,580	5.624	2.236	2.234	27.90
40 ft	34,000	5,870	28,130	11.786	2.236	1.968	51.90

● CHARACTERISTICS

Flatracks are especially suited to heavy loads or cargo that needs loading from the top or sides, such as pipes and machinery. There are collapsible and non-collapsible containers with or without walls. Manufactured from steel.

GARMENT CONTAINERS

● DIMENSIONS

Type	Container Weight			Interior Measurement				Door Open	
	Gross (kg)	Tare (kg)	Net (kg)	Length (m)	Width (m)	Height (m)	Capacity (m^3)	Width (m)	Height (m)
20 ft	24,000	2,240	21,760	5.898	2.352	2.394	33.20	2.343	2.280
40 ft	30,480	3,885	26,595	12.031	2.352	2.394	67.74	2.343	2.280

● CHARACTERISTICS

Use for all kinds of garment. The containers are specially designed for garment product and related industry. There are some options of using a string or bar system or a combination of both. The containers allow increased flexibility, greater load Internal Capacity and savings on transportation and handling cost.

HIGH CUBE CONTAINERS

● DIMENSIONS

Type	Container Weight			Interior Measurement				Door Open	
	Gross (kg)	Tare (kg)	Net (kg)	Length (m)	Width (m)	Height (m)	Capacity (m^3)	Width (m)	Height (m)
40 ft	30,480	3,980	26,500	12.031	2.352	2.698	76.30	2.340	2.585
45 ft	30,480	4,800	25,680	13.544	2.352	2.698	86.00	2.340	2.585

● CHARACTERISTICS

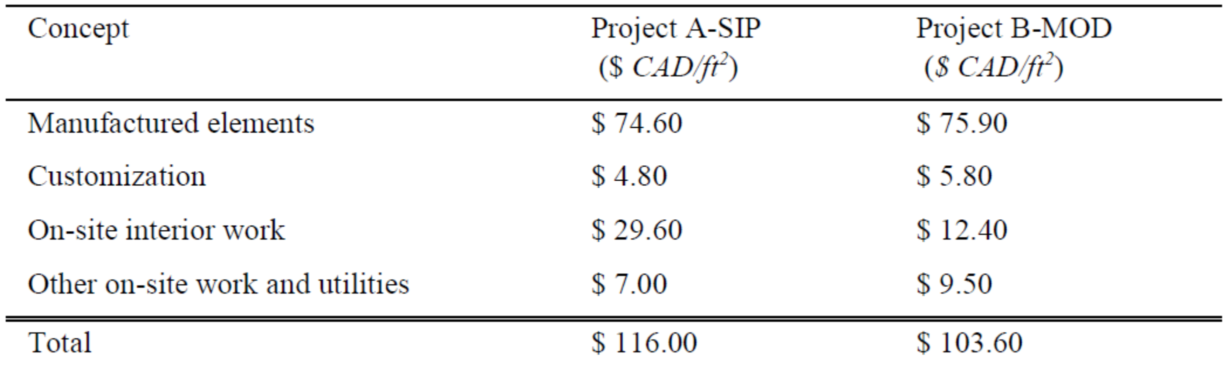
With high cube containers, you gain an extra foot in height compared with general-purpose containers. Ideal for light, voluminous cargo or bulky cargo. These extra volume containers come in steel and aluminium.

Figure 30. Container specifications showing defined types and dimensions (source: Hapag-Lloyd)

Except for the pros and cons, in the construction, one of the most important factors is cost. As a research of (Lopez & Froese, 2016) prefabricated method is relatively the inexpensive one. In this research they compared panelized or modular construction system. Two case study analysis were performed as;

- Project A-SIP: Structural insulated panels (single-family home built)
- Project B-MOD: Prefabricated modules (single-family home built)
  - This prototype is a single family home and consists of 2 storeys, 2 bathrooms, 3 bedrooms with a total construction area of 1620 ft^2 at Vancouver, Canada.

Table 1. Comparison for cost analysis Project A-SIP and Project B-MOD (source: Lopez & Froese, 2016)



Concept	Project A-SIP ($ *CAD/ft^2*)	Project B-MOD (*$ CAD/ft^2*)
Manufactured elements	$ 74.60	$ 75.90
Customization	$ 4.80	$ 5.80
On-site interior work	$ 29.60	$ 12.40
Other on-site work and utilities	$ 7.00	$ 9.50
Total	$ 116.00	$ 103.60

The results show that more cost-effective method is modular one. Lopez and Froese (2016) also stated that the difference of costs between two cases is approximately 11% which leads to rise in the labor and time for MEP and drywall operations to install and connect the respective systems or components and this can be observed on-site interior work. On the other hand, the two alternatives have similar costs, including manufacturing, transporting and delivering.

4.2 Case Studies

Case 1: Ken Block's Container Headquarters

The company has 25 workers in the old plant including two different parts: one of them is marketing and management, other one is area of service and workshop. The main design idea is to use recycled materials with aiming sustainability.

Figure 31. Office hall of Ken Block's (source: DesignBoom)

12000 ft^2 Old industrial building was redesign with modular construction method by using shipping containers. In the construction, 17 recycled shipping containers were used. These containers are coloured with green and blue. The containers also have some logos of whose supporters.

The company were willing to design in more flexibility because Ken Block works for motorsports and can need more space. The container looks also provided facility view while modern working areas were designed (*figure 32*).

Figure 32. Service part of building with customized container (source: DesignBoom)

Figure 33. Inner view of container (source: DesignBoom)

Bamboo and skateboard are used in the slab construction to ensure sustainability and use of recycled material.

Figure 34. Perspective view from top of container (source: DesignBoom)

Case 2: Cramer Office

Cramer office has 150 employees who are working for marketing and brand consulting. Six boxes were used in design that includes three of them are for meeting and the other three are open offices.

Parallel with company works, spaces were designed with new technology and smartness. In the meeting spaces, there is an intelligent system to show daily arrangements and their organizations.

Each box is 20 ft container which was aimed to be sustainable and environmental. The boxes were also enabled to customize with different colours.

Figure 35. Office building of Cramer (source: Dwell)

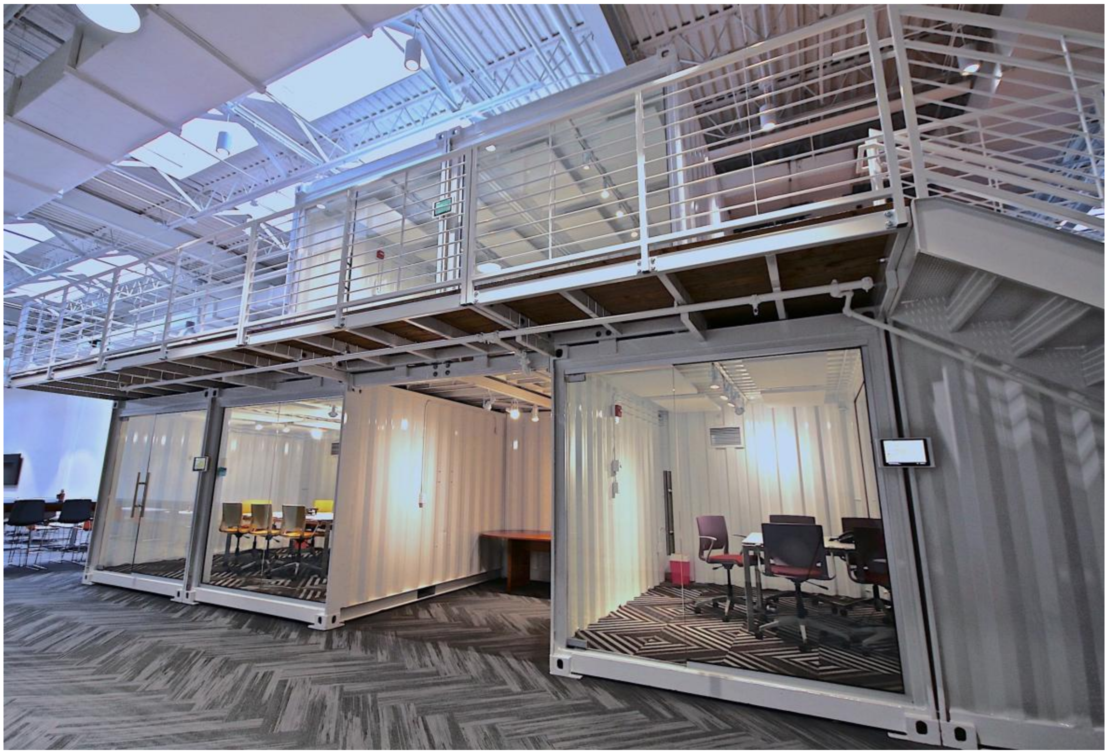


Figure 36. Two-floor container block (source: Dwell)

Figure 37. Meeting space of Cramer (source: Dwell)

Figure 38. Cafe and resting space (source: Dwell)

Case 3: Kohlman

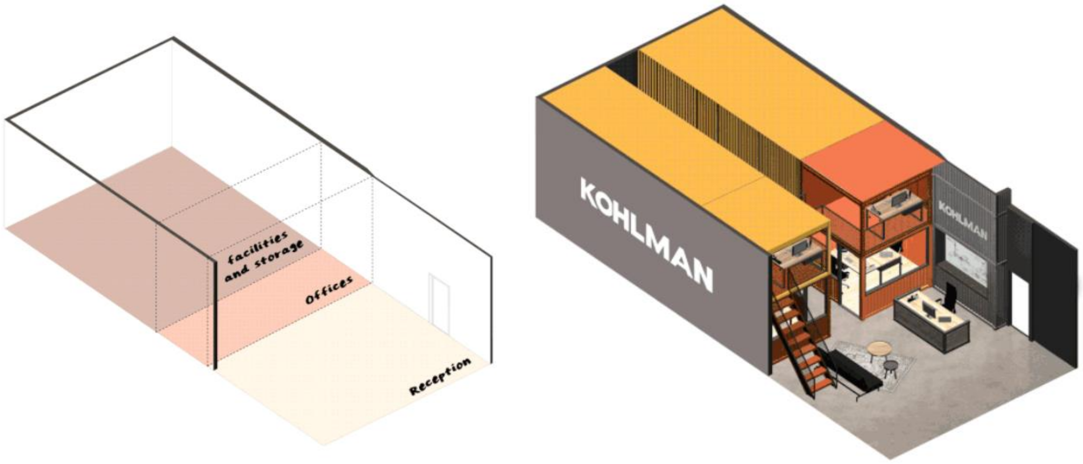


Figure 39. Axonometric view (source: Design-milk)

The new office design of the company, which sells bathroom products, consists of two-story blocks by placing the containers upside down. The building has limited spaces but, using containers provides to use two floors for functions including office, facility and storing.

Figure 40. Colored containers of Kohlman (source: Design-milk)

The containers were colored and finishes of openings were highlighted with black colored steel. The lighting elements are also compatible with these steels.

Figure 41. Inside of containers (source: Design-milk)

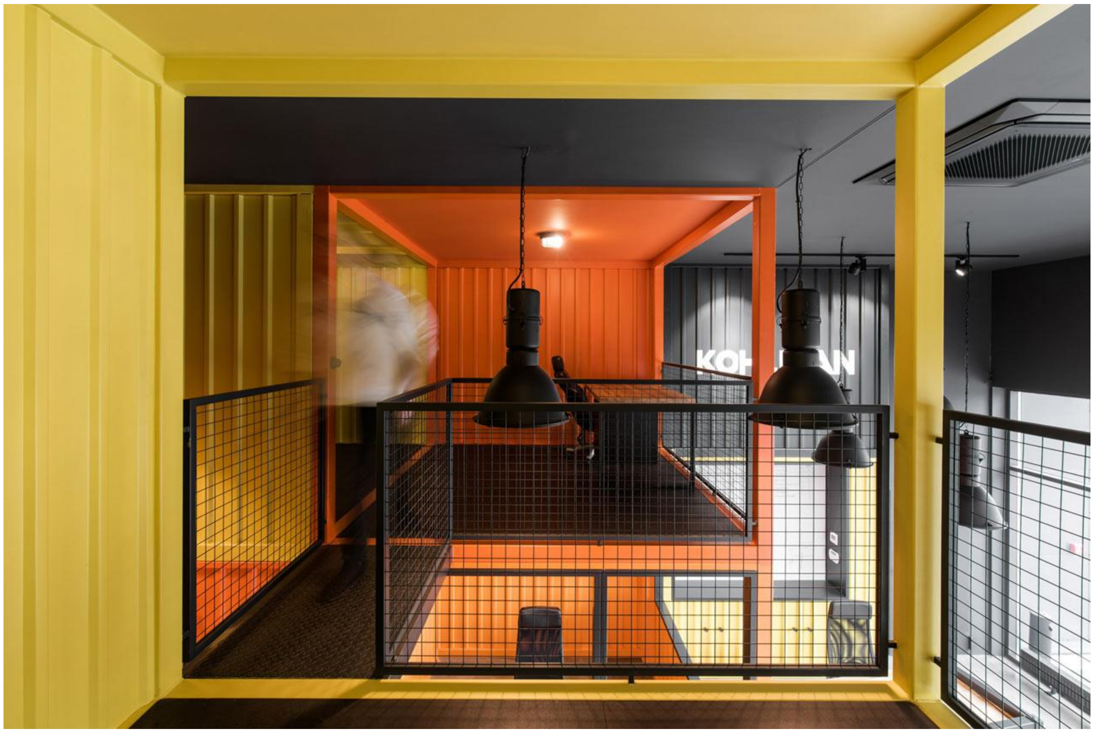


Figure 42. Upper containers (source: Design-milk)

5. Modularity in Building

A module is each of a group of standardized units which are used to build multiple or complex structures. The module can be also called a detailed part of entire work that is designated detailed with specialized uses can be reformed as whole building by combining joints. The modules are prefabricated in a manufacturing facility that means away from construction sites. In the construction industry, these prefabricated units are totally installed with electrical, mechanical and plumbing and designed with trim works. Modular construction defines to assembly a set of building components as the module formed on the dimensions or standards which restrict and determine the design decisions and transported on-site. The modular building is composed of many rooms with units preassembled with technical installations.

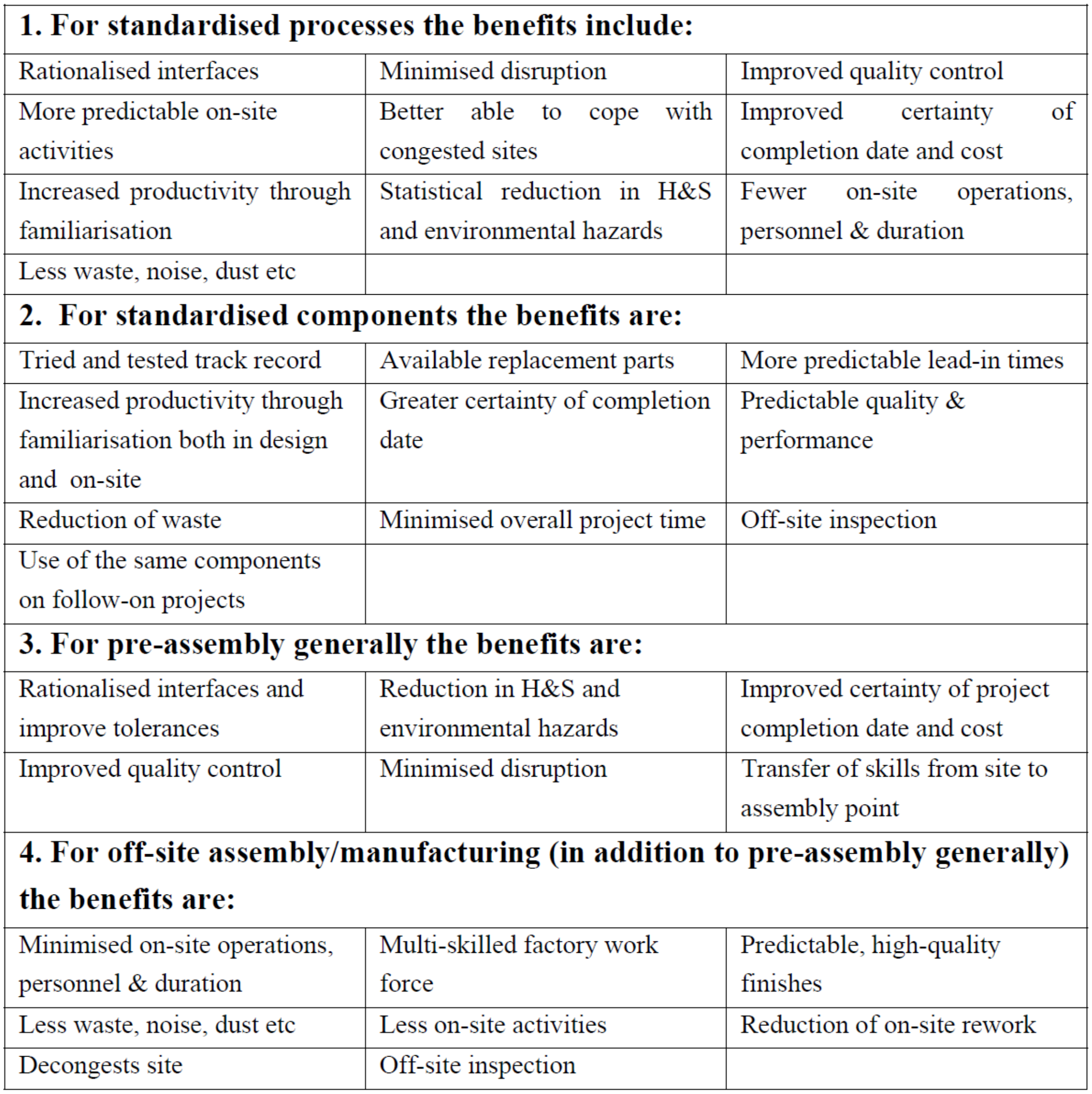
Modules are also standardized units in the market that are also stated by Erixon (1998), the specified functions of modules are used to solve technical problems. Modularity requires standardizing, which means a module unit enables to modify and transform into another unit. Besides, standardization and modularity are not in the same meaning. According to Borjesson (2012), while modularization varies with standardized, standardization limits variations and their performance which causes to not preferred by clients.

In construction, standardization and pre-assembly have been discussing for many years. However, effective implementation of them over has increased with numerous studies and was dedicated as part of solution to the problems in the building services and construction industry. Standardization is a way to combine numerous elements, approaches or procedures into common fields and to specialize them for users such as companies, contractors or customers. On the other hand, pre-assembly is named entire actions before appearing of last jobs such as installation of a system or building component. To make detailed, pre-assembly can be divided into four categories that are building components such as openings, cross-sectional elements as windows frames and finishing panels, non-sectional such as sanitary system, water hoses, and modules for modular systems to create total module (Neale, et al., 1993, Pasquire, et al., 2002).

5.1 Benefits of Modularity in Building Design

In previous part, standardization and pre-assembly were defined. They also provide many potential benefits of modularity in terms of processes and components have been summarized by (Pasquire & Gibb, 2002) and listed in *table 2*.

Table 2. Benefits of modularity (source: Pasquire & Gibb, 2002)



1. For standardised processes the benefits include:		
Rationalised interfaces	Minimised disruption	Improved quality control
More predictable on-site activities	Better able to cope with congested sites	Improved certainty of completion date and cost
Increased productivity through familiarisation	Statistical reduction in H&S and environmental hazards	Fewer on-site operations, personnel & duration
Less waste, noise, dust etc		
2. For standardised components the benefits are:		
Tried and tested track record	Available replacement parts	More predictable lead-in times
Increased productivity through familiarisation both in design and on-site	Greater certainty of completion date	Predictable quality & performance
Reduction of waste	Minimised overall project time	Off-site inspection
Use of the same components on follow-on projects		
3. For pre-assembly generally the benefits are:		
Rationalised interfaces and improve tolerances	Reduction in H&S and environmental hazards	Improved certainty of project completion date and cost
Improved quality control	Minimised disruption	Transfer of skills from site to assembly point
4. For off-site assembly/manufacturing (in addition to pre-assembly generally) the benefits are:		
Minimised on-site operations, personnel & duration	Multi-skilled factory work force	Predictable, high-quality finishes
Less waste, noise, dust etc	Less on-site activities	Reduction of on-site rework
Decongests site	Off-site inspection	

Another important benefit is further value of modular construction and financial saving. The consulting companies make research about modular construction and its benefits especially costs. First example was studied by the KPMG National Audit (2015) to define financial benefits of modular construction in terms of on-site inspection, maintenance, borrowing period, revenue stream. Although office shows unit costs of volumetric modules for new houses were higher than traditional onsite work construction, financial benefits of modular construction solutions were equal to £90/m^2 in 2015 prices. These savings are shown in *figure 32*.

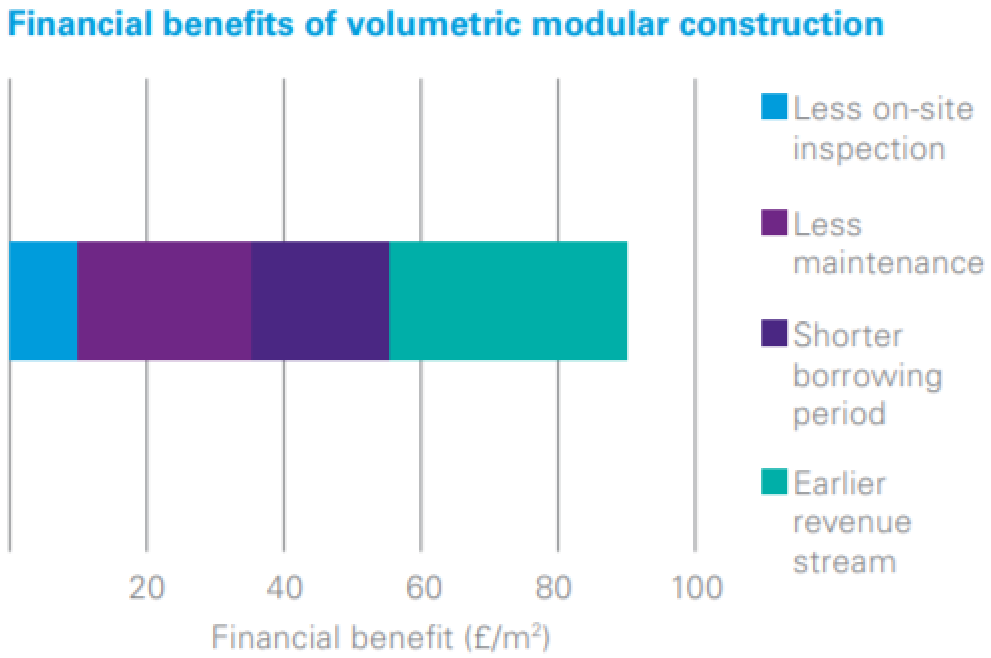
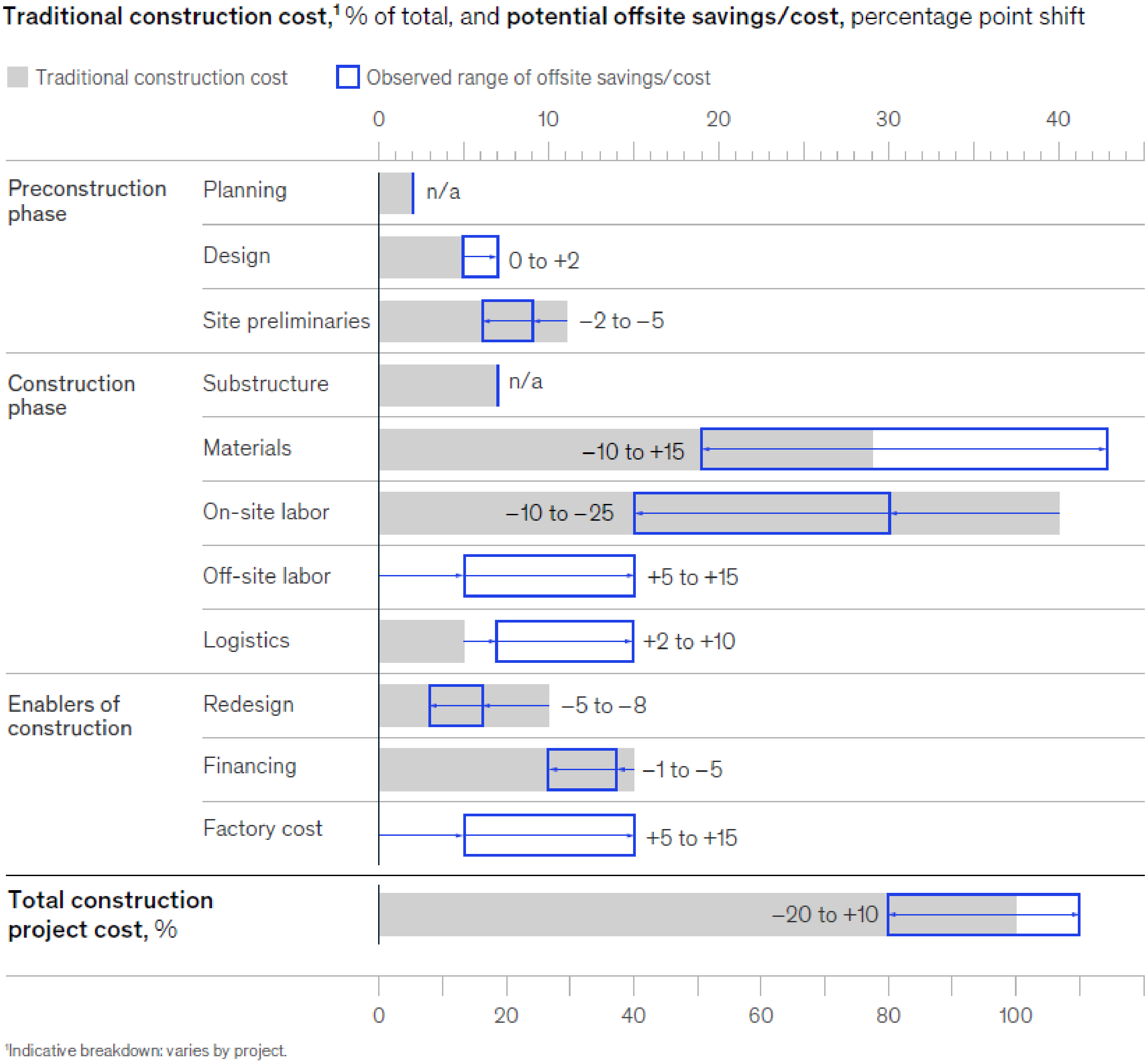


Figure 43. Financial benefits of volumetric modular construction (source: KPMG Audit Office, 2015)

Construction savings come from different stages. First, those who participate outside the process and the need for them are reduced. Thus, the additions to prices, which are added as profit, are saved. This increases the cost of on-site work and therefore reduces the cost of material used and logistics. Although modular systems can be redesigned with low costs, they have high delivery costs. For this reason, dormitories, hotels, and low-cost housing offer considerable savings while this saving is not easy for offices and high-quality housing (McKinsey&Company, 2019).

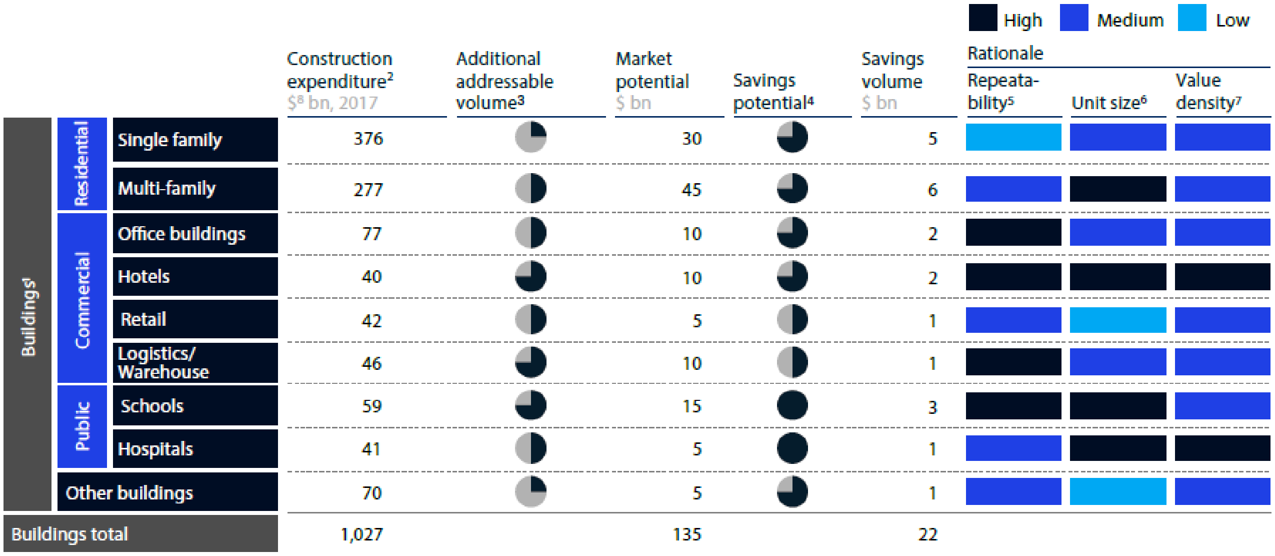
Table 3 shows all costs and savings which consist of the substructure, materials, labors, logistics. Due to more of an in-situ substructure, the overall savings are affected when compared with a modular approach including off-site labor. 20% savings can be observed; however, logistics or material costs can be more than labor savings, and this causes 10% of costs to increase.

Table 3. Traditional construction costs and potential savings (source: McKinsey&Company, 2019)



Building types are important factor to define savings of modular construction. According to report by McKinsey&Company, in United States, modular construction method of all building types can save $22 billion annually for 2030 as seen in *table 4*. The most saving volume is expected to observe in residential buildings especially in multi-family houses. Retail, logistics/warehouse, hospitals and other buildings -except for listed types- could have fewer financial savings.

Table 4. Building types, their costs and annual savings for 2030 (source: McKinsey&Company, 2019)



⬛ High 🟦 Medium ⬜ Low

			Construction expenditure[2] $[8] bn, 2017	Additional addressable volume[3]	Market potential $ bn	Savings potential[4]	Savings volume $ bn	Rationale Repeatability[5]	 Unit size[6]	 Value density[7]
Buildings[1]	Residential	Single family	376	◔	30	◕	5	⬜	🟦	🟦
		Multi-family	277	◑	45	◕	6	🟦	⬛	🟦
	Commercial	Office buildings	77	◑	10	◕	2	⬛	🟦	🟦
		Hotels	40	◕	10	◕	2	⬛	⬛	⬛
		Retail	42	◑	5	◑	1	🟦	⬜	🟦
		Logistics/ Warehouse	46	◕	10	◑	1	⬛	🟦	🟦
	Public	Schools	59	◕	15	●	3	⬛	⬛	🟦
		Hospitals	41	◑	5	●	1	🟦	⬛	⬛
	Other buildings		70	◔	5	◕	1	🟦	⬜	🟦
Buildings total			1,027		135		22			

[1] European countries included: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, UK.

[2] Includes only new building projects. Renovation/maintenance projects are less suitable for modular construction, but offer other productivity gain potential.

[3] Informed estimates. A full moon corresponds to a potential construction project value for (additional) modular construction of ~30%, a quarter moon thus to ~7.5%, in 2030.

[4] Informed estimates. A full moon corresponds to savings potential of ~20%, a quarter moon thus to ~5%, for each € of addressed construction expenditure.

[5] No unique layout requirements (either from regulation, or design expectations).

[6] Small unit size allows standard transportation.

[7] High complexity of units, high share of wet rooms, etc.

[8] Used 2017 average annual exchange rate to convert to $ from Euroconstruct data in €.

The other benefit of modularity is in architectural design that is more flexibility, space-saving, simplified construction techniques and suitable growth of project. In addition, modularity provides many benefits in construction, including the time savings, improved quality of work, increased onsite safety performance, decreased onsite works, eliminated damages on nature and media by interventions. Besides, modular constructions with its limited shape and volume (mentioned in part 4.1) result in challenge with the execution of the mechanical, electrical and plumbing during the assembly (Korman T. M., 2001).

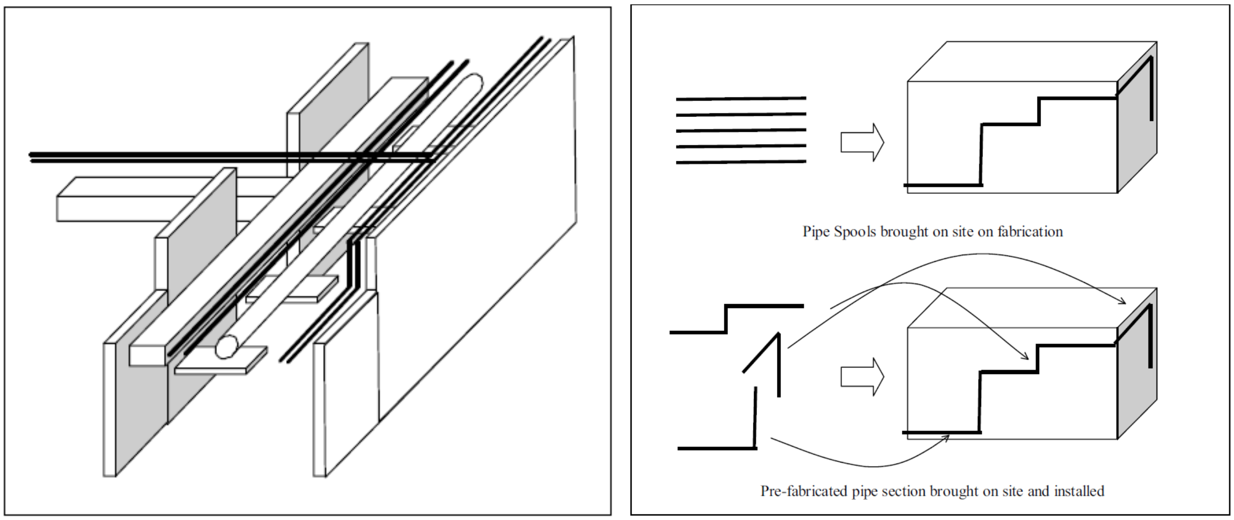
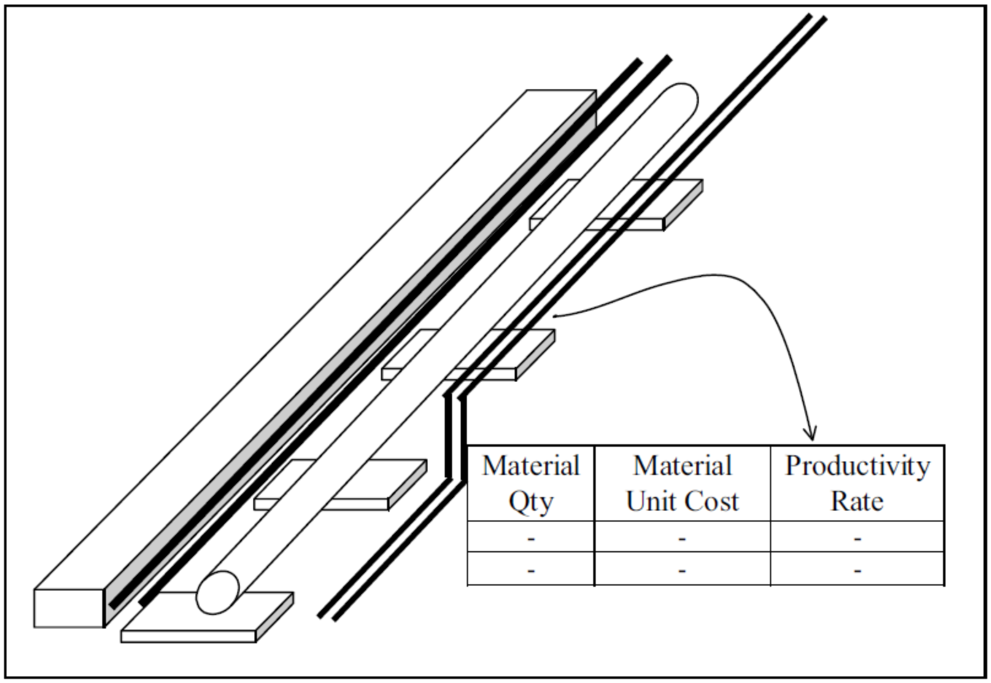


Figure 44. Rendering building systems which are located on the corridor and prioritizing systems in modular units during BIM (source: Korman, 2001)

In order to design the mechanical, electrical and sanitary installations correctly, the number of units can be decided using BIM, conflicts can be avoided, and the installation process can be prioritized. Subsequently, the components designed in this BIM can be checked for suitability by analysis such as various pricing and productivity calculations. (Korman T. L., 2010).

The designed 3D model through BIM helps to decrease risks, to create drawings easily, to fabricate easily of systems and less material wasted by showing all errors and overlapping. In addition, the 3D BIM models consider codes and standards with existing database inside of software. Also, material quantity, material unit cost and productivity rate can be defined through the system as seen in *figure 33*.

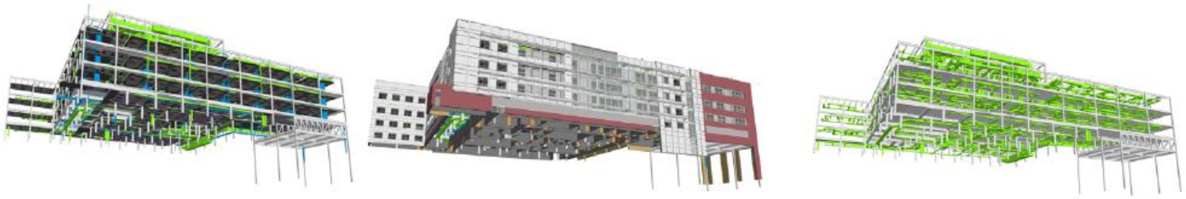


Material Qty	Material Unit Cost	Productivity Rate
-	-	-
-	-	-

Figure 45. Data combination including quantity, costs and productivity (source: Korman, 2001)

5.2 Modularity and Building Information Management

Interdisciplinary BIM workflow enables the efficient control by combination of structural, architecture and MEP BIM models in the same file (*figure 33).* This makes easier to gather analysis of modular components that provide new techniques in data management including the execution of MEP systems are drawn with the definition of locations for the service systems.



(a) Structural BIM Model (b) Architecture BIM Model (C) MEP BIM Model

Figure 46. BIM models in healthcare expansion project (source: Korman & Lu, 2010)

BIM monitors component changes identify deviations and align outputs with the information needs of the building system. To put it all in simple terms, as building systems, mechanical, electrical and plumbing systems are significant to be coordinated and fabricated in modular construction. As stated by Korman (2001), due to the responsibility of multi-disciplinary teams, there are many problems such as disintegrated and not coordinated design, construction, mechanical and electrical teams, different organization scenarios with the variation of technology level between engineers and contractors and not represented process as model for use by contractor's plan production.

An efficient way to solve these problems in modular construction appears with Building Information Modelling (BIM) which is used to coordinate, document and fabricate. The remarkable benefits of BIM, causing to be more competitive in modular construction industry, can be concluded as more rapid and efficient processes which help information to share, better design, monitoring LCA and environmental data, advanced production quality, exploit action from digital data and, enhanced client assistance, information storage during life span and, coordination and execution stages.

Nowadays, many remarkable projects are successfully provided by BIM services. These projects can be listed as:

- Qatar National Museum,
- Sydney Opera House,
- Petroleum Headquarters,
- Nanjing International Youth Cultural Centre,
- Beijing National Museum
- National Library of Sejong City

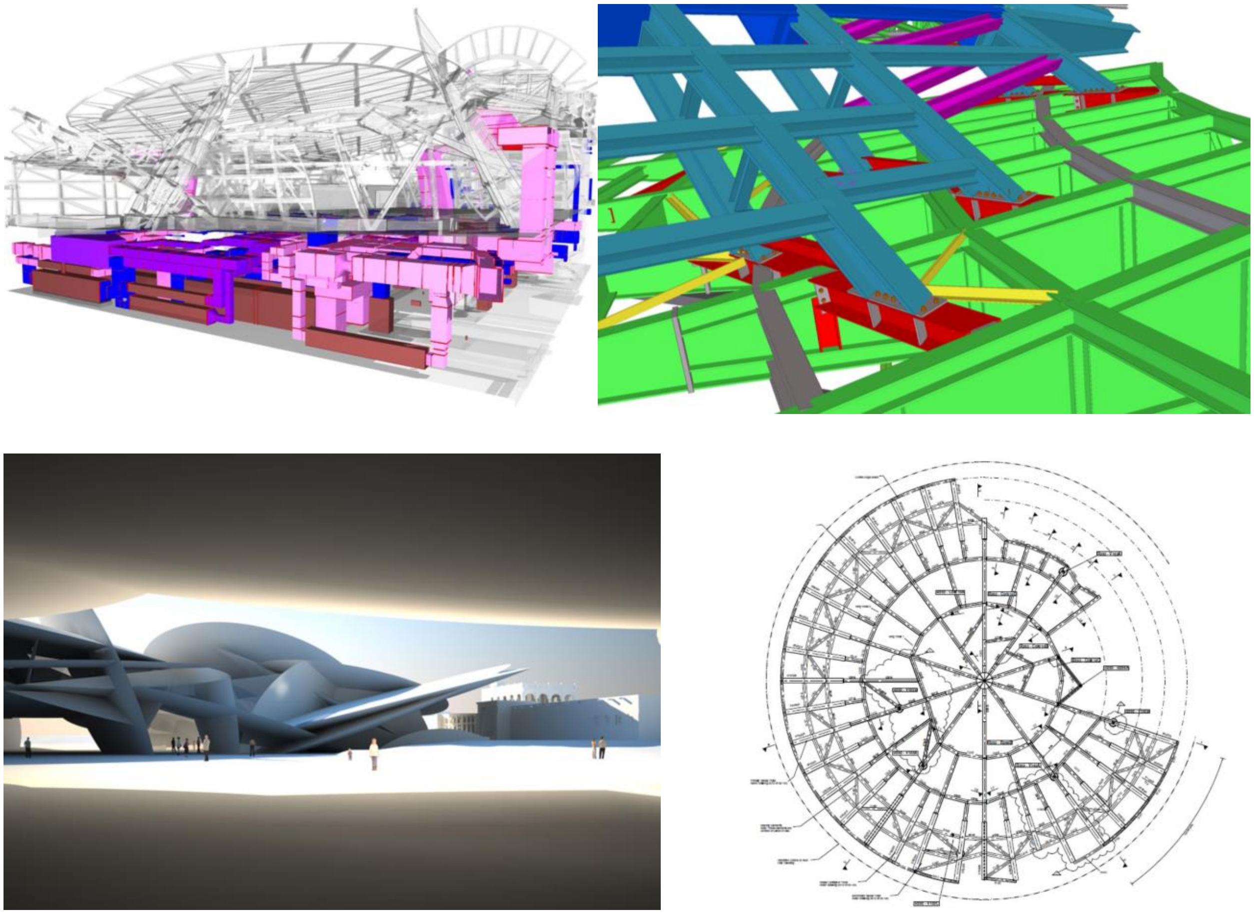
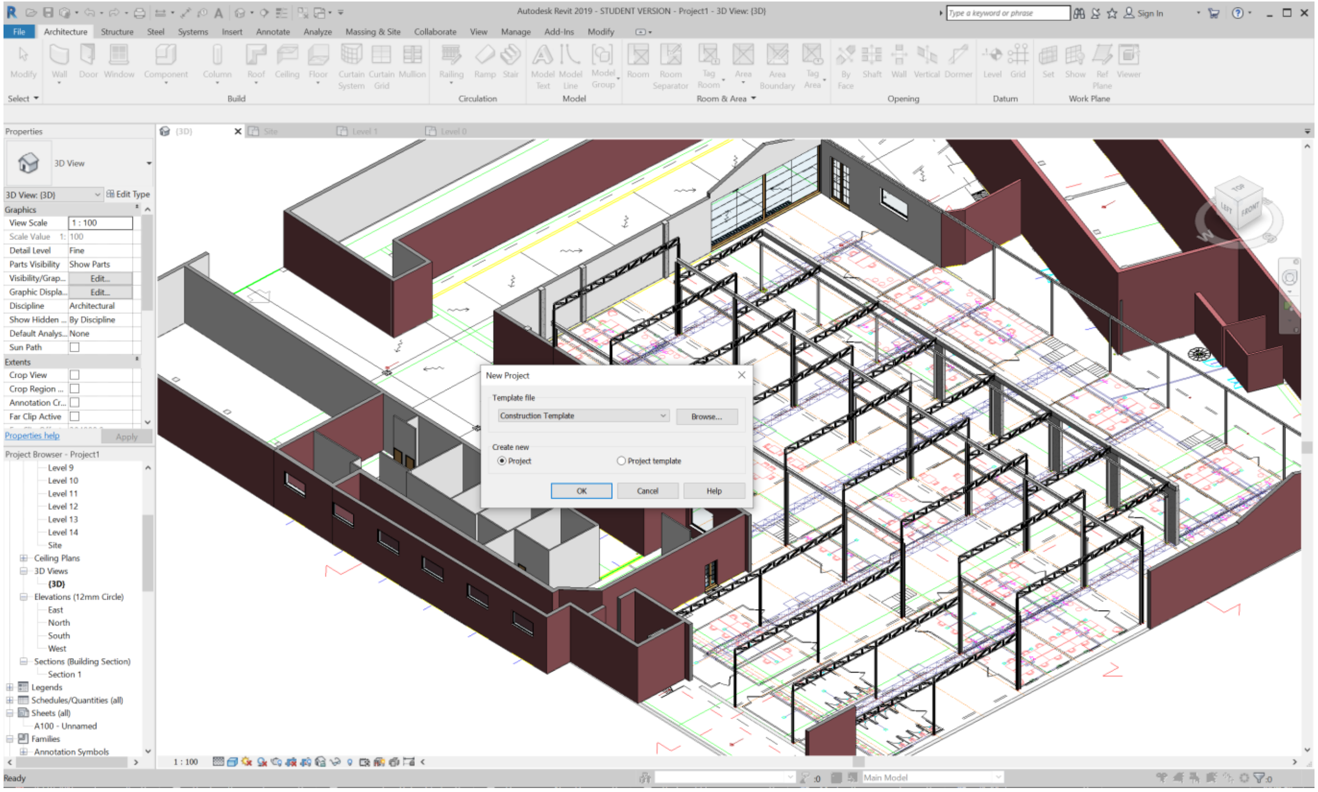


Figure 47. National Qatar Museum (source: Global BIM Awards, 2012)

Figure 48. Various units at different scales and building components in construction site (source: Zhanga et al., 2016)

To improve parametric design and support modularity, BIM can be used at different module levels. Whenever one module is taken apart from space modules such as kitchen, bathroom or office unit, the modularization of building components such as wall panels or MEP components is also enabled in BIM (*figure 36*).

To start the design process, first open a draft file and determine the unit to be drawn. Then, the architectural layout is created according to the design decisions. When each discipline starts to new project, they can change template files as construction, architectural, structural and mechanical templates. After the design process with the completion of the architectural model, the structural group performs its own tasks with suitable template and module selections. After the structural plan is finished, the mechanical plan is reached to associated group and the mechanical plan is completed with the help of various BIM tools (Zhanga, Longa, Lva, & Xianga, 2016).



3D View: {3D}

Graphics	
View Scale	1 : 100
Scale Value 1:	100
Detail Level	Fine
Parts Visibility	Show Parts
Visibility/Grap...	Edit...
Graphic Displa...	Edit...
Discipline	Architectural
Show Hidden ...	By Discipline
Default Analys...	None
Sun Path	☐
Extents	
Crop View	☐
Crop Region ...	☐
Annotation Cr...	☐
Far Clip Active	☐

New Project

Template file: Construction Template

Create new: ● Project ○ Project template

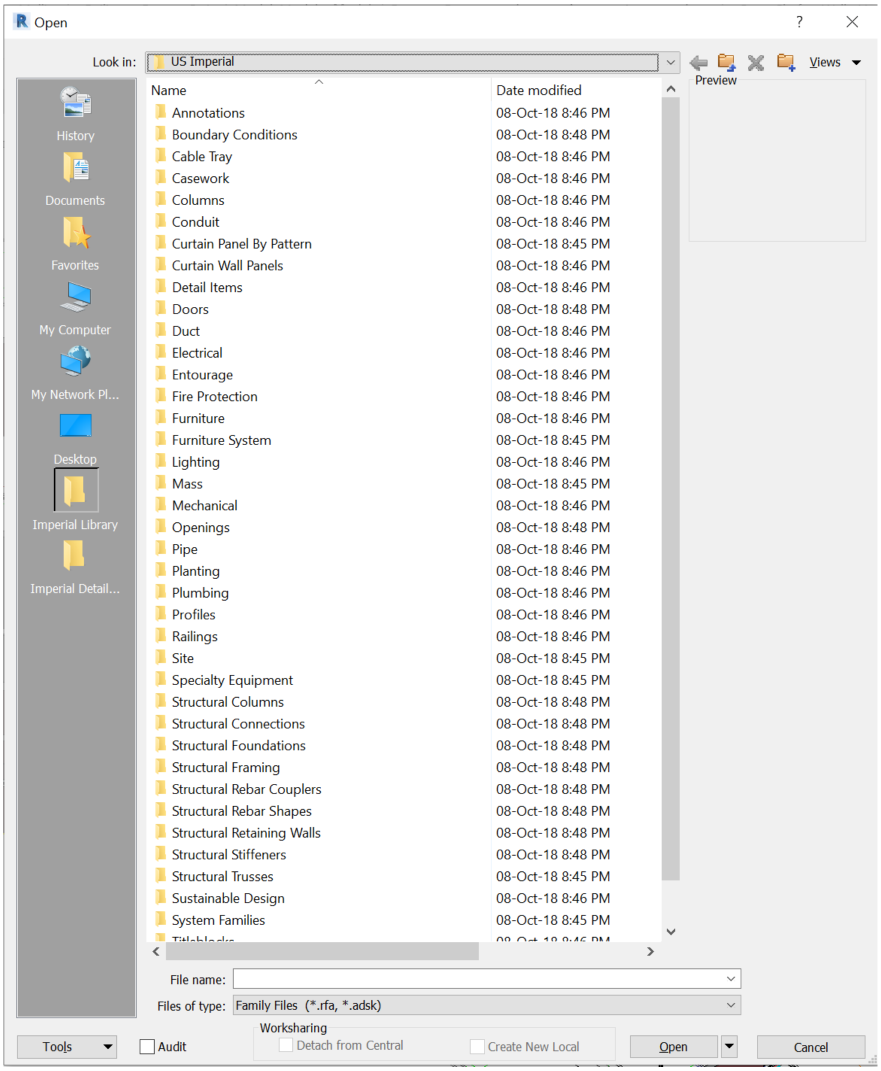
OK Cancel Help

Figure 49. Choosing a Revit template while opening new project

In modular design, the significant part is to create family in Revit since these families are stored in software library and it is possible to change and control same family group by editing only one. Modular units are repeated, and design is faster by using family tool.

5.2.1 BIM Background and Applications

BIM is a platform where all responsible and professional people can work together, aiming to create accurate, concrete and computable data by combining the data of various design processes created in three dimensions. In addition, this 3-D environment provides precise and rigorous steps of producing the required products, obtaining these products from the manufacturer and bringing them together in the field (Eastman, Teicholz, Sacks, & Liston, 2011).



Look in: US Imperial

Name	Date modified
Annotations	08-Oct-18 8:46 PM
Boundary Conditions	08-Oct-18 8:48 PM
Cable Tray	08-Oct-18 8:46 PM
Casework	08-Oct-18 8:46 PM
Columns	08-Oct-18 8:46 PM
Conduit	08-Oct-18 8:46 PM
Curtain Panel By Pattern	08-Oct-18 8:45 PM
Curtain Wall Panels	08-Oct-18 8:46 PM
Detail Items	08-Oct-18 8:46 PM
Doors	08-Oct-18 8:48 PM
Duct	08-Oct-18 8:46 PM
Electrical	08-Oct-18 8:46 PM
Entourage	08-Oct-18 8:46 PM
Fire Protection	08-Oct-18 8:46 PM
Furniture	08-Oct-18 8:46 PM
Furniture System	08-Oct-18 8:45 PM
Lighting	08-Oct-18 8:46 PM
Mass	08-Oct-18 8:45 PM
Mechanical	08-Oct-18 8:46 PM
Openings	08-Oct-18 8:48 PM
Pipe	08-Oct-18 8:46 PM
Planting	08-Oct-18 8:46 PM
Plumbing	08-Oct-18 8:46 PM
Profiles	08-Oct-18 8:46 PM
Railings	08-Oct-18 8:46 PM
Site	08-Oct-18 8:45 PM
Specialty Equipment	08-Oct-18 8:45 PM
Structural Columns	08-Oct-18 8:48 PM
Structural Connections	08-Oct-18 8:48 PM
Structural Foundations	08-Oct-18 8:48 PM
Structural Framing	08-Oct-18 8:48 PM
Structural Rebar Couplers	08-Oct-18 8:48 PM
Structural Rebar Shapes	08-Oct-18 8:48 PM
Structural Retaining Walls	08-Oct-18 8:48 PM
Structural Stiffeners	08-Oct-18 8:48 PM
Structural Trusses	08-Oct-18 8:45 PM
Sustainable Design	08-Oct-18 8:46 PM
System Families	08-Oct-18 8:45 PM

File name:

Files of type: Family Files (*.rfa, *.adsk)

Figure 50. Family files in Revit library

BIM provides logical building elements such as walls, steel profiles, windows and building service systems such as piping and sanitary installations. To provide them, BIM uses technological products or datasheets that help to create these elements in the context of the characteristics of the building. In this context, it contains the technical information collected about the various steel profile dimensions, window or door dimensions, required pipe cross-sections and how they are positioned on the market (Cooperative Research Centre Construction Innovation, 2007).

Nowadays, BIM is used as a common communication tool by people working from different disciplines to collect all data together and view them in three dimensions. However, defining BIM only as a platform, where all products are transferred in three dimensions, is not a correct description. However, most people use the BIM model as a professional program that can be placed in the right places of three-dimensional information groups as independent or established units interacted with each other. Besides, BIM improves cooperation and coordination in order to ensure that all project employees can be actively involved in all stages, by reducing overall work time. With the ability to provide this whole process, BIM helps determine the steps for the next process, providing accurate and tangible information that is more accurate and concrete for all working groups. To achieve this, all groups provide their data as same or compatible level of details. This is defined as "LOD" -Level of Detailing- which has classification according to considered data levels. These levels are LOD100, LOD200, LOD300, etc. that means orderly conceptual design with no more detail, design development including much detail and documentation including required data. This continues by recognizing more details.

6. Refurbishment Strategy

Building occupants and owners change in building life cycle, and this results in building renovation during these changes. These cause to lose of building spaces because of the construction and significant cost. Adjustments in the use of buildings can also cause changes in the total capacity of buildings, the use of buildings and relationship between environment and people. Renovation projects are provided by more changes in all system such as building structure, envelope, service systems and its interior. It is also stated by Slaughter (2001) that maintaining the current situation of the buildings, increasing the workability and usability of the building in a faster and more economical way throughout the life of the building contributes value to these buildings and prevents the disruption of the users' use of the building.

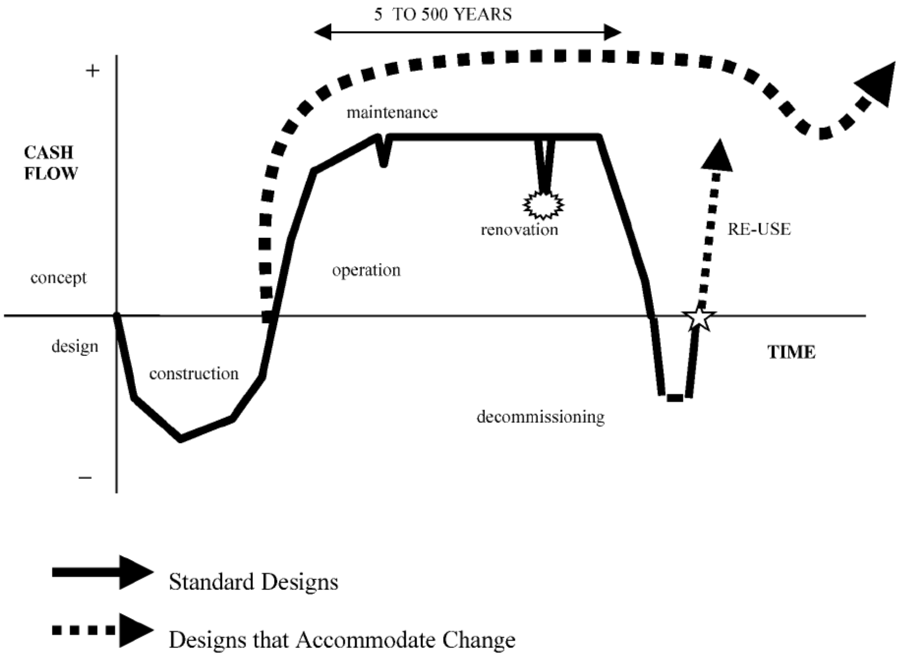


Figure 51. Changes during the life of buildings and the effects of these changes (Slaughter, 2001)

In this project, different types of changes were considered as a building envelope including main components as wall, roof, slab, building services such as heating, cooling, ventilation and other services, building functions that are decided in program demands. As a result, refurbishment strategy is tackled into three main processes. First one is refurbishment of building including thermal mass and loads improvement with new occupant profile, second one is reuse of inner space with prefabricated modules, last one is reconditioning of roof with PV panels.

6.1 Program of Demands

In the previous part, refurbishment strategies are discussed in consideration of literature reviews and research. As a decision of building analysis, since Bombelli building isn’t used daily life; however, the building can host many special events due to building capacity. All these studies and analyses emphasize that there should be a change in the function of the building. The function change also brings together several requirements and demands. These can be divided into the demands of the new use and a set of technical requirements depending on the use. In this section, the thoughts that arise as a result of brainstorming on the needs of the new user will be mentioned and the technical requirements will be explained in the next section.

In part 5.1, the cost savings of building types have discussed in terms of modular construction methods. When compared to other uses seen in this part 5.1, the most cost-saving uses are listed as housing, school, office and hotel, respectively. Compared to reproducibility and size of unit and density, it is seen that hotel use is at the highest rate.

When the usability and volume of the building are considered, it was considered that the building isn’t suitable for residential and school use because of the old usage being industrial. Particularly considering that the school usage doesn't comply with the flexibility principle of the project, a more flexible and changeable design is aimed by preferring commercial use. This was discussed as the most convenient office use for commercial use, and the hotel can meet the needs of office users, and then the program was shaped according to these decisions. Considering the use of office and hotel, the modularity of these units may also indicate that they may change regularly. In order to ensure the continuity of these modifications and the flexible use, common office spaces have been considered. In this way, these offices will be rented at certain periods and there will be a continuous flow in the building. This decision of renting office was also supportive in terms of knowing the number of occupants in the building and analysing the user needs accordingly and controlling whether the building requirements were met.

In fact, the research focused on the future tendency in the buildings. The design of existing buildings is not suitable for change, the existing interior walls are limited by the need for change and need to demolish, which requires more cost and more time, that hinders radical changes in functions.

6.2 Design Ideas

After deciding on the use of the building and its main program, design ideas were discussed to be considered in order to provide a flexible design. Because of the aim of a modular design and following a sustainable approach, it is aimed to obtain a reusable and aesthetic image by using container logic. During this period, various common office uses, container units, which are currently designed or presented for leasing purposes have been examined. Although the dimensions of the building are one of the biggest constraints in the examples, it has been observed that this problem can be solved because the containers are small units. Today, the idea of an open office has become one of the trend issues in the creation of a working space. This is a popular idea in terms of providing offices to newly founded small-sized companies “start-ups” by renting open offices, creating an insight into the company with the place to welcome visitors and make meetings, and to get to know each other and create networks. In this research, these open offices were also questioned if they can be moved and how to design it. In order to gain the lost value of an old industrial building and provide income to its owner, the design of the office function can be changed to another function if desired. As a solution, prefabricated units which can be installed, reused and installed quickly can be considered considering the results of modular design.

The main concept as flexibility is provided by the modular construction method which can excel where speed, security, and safety are outstanding. Because of their design, containers provide ease of transportation and can be easily separated into components. In this way, while the quick installation is provided, it is also provided to be divided into quick parts. In general, it is known that these modules are easily movable and displaceable since their weight and portability are tested. It is widely used today because it is quick to modify and more useful than expected.

Figure 52. Hotel containers with modern design (source: CAPSA)

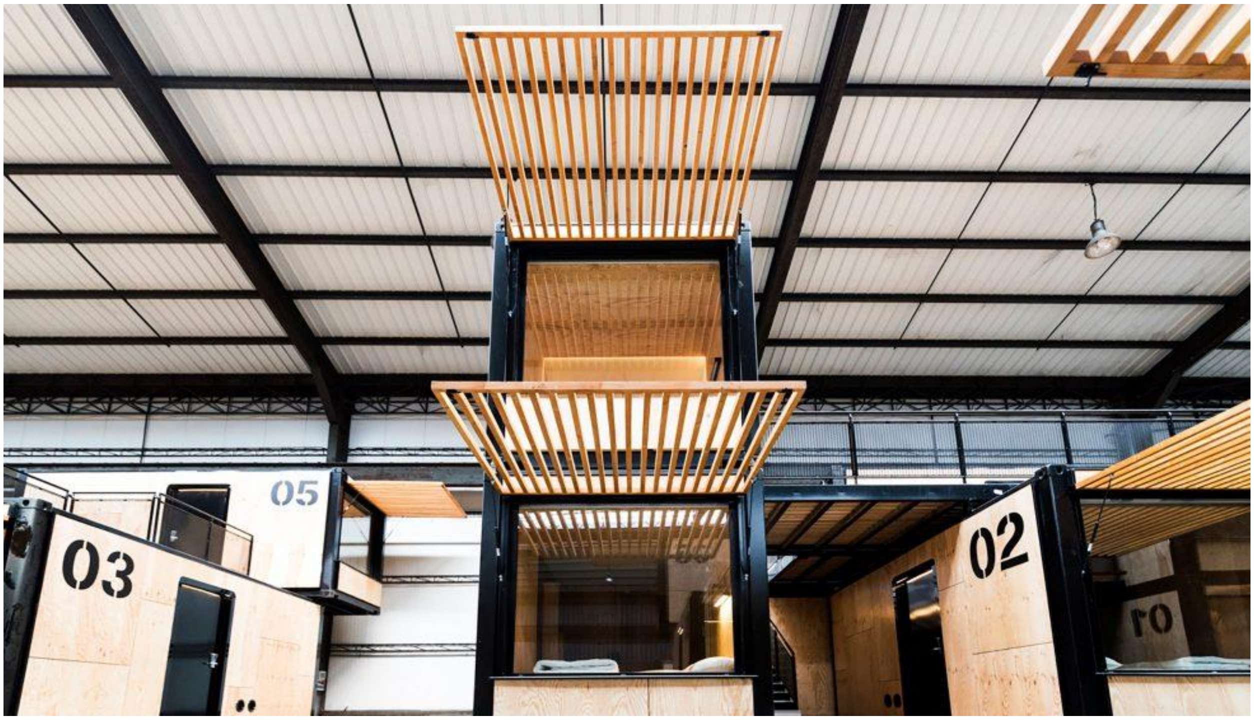


Figure 53. A view from the ground to the position of containers (source: CAPSA)

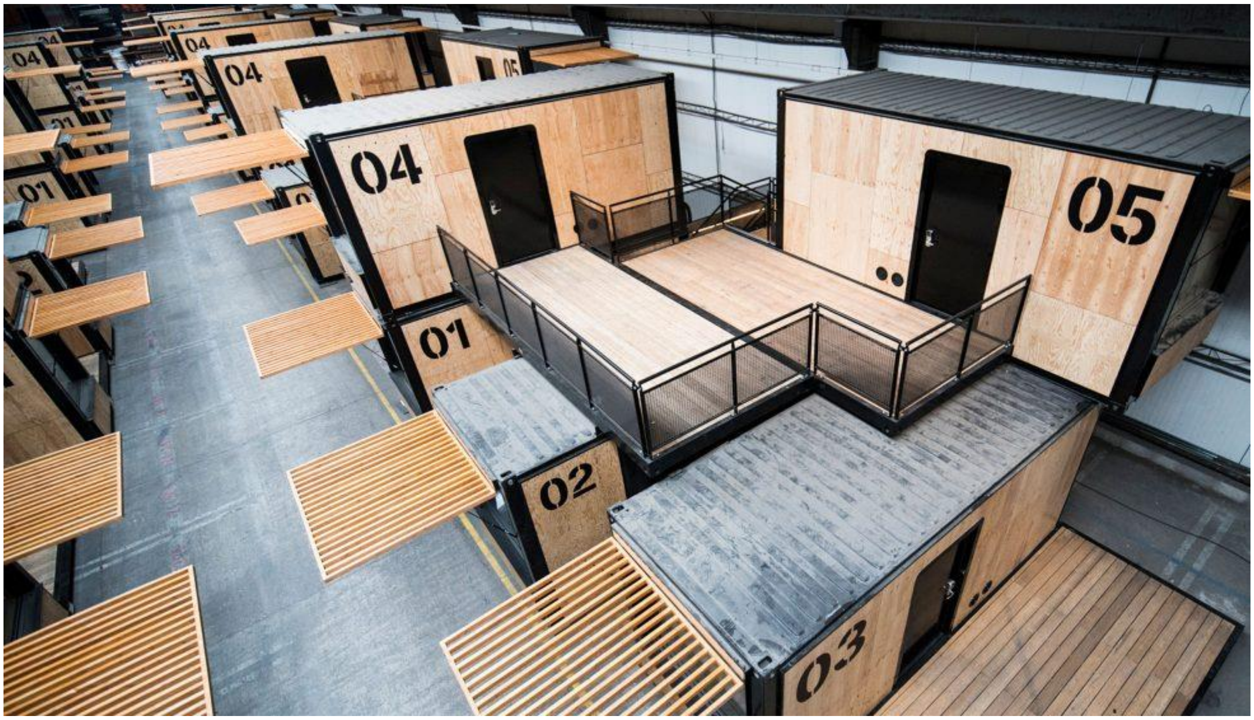


Figure 54. Perspective view of containers on the upper (source: CAPSA)

These containers provide users with the feeling that they are in their own offices because they can differentiate in the location and can be customized to the user. This can be interesting to rent it as an office just because they can do the customization. However, accommodation for those concerned is another important use. The use of containers for accommodation is convenient to ensure that people do not have to waste time and are on a project when they have limited time to come out and come back or have short-term guests.

Figure 55. Coworking offices in old industrial building for Bakke Rij (source: TreeHugger)

Except for main uses of office and accommodation, users will also need places for lunch and dinner, or between working and eating. These spaces are also designed according to the needs of the container in such a way that enough size and necessary equipment are provided.

Figure 56. Coworking spaces of Drukta + Formail Office (source: Architizer)

Figure 57. Other containers of the coworking office in Drukta+Formail (source: Architizer)

Figure 58. Free hall with cafe in old industrial building (source: TreeHugger)

Throughout research and project, the design idea was offered people multipurpose, good design solutions considering being flexible to change if needed during life span and efficient space uses in terms of needed capacity and less energy consumption.

6.3 Case Study

After examination of different case studies in terms of their refurbishments and reuse strategies, our project case study was analyzed in terms of structure, function, layout and dimensions. The case study -Bombelli- is locate on Lambrate, Milano and it is old manufacturing plant area. Total area consists of 6 different buildings including main manufacturing space and other supporting uses around it (*figure 47*).

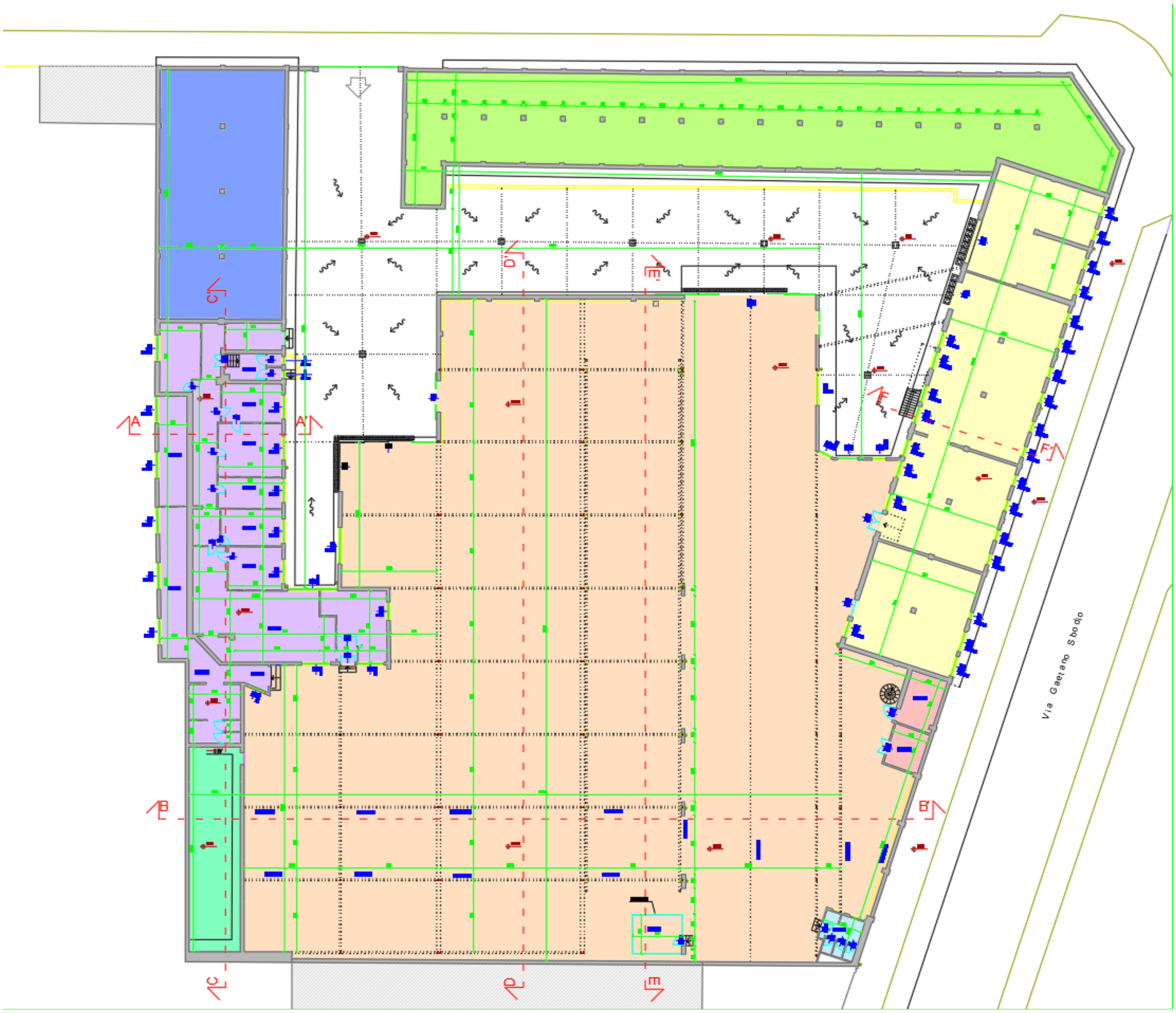


Figure 59. Layout of the case study -Bombelli-

Figure 60. Section of the main building - old plant

7. Prefabricated Unit Design

The prefabricated unit is assumed as a freight container that is designated for intercontinental traffic for dimensional requirements and used in proposal for redesign of Bombelli. The definition of freight container is indicated in the referenced normative ISO 830:1999 Freight containers terminology. A freight container is defined as the unit is easy to install and with a volume of 1 cubic meter or more, which allows for reuse and is durable, which can be carried at one time and does not require more equipment to be transported, and can provide a transition from one use to another. Another definition is freight containers manufactured in accordance with ISO standards.

7.1 Requirements and Demands

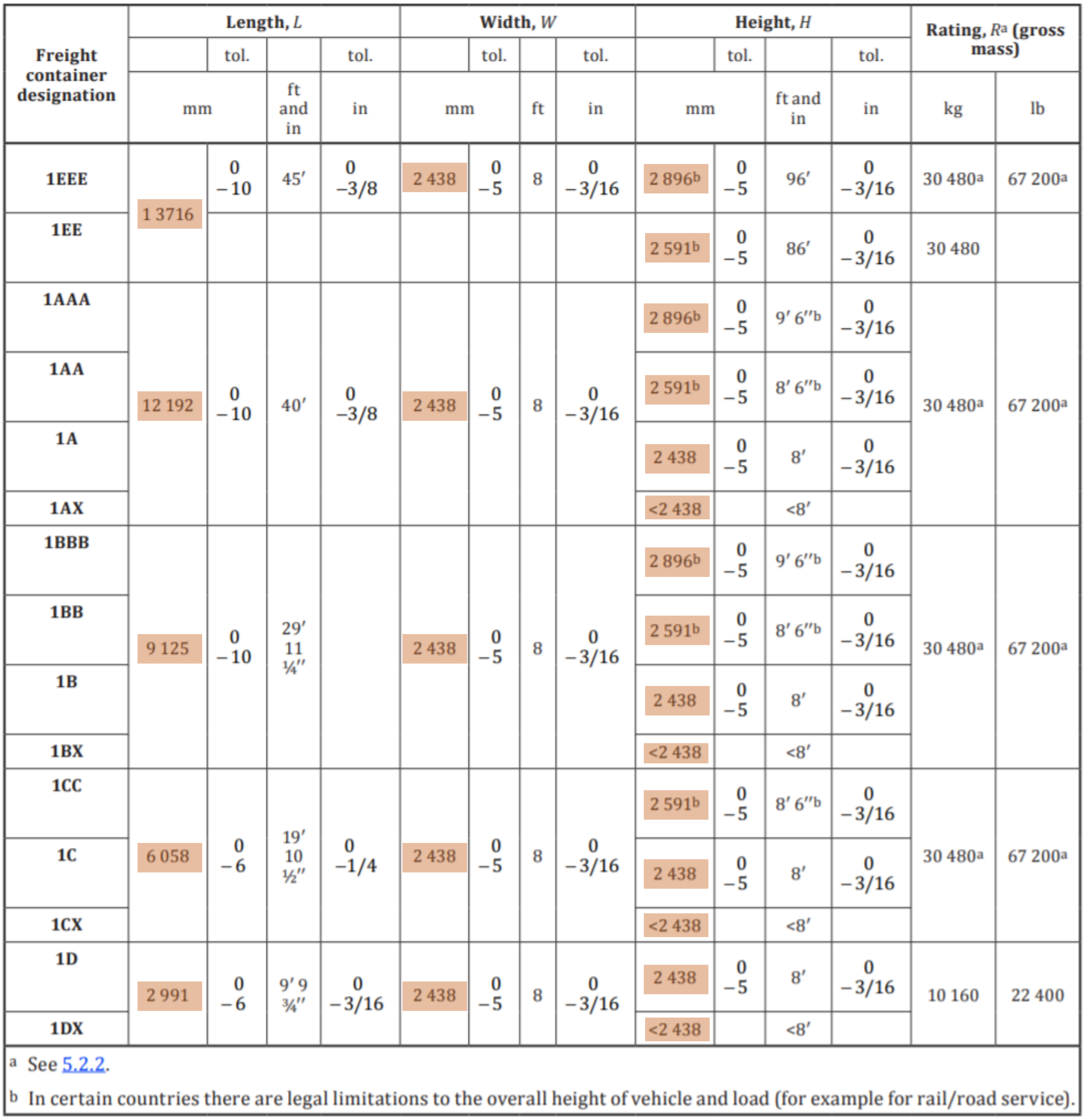
Bombelli has an old industrial building that is used for special events. The building necessitates different components or processes to improve the performance level.

In order to increase the building performance, the previous use and the performance of this use should be increased to a certain condition. For the new user profile to be able to use the new function of the building efficiently, all requirements must be met, and all the needs of the building must be defined appropriately. Proper redesign of building service systems in the public space and its suitability for flexible use are the main requirements within the scope of the building. The reason for this is that the industrial function, which is the old function of the building, is not sufficient for the occupants to meet the daily living conditions. In this context, the project has been designed by preserving the existing form and structure of the building, redesigning the service systems of the building, allowing these systems to be flexible enough to allow the design of the building, and taking into consideration the durations and number of users in the building.

The beginning of the design process is followed by the requirements and the program of demands which is contextualized with brainstorming. The requirements such as geometry, weight and structure for the design and implementation of these containers are described in BS ISO 668: 2013 and ISO 1496-1: 2013. Two of these documents comprise the types of containers reported by ISO system and rigorous specifications for shipping.

Series 1 is the container designations and dimensions as length *L*, width *W*, and height *H*, for an ISO container are gathered by BS ISO 668: 2013 and ISO 1496-1: 2013, the following tables represent external dimensions, minimum internal dimensions, minimum door opening dimensions.

Table 5. The dimensions and weights (source: ISO 668: 2013)



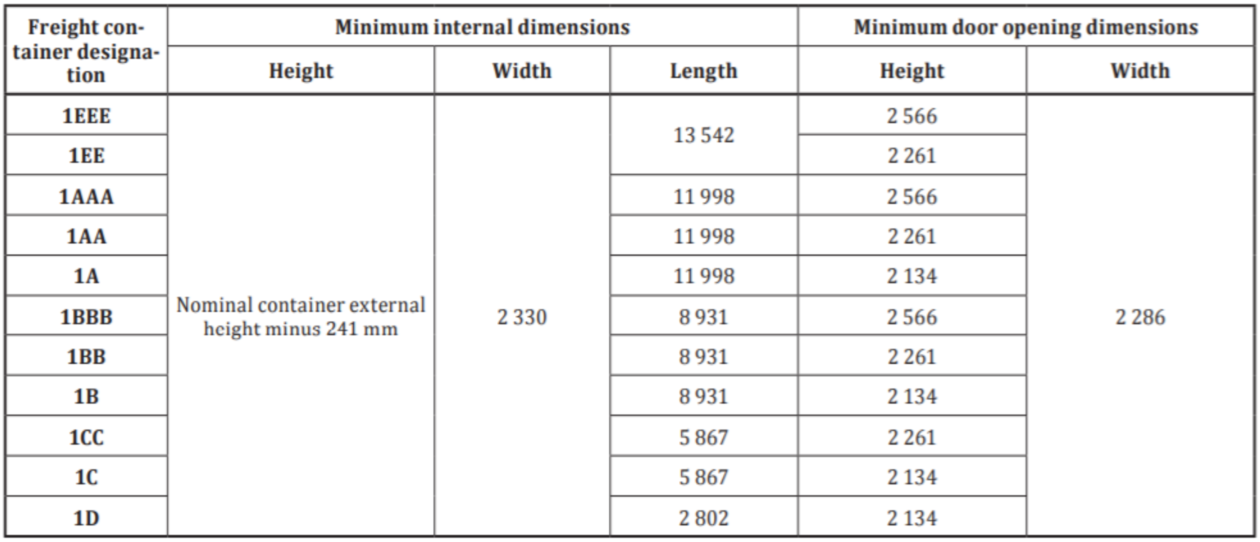
Freight container designation	Length, *L*				Width, *W*				Height, *H*				Rating, *R*[a] (gross mass)	
		tol.		tol.		tol.		tol.		tol.		tol.		
	mm		ft and in	in	mm		ft	in	mm		ft and in	in	kg	lb
1EEE	1 3716	0 −10	45′	0 −3/8	2 438	0 −5	8	0 −3/16	2 896[b]	0 −5	96′	0 −3/16	30 480[a]	67 200[a]
1EE									2 591[b]	0 −5	86′	0 −3/16	30 480	
1AAA	12 192	0 −10	40′	0 −3/8	2 438	0 −5	8	0 −3/16	2 896[b]	0 −5	9′ 6″[b]	0 −3/16	30 480[a]	67 200[a]
1AA									2 591[b]	0 −5	8′ 6″[b]	0 −3/16		
1A									2 438	0 −5	8′	0 −3/16		
1AX									<2 438		<8′			
1BBB	9 125	0 −10	29′ 11 ¼″		2 438	0 −5	8	0 −3/16	2 896[b]	0 −5	9′ 6″[b]	0 −3/16	30 480[a]	67 200[a]
1BB									2 591[b]	0 −5	8′ 6″[b]	0 −3/16		
1B									2 438	0 −5	8′	0 −3/16		
1BX									<2 438		<8′			
1CC	6 058	0 −6	19′ 10 ½″	0 −1/4	2 438	0 −5	8	0 −3/16	2 591[b]	0 −5	8′ 6″[b]	0 −3/16	30 480[a]	67 200[a]
1C									2 438	0 −5	8′	0 −3/16		
1CX									<2 438		<8′			
1D	2 991	0 −6	9′ 9 ¾″	0 −3/16	2 438	0 −5	8	0 −3/16	2 438	0 −5	8′	0 −3/16	10 160	22 400
1DX									<2 438		<8′			

[a] See 5.2.2.

[b] In certain countries there are legal limitations to the overall height of vehicle and load (for example for rail/road service).

Nominal dimension is the measurement that indirectly shows the two boundaries between which a dimension may change due to insensitivity caused by unavoidable reasons in construction. For example, if 10-cm wood is assumed, the measure is 10 cm ± 0.3 cm which is accepted before cut and after planing.

Table 6. Internal and opening (dimensions in mm) (source: ISO 668: 2013)



Freight container designation	Minimum internal dimensions			Minimum door opening dimensions	
	Height	Width	Length	Height	Width
1EEE	Nominal container external height minus 241 mm	2 330	13 542	2 566	2 286
1EE				2 261	
1AAA			11 998	2 566	
1AA			11 998	2 261	
1A			11 998	2 134	
1BBB			8 931	2 566	
1BB			8 931	2 261	
1B			8 931	2 134	
1CC			5 867	2 261	
1C			5 867	2 134	
1D			2 802	2 134	

Internal dimensions are the largest dimensions considering the biggest size of container without taking into account the internal extensions of the upper corner elements.

Another requirement is that loads are favorable to carry according to ISO 1496-1:2013. According to carrying points of shipping containers, these corner points should be tested to analyse their suitability. The analyses were provided for two corners and four corners to verify safety of containers.

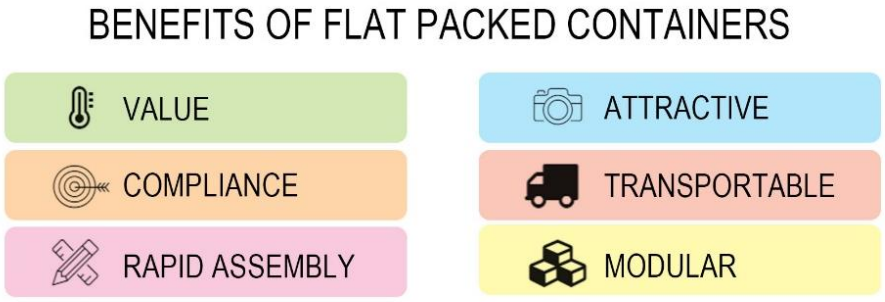
Apart from the portability of the containers, it must also be checked whether they are able to provide the strength when they are loaded on top or in the action of an impact. When producing containers, these properties of galvanized steel below are taken into consideration (Bauhu International Modular Construction Solutions, n.d.)

Table 7. Structural properties (source: BAUHU)

Material	Yielding (N/mm^2)	Tensile (N/mm^2)
S320GD+Z;+AZ	320	390
S350GD+Z;+AZ	350	420

7.2 Design Process

Modular structures in design allowing multiple modules to be arranged together to form clusters or large complex volumes. In consideration with flexibility phenomena in the building, allowing for multiple units enables to be added later without the need for any foundation buildings that can be placed on any level area and easily moved.



In the design meaning, three important factors are considered for modular design method. These factors are functional and structural. The design should firstly be applied in a practical way and aesthetically appealing to the eye. For this purpose, according to the purpose the building serves, it should include specific elements to the users. These elements may be related to the function as well as other requests of the users. As in this example, it is clear that the building, which will serve the office and hotel use, will need computers and other office supplies as equipment or other accommodation needs. All these must be taken into account when designing modular and evaluating the distribution of systems in the building. The other factor is the building structure affecting the design of modules inside building. This structural arrangement is important both for the placement of the modules inside the building and for not damaging the structure of the building. If it is considered that the upper units will be arranged, this situation should be taken into consideration in order to ensure the balance of the modular units and not to disturb the stability of the building itself.

Focused on building issues, Bombelli has an irregular shape and excessive numbers of steel columns. Steel columns are positioned at each 5850 mm y-axis and each 7560/7860-mm or 11120/11500-mm x-axis. These issues are stringent restrictions for maximum length or width in the plan. On the other hand, it has limited building height with steel beams joining at the top of steel columns. The building height is dimensioned as maximum height 7050 mm and minimum height 5230 mm.

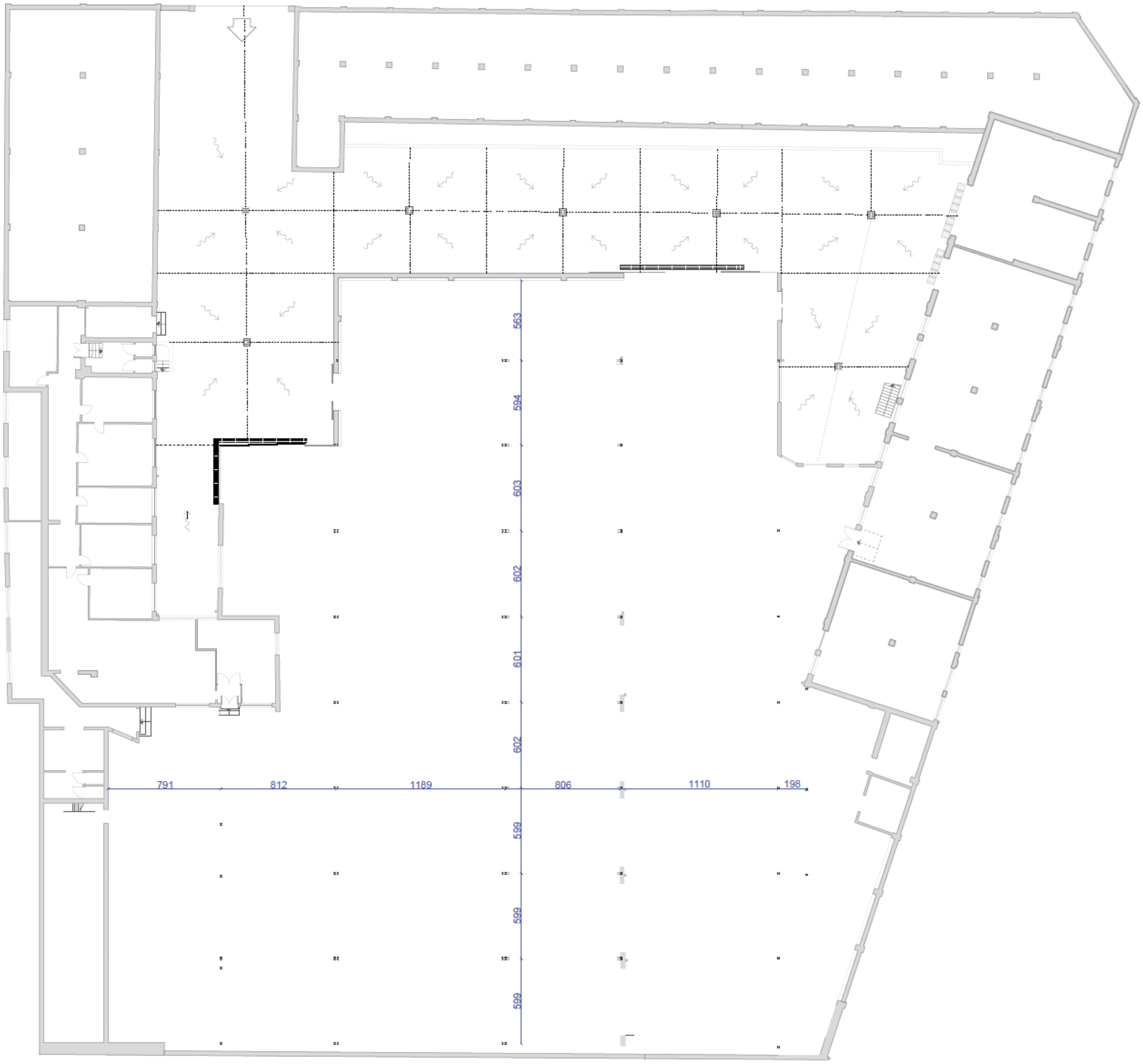


Figure 61. Dimension between columns

Considered these structural restrictions, 1CC is chosen as a container designation group. The inter space of building has divided into grids by considering the placement of structural elements such as columns.

Figure 62. Grid plan of redesigning of building

Then the grid area was divided into more pieces according to equal dimensions as possible and one container dimension *figure 64*.

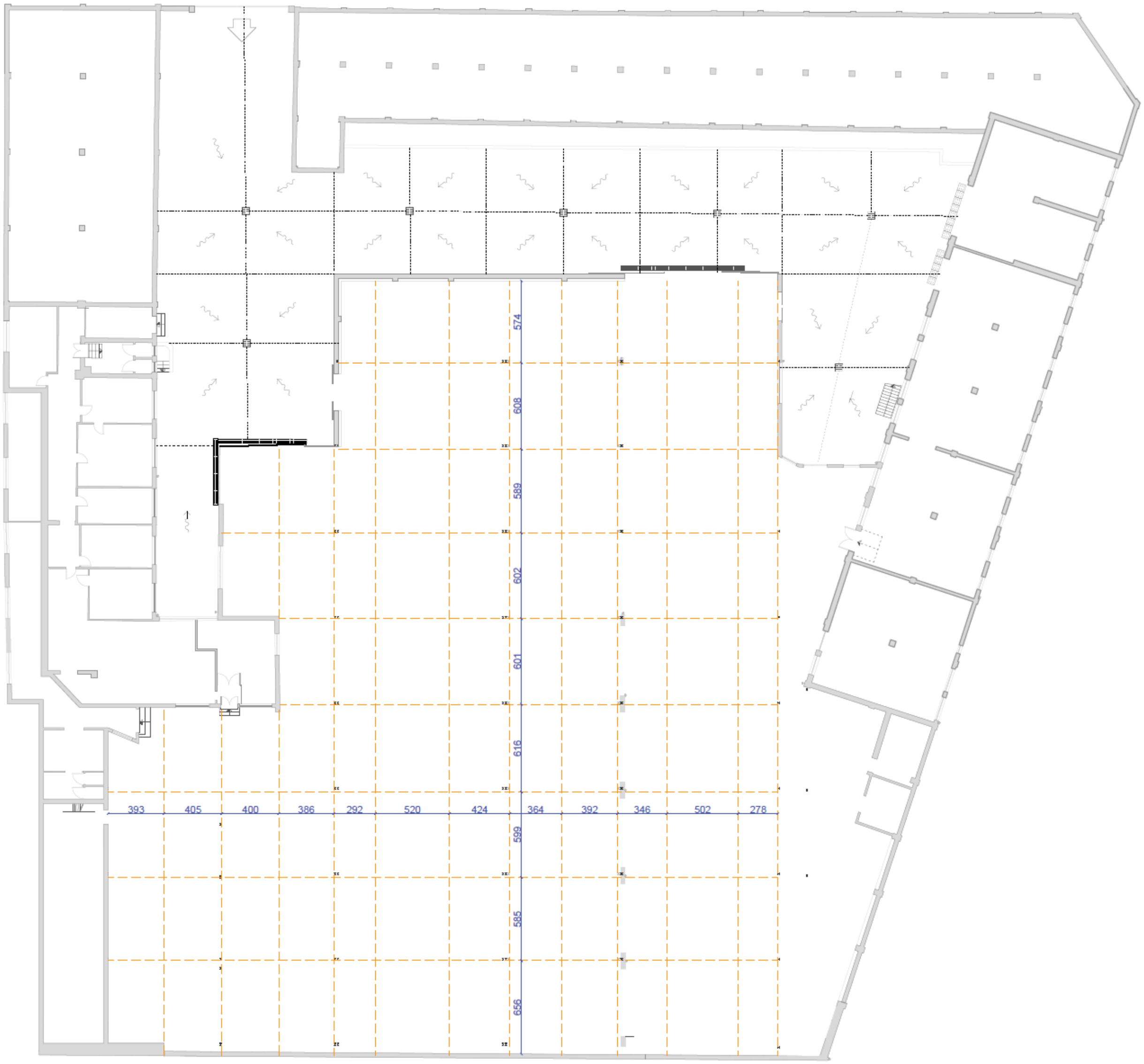


Figure 63. Final grid plan to placement of containers

According to final grid plan, alternative plan solutions with containers were produced by considering functions. The containers were imagined moving in these grids and lifted by forklift. These design solutions aim to show the flexibility of different uses and users if they change throughout the life span. The different plan alternatives were designed by considering renting schedules of companies. From first plan to second plan, the boxes were changed because the companies finish their contract, or change their working spaces and newcomers have different sizes and prefer to customize their offices.

First alternative: 32 containers for office use, 20 containers for housing, 10 containers for technical rooms, 2 containers for social needs.

Figure 64. First alternative - ground

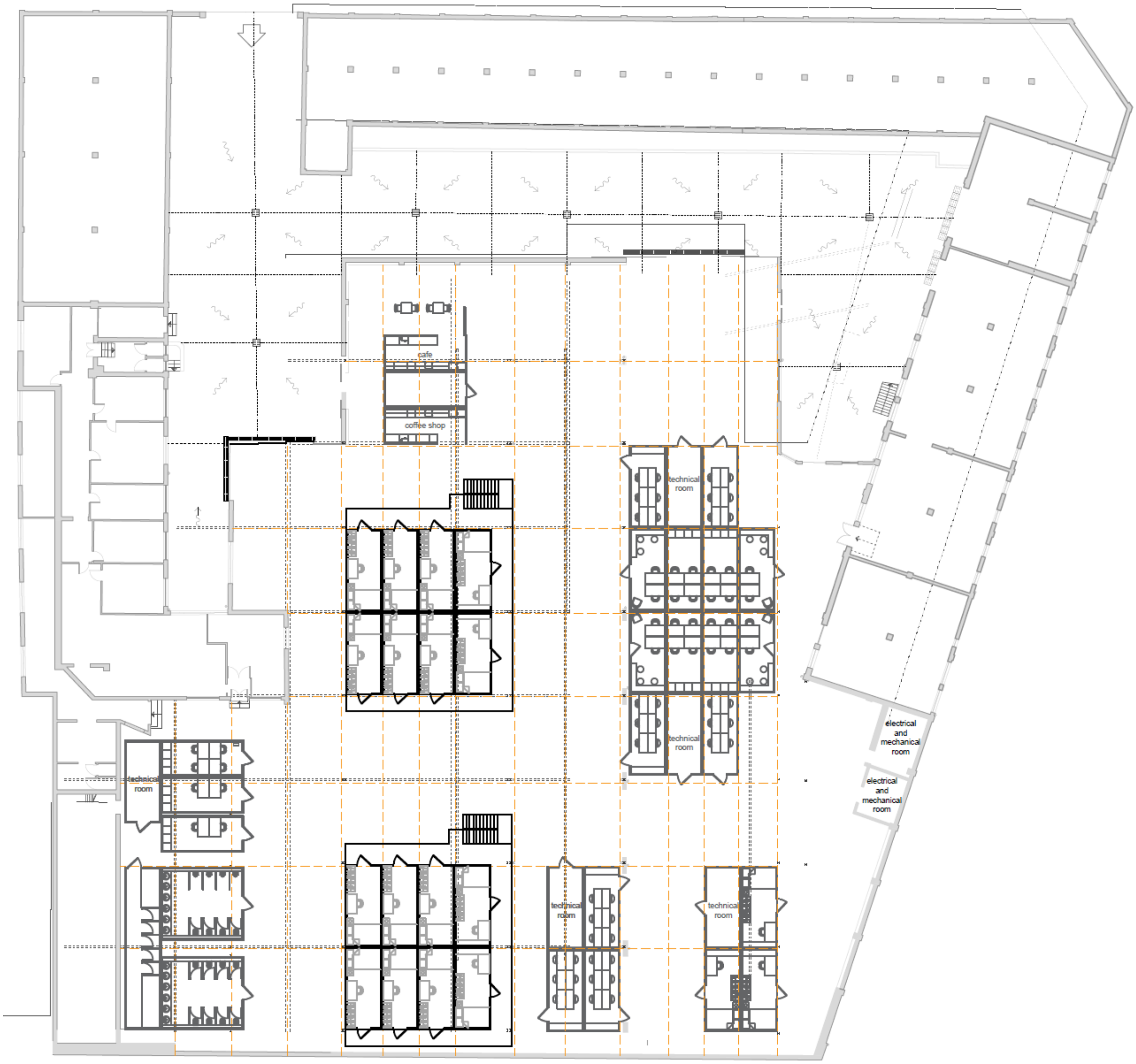


Figure 65. First alternative - upper

Second alternative: 37 containers for office use, 20 containers for housing, 10 containers for technical rooms, 2 containers for social needs.

Figure 66. Second alternative - ground

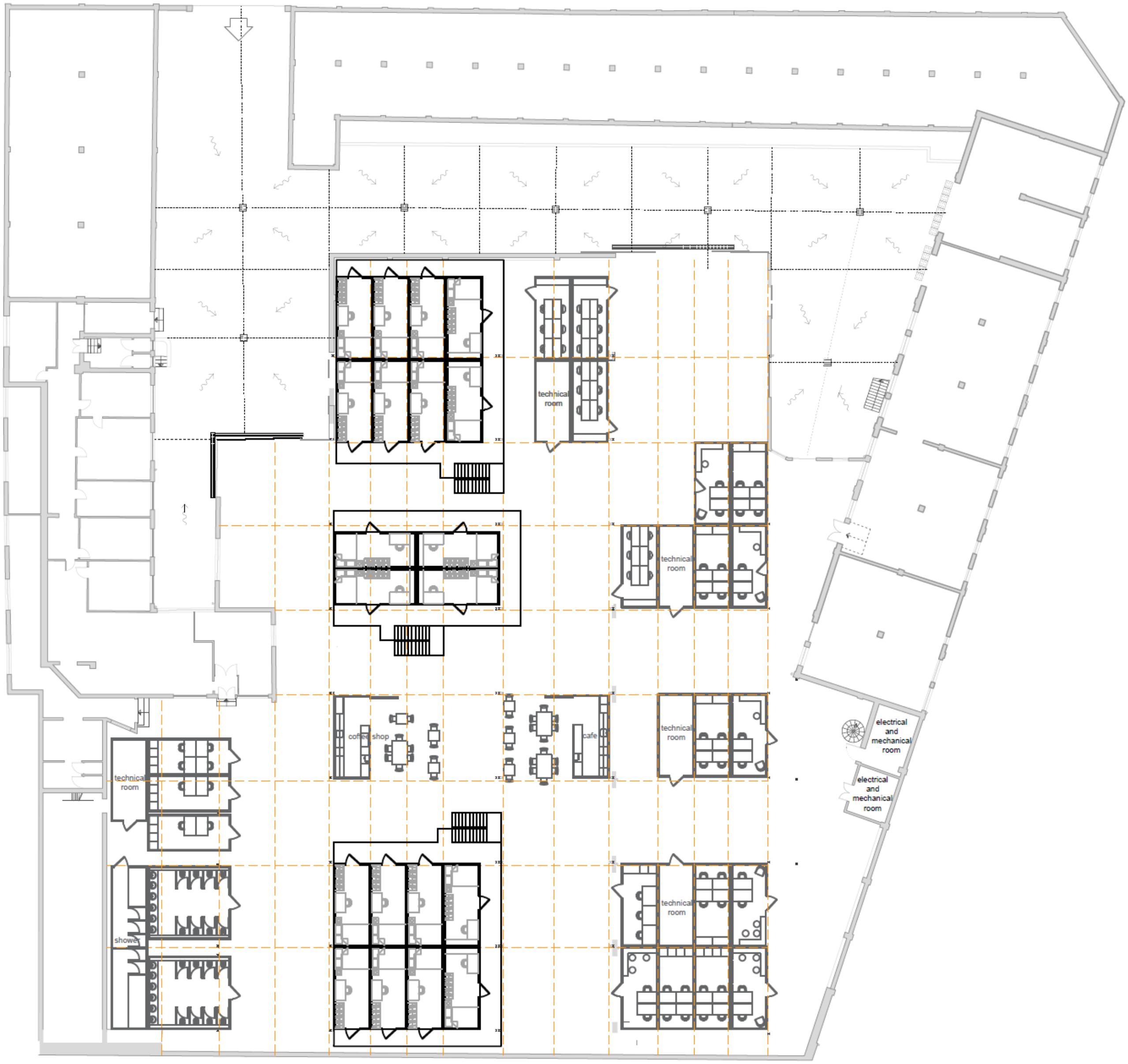


Figure 67. Second alternative – upper

Third alternative: 37 containers for office use, 20 containers for housing, 10 containers for technical rooms, 2 containers for social needs.

Figure 68. Third alternative – ground

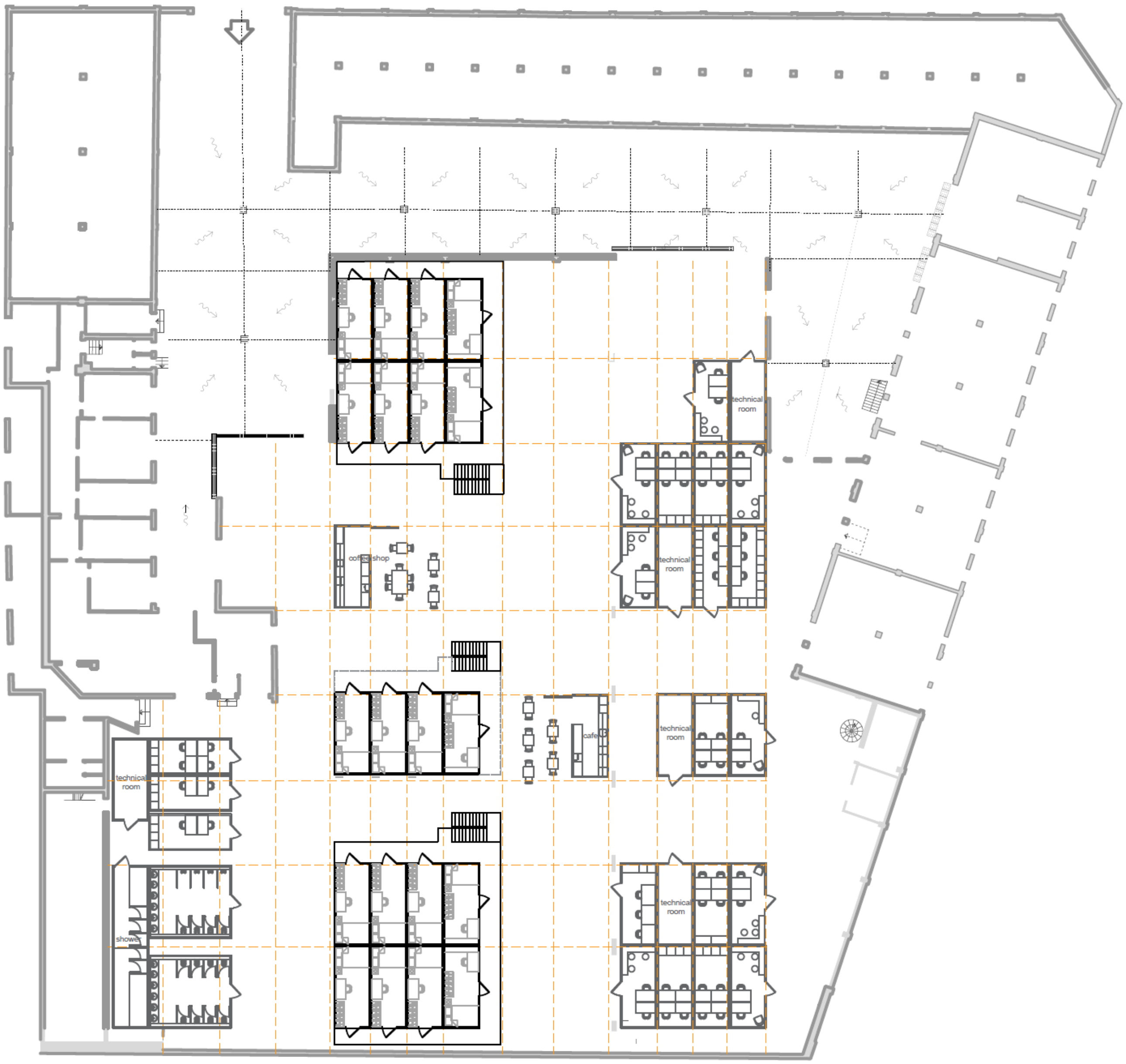
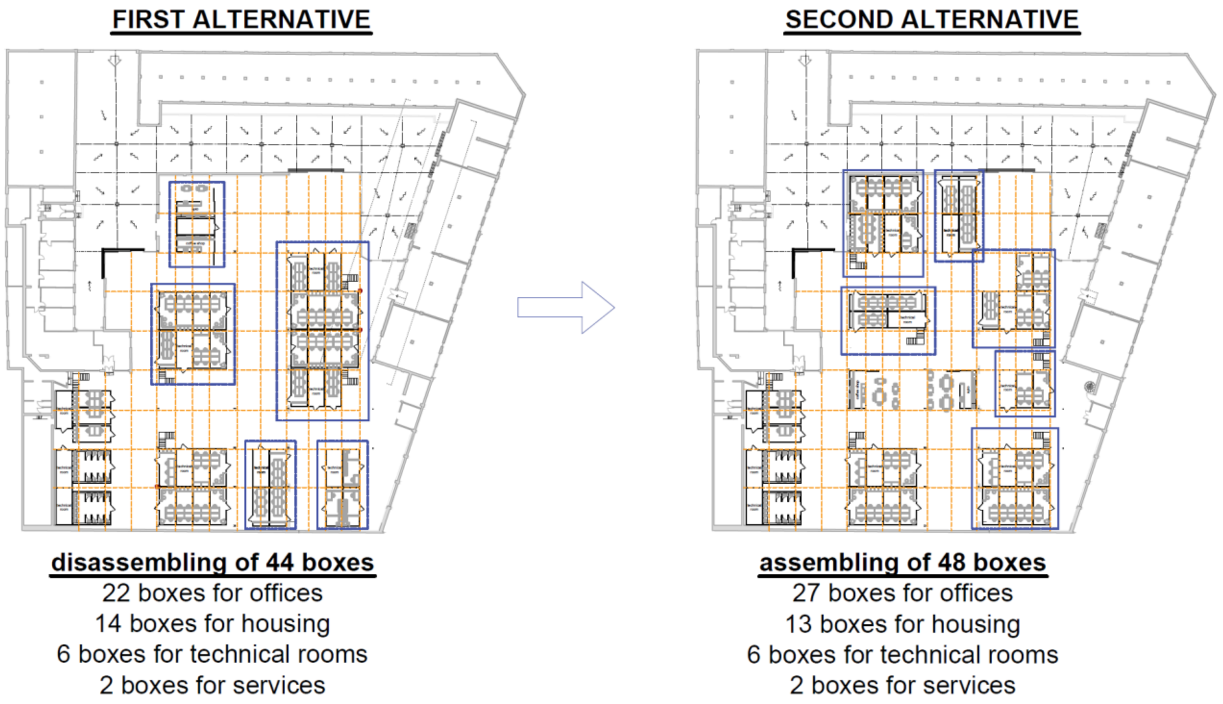


Figure 69. Third alternative – upper

Those three alternatives show how the boxes can change with different users and their needs in 3/6/12 month period.

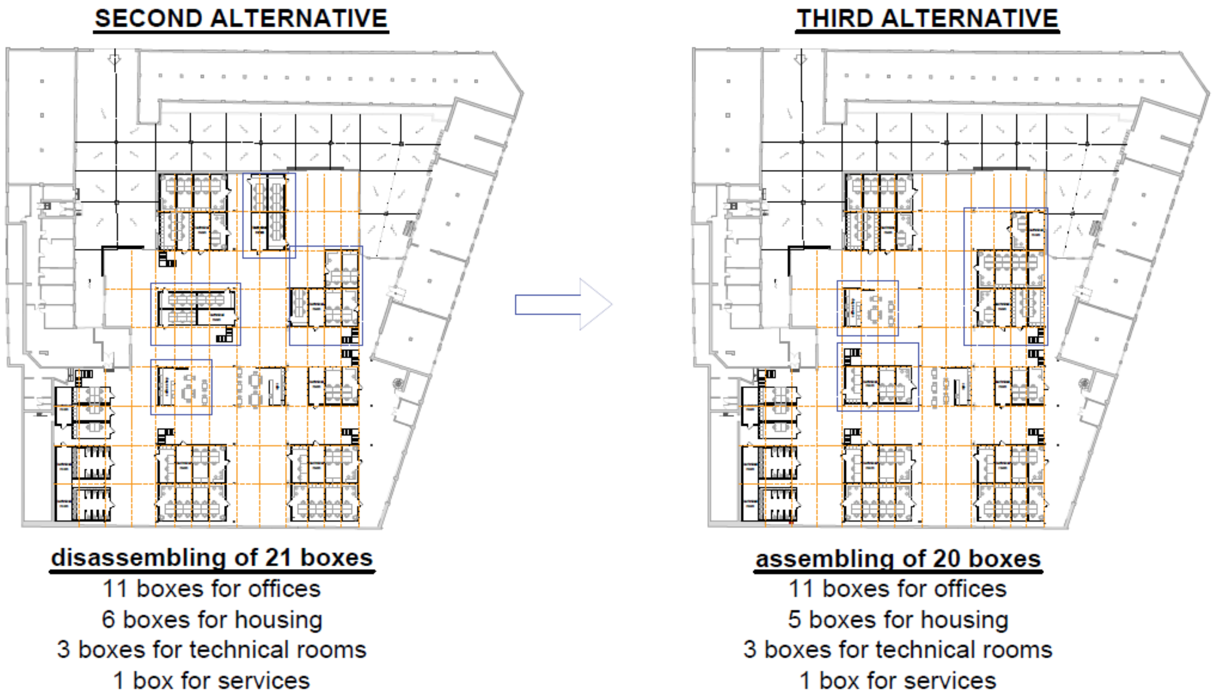

FIRST ALTERNATIVE

disassembling of 44 boxes
22 boxes for offices
14 boxes for housing
6 boxes for technical rooms
2 boxes for services

SECOND ALTERNATIVE

assembling of 48 boxes
27 boxes for offices
13 boxes for housing
6 boxes for technical rooms
2 boxes for services

Figure 70. Change from first plan to second plan with numbers of disassembling and assembling boxes


SECOND ALTERNATIVE

disassembling of 21 boxes
11 boxes for offices
6 boxes for housing
3 boxes for technical rooms
1 box for services

THIRD ALTERNATIVE

assembling of 20 boxes
11 boxes for offices
5 boxes for housing
3 boxes for technical rooms
1 box for services

Figure 71. Change from second plan to third plan with numbers of disassembling and assembling boxes

After complete layout, one of the alternatives is modelled in BIM. This provides to change from one plan to another plan, occupant numbers and their schedules in anytime easily and to see the available electrical or mechanical systems in placements.

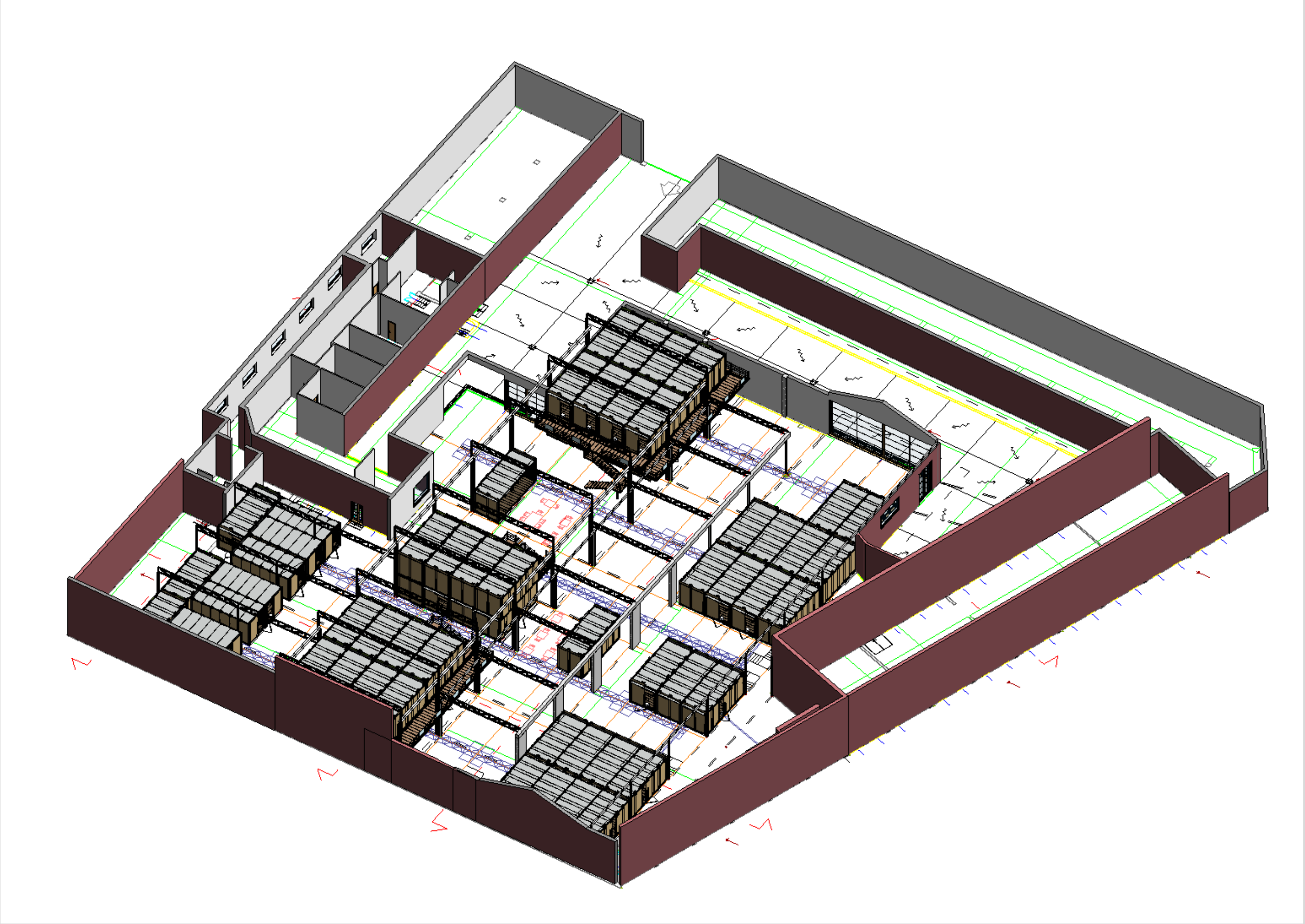


Figure 72. BIM model of one of alternatives

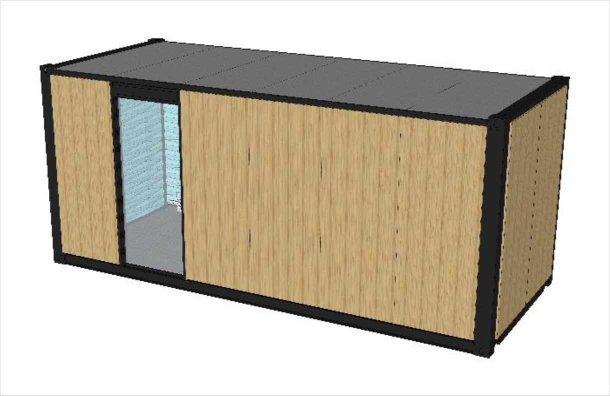


Figure 73. 1-office-box

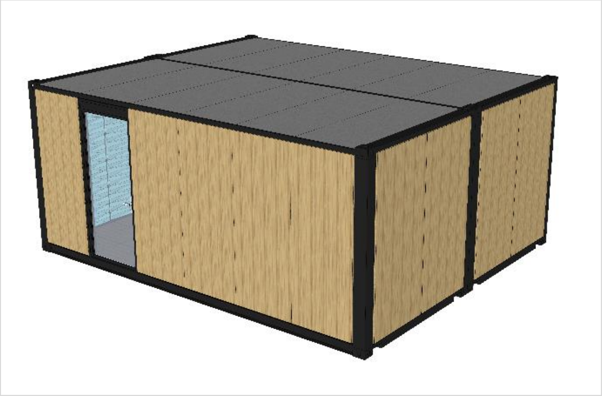


Figure 74. 2-office-box

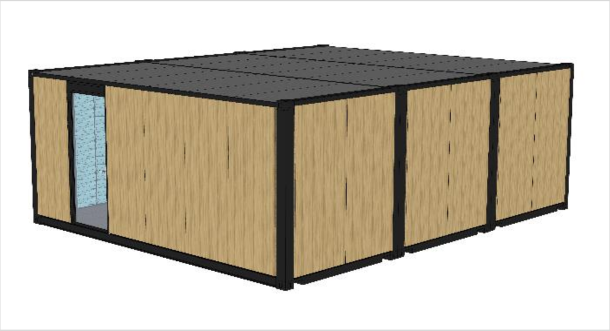


Figure 75. 3-office-box

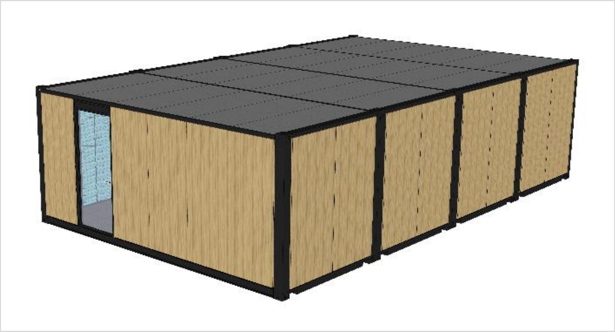


Figure 76.4-office-box

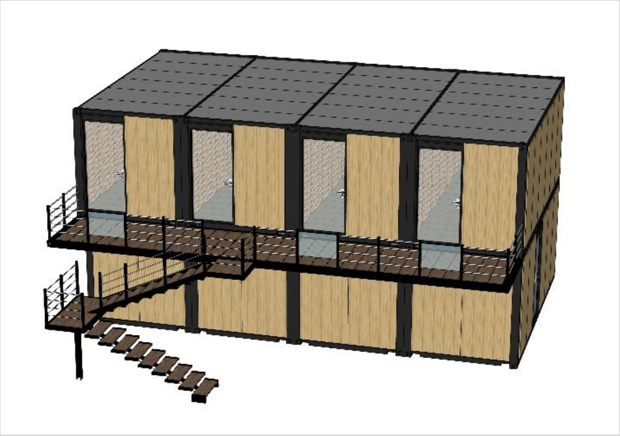


Figure 77. 3-office-box

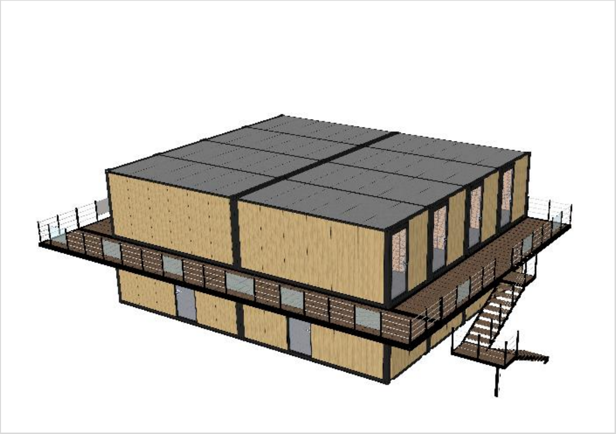


Figure 78. 4-office-box

The boxes are flat back containers and unwelded. The reason for the selection of the flat back modules is to make easier to transport, to be assembled in short time with supplied complete. When the boxes are reached to site by shipping trucks, they can be moved or lifted by forklifts.

The flat packing enables to put all materials into one pack. In that way, it leads to save the storage space, install easily and avoid damage during transportation.

Although design strategy is defined as modularity for building inner space, construction techniques of prefabricated units are panelized which is a method of constructing the wall, roof and filing layers, produced in another location outside the place, then carried out by moving the units to site to install the units. Apart from the structural elements, the other elements are usually produced as panels and are easy to carry.

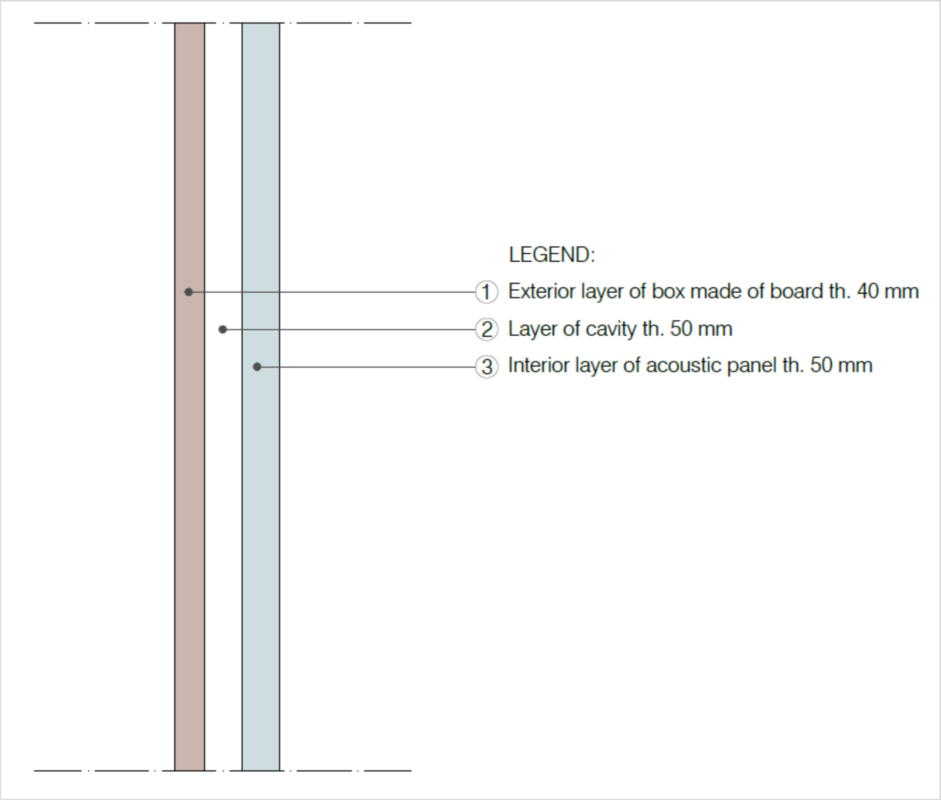
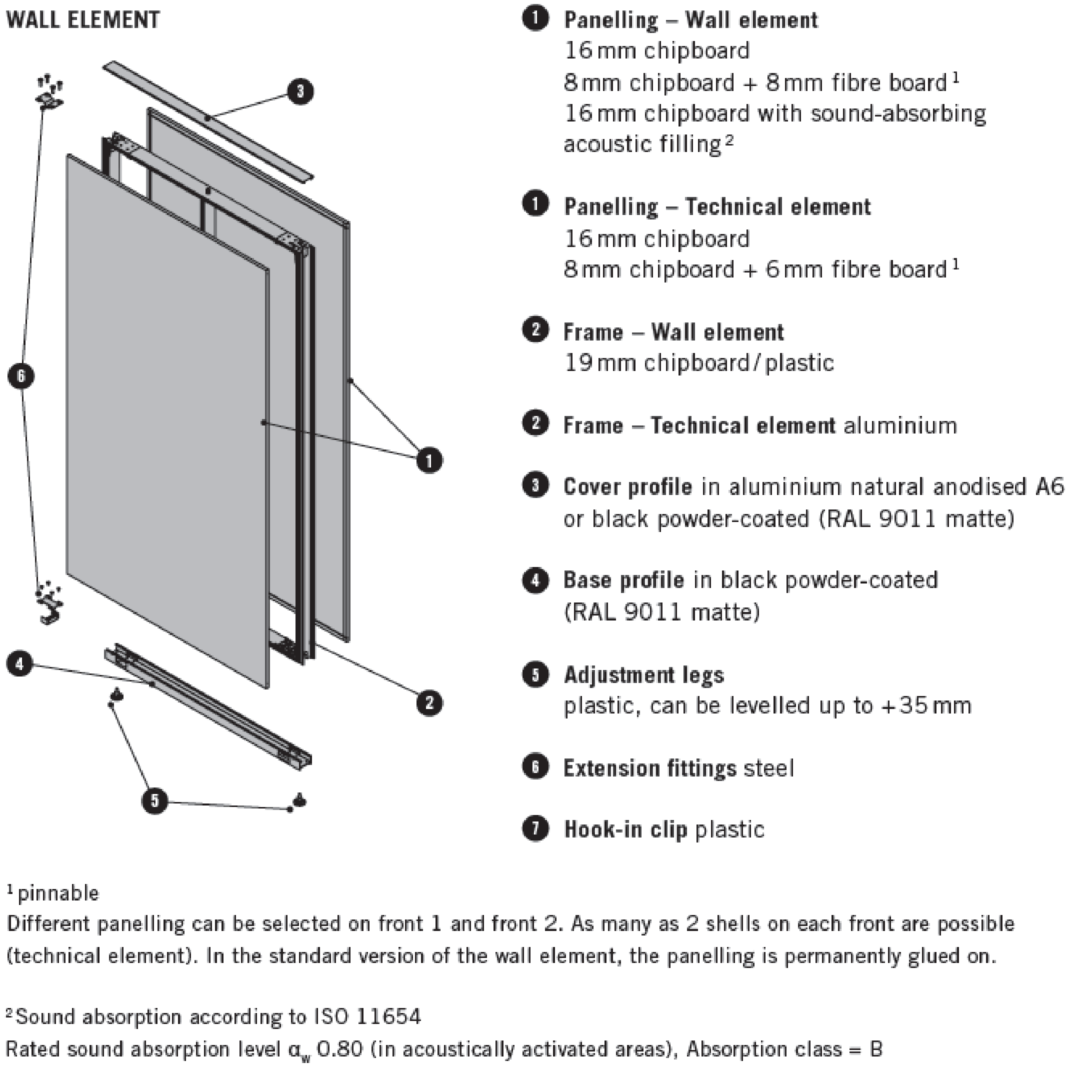


Figure 79. Wall layer of prefabricated boxes

Office use of prefabricated units requires to acoustic insulation on the wall boxes and roof to design working spaces in comfort. This acoustic panel is also supplied by specific wall system of whose producer create mobile phone hubs or meeting pods in the market. The acoustic wall is connected to structure of prefabricated unit that is shown in *figure 76* and *77*.



❶ **Panelling – Wall element**
16 mm chipboard
8 mm chipboard + 8 mm fibre board [1]
16 mm chipboard with sound-absorbing acoustic filling [2]

❶ **Panelling – Technical element**
16 mm chipboard
8 mm chipboard + 6 mm fibre board [1]

❷ **Frame – Wall element**
19 mm chipboard / plastic

❷ **Frame – Technical element** aluminium

❸ **Cover profile** in aluminium natural anodised A6 or black powder-coated (RAL 9011 matte)

❹ **Base profile** in black powder-coated (RAL 9011 matte)

❺ **Adjustment legs**
plastic, can be levelled up to +35 mm

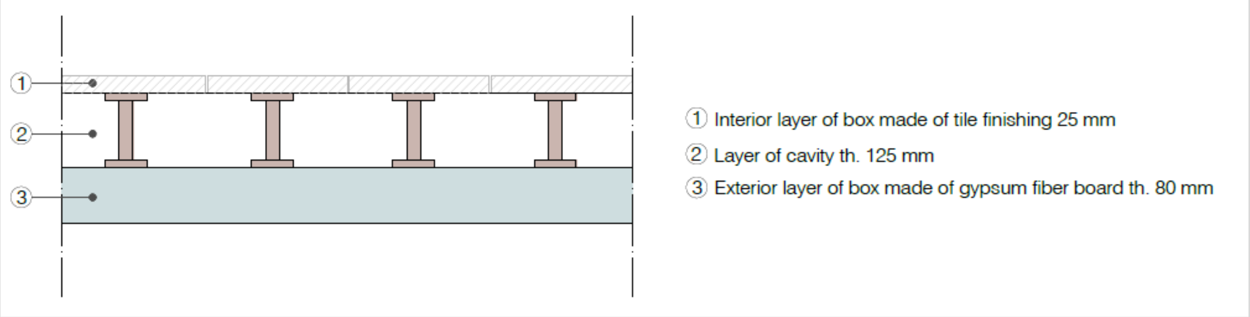
❻ **Extension fittings** steel

❼ **Hook-in clip** plastic

[1] pinnable
Different panelling can be selected on front 1 and front 2. As many as 2 shells on each front are possible (technical element). In the standard version of the wall element, the panelling is permanently glued on.

[2] Sound absorption according to ISO 11654
Rated sound absorption level α_w 0.80 (in acoustically activated areas), Absorption class = B

Figure 80. Wall elements of box from a technical datasheet of a producer in market (source: Bene GMBH)



① Interior layer of box made of tile finishing 25 mm
② Layer of cavity th. 125 mm
③ Exterior layer of box made of gypsum fiber board th. 80 mm

Figure 81. Slab layer of prefabricated boxes

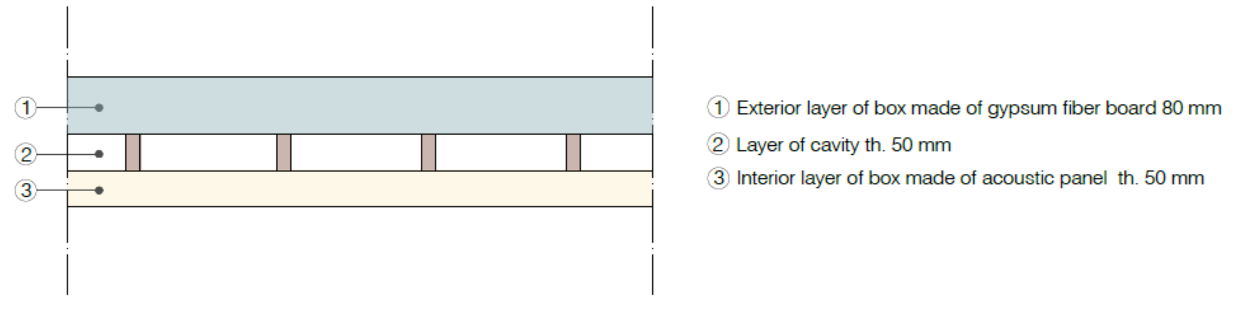
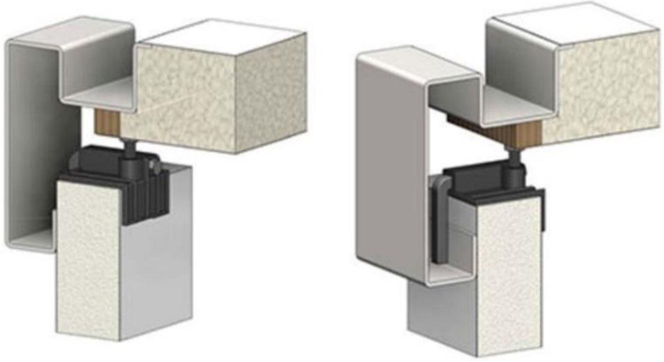
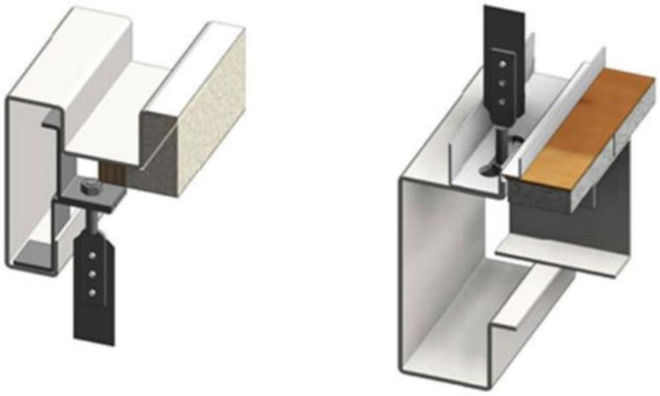


Figure 82. Roof layer of prefabricated boxes

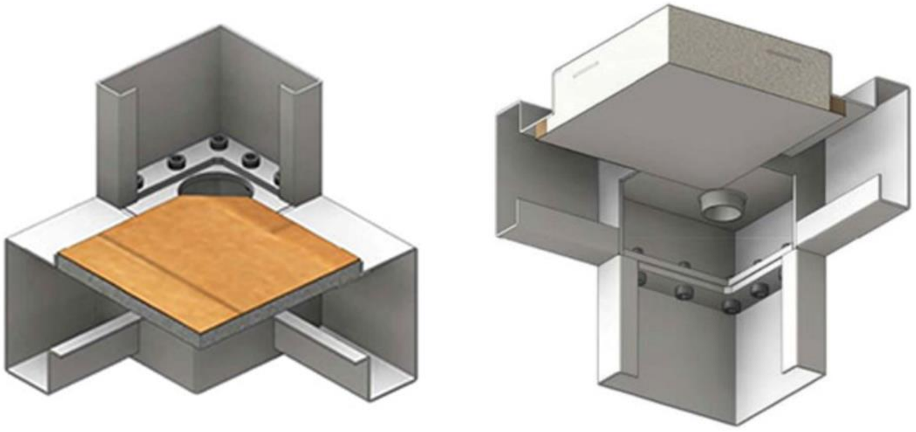


Connection of wall panel to top of box



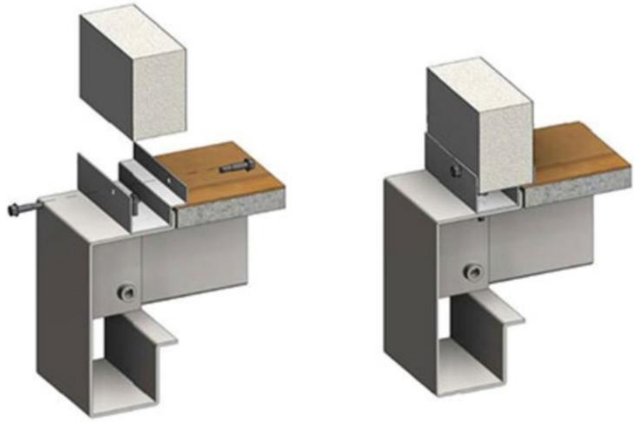
Connection of wall panel

Figure 83. Connection details of wall panel to box (source: PTH)

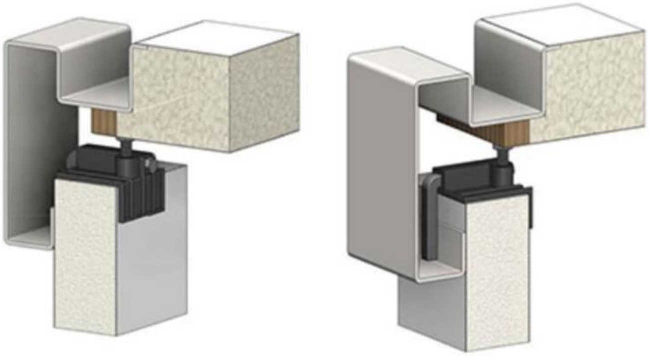


Connection of column to bottom of box

Connection of column to top of box



Connection of wall panel to bottom of box



Connection of wall panel to top of box

Figure 84. Connection details of column and wall panel to box (source: PTH)

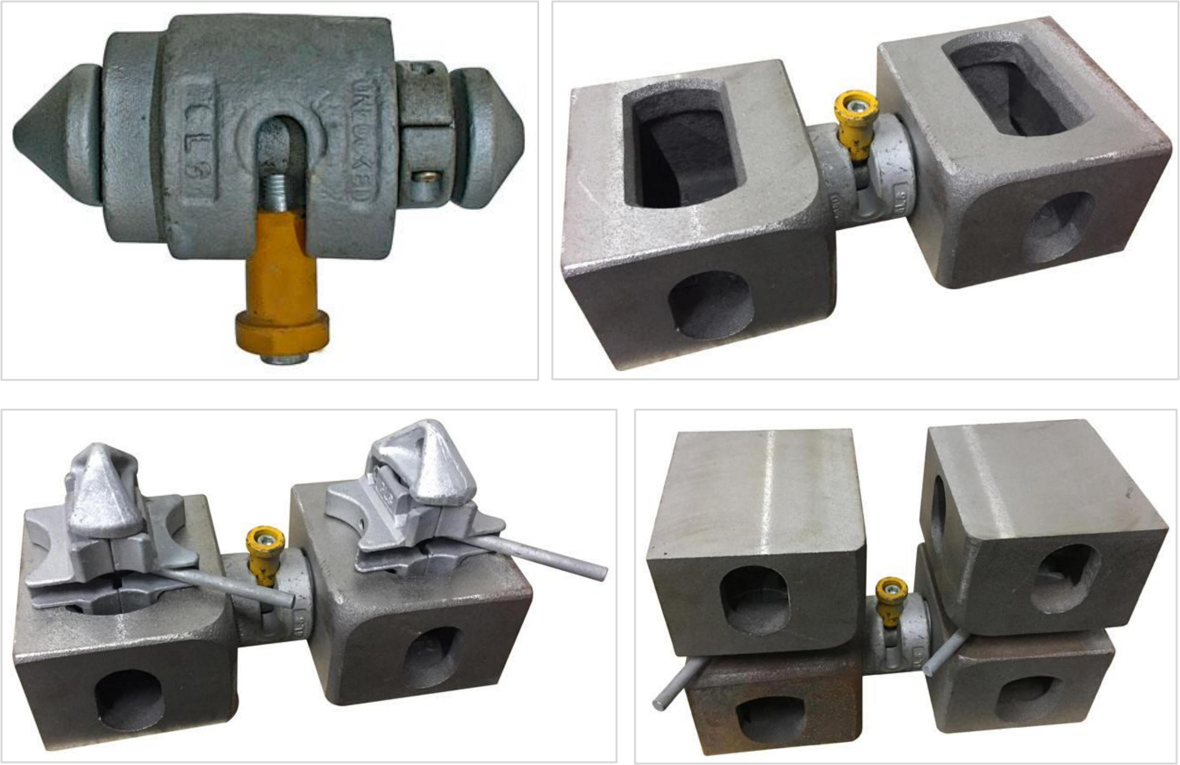


Figure 85. Connection of containers side-to-side (source: Pacific Marine&Industrial)

7.3 Development of the Simulation Model

In this section, the design decisions have been completed and the building was modelled in IESVE and the energy performance analysis was done by entering the data respectively. Since the building was planned to be improved in accordance with the refurbishment strategy, the current state of the building was first modelled and the existing layers of wall, floor and roof were entered in IESVE. Since it was known that there wasn't insulation on wall, roof and floor, the energy requirement was high.

In line with the design decisions, other important factor is to decide the necessary internal loads and working periods with consideration of building new function. Then, the energy analyzes were gathered by IESVE, and the building envelope is improved. The following these enhancement, heating, cooling modes and ventilation were installed in the model with proper factors.

Following to improvement of building system, second part of refurbishment as reuse of building was analysed. The boxes were added as thermal zones and the layers of boxes were defined in IESVE. Then, the internal gains in boxes were loaded according to occupation profile.

The last refurbishment strategy is enhancement of roof with PV panels. PV panels had important role for building since the new installed machines such as equipment of heating, cooling and ventilation systems need more energy. To decrease the energy demand of building, PV panels were prior source to supply this energy. In last part 7.4, the energy analysis is shown after building PV panels on the roof.

7.3.1 Base Model - Building Design

Base model design starts with the model of thermal zones in Bombelli building. The building was old industrial plant, so inner space has no partition due to need of large space in manufacturing. This causes to design only one thermal zone.

As building elements, exact data of the building hasn’t existed. The building walls, slab and roof were decided according to CAD file of old project, old hand drawings and pictures. When sections of the building are examined, there are two different wall types 31 cm and 20 cm. The main body of the wall is brick and the interior and exterior parts are covered with finishing. On the other hand, the slab was differentiated with two different finishing materials. One of them is wood flooring and the other is concrete. Since there isn’t any information about if wood finishing was built after construction of slab, the two types were also considered in analyses. Besides, roof has many hand drawings without any dimensions; however, it was understandable in section drawings in CAD. The roof is inclined and there are many windows on the roof in shorter section of triangle.

Wall:

- 31 cm wall – U-value: 3.72 W/m^{2}K
- 20 cm wall – U-value: 2.16 W/m^{2}K

Slab:

- With concrete finishing – U-value: 1.25 W/m^{2}K
- With wood finishing – U-value: 1.03 W/m^{2}K

Roof:

- Inclined roof – U-value: 6.58 W/m^{2}K

Wall

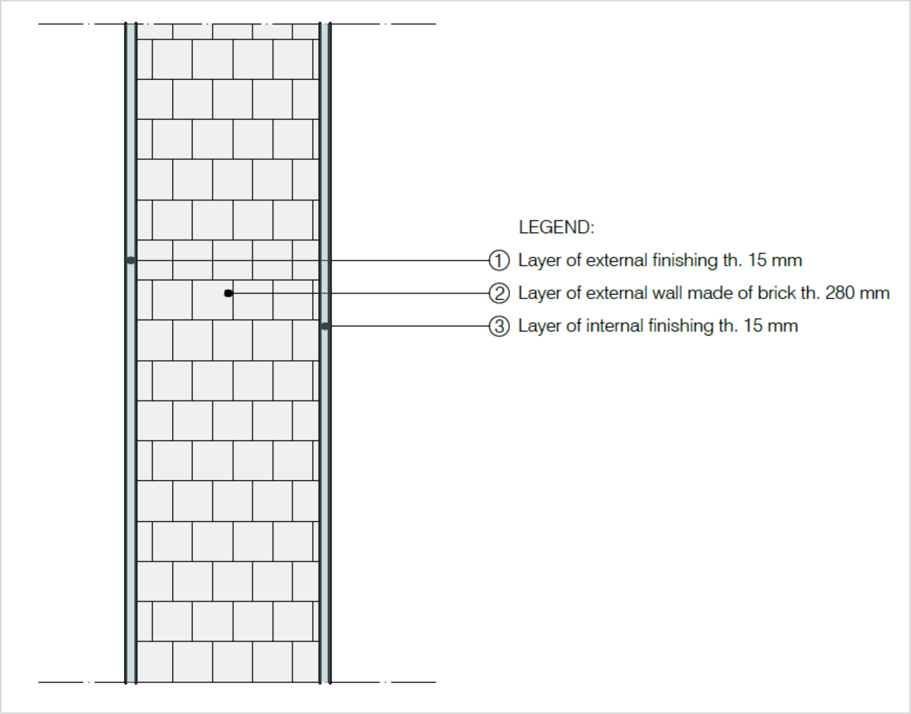


Figure 86. Existing layers of external wall made of brick with thickness 31 cm

Figure 87. The wall made of brick presented in the building

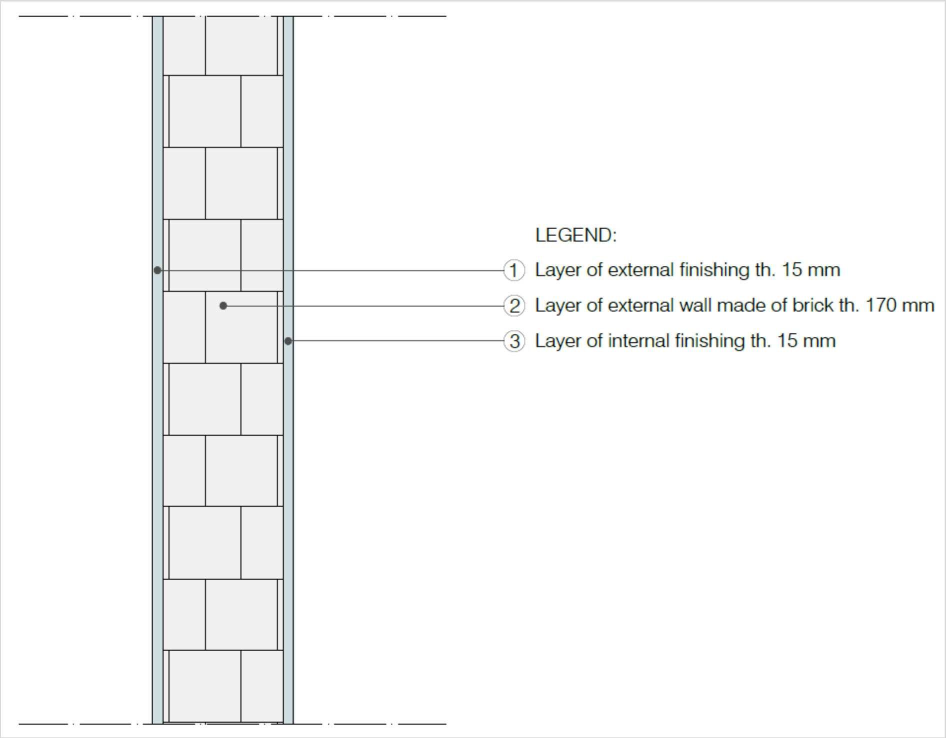


Figure 88. Existing layers of external wall made of brick with thickness 20 cm

Figure 89. The wall made of brick presented in the building

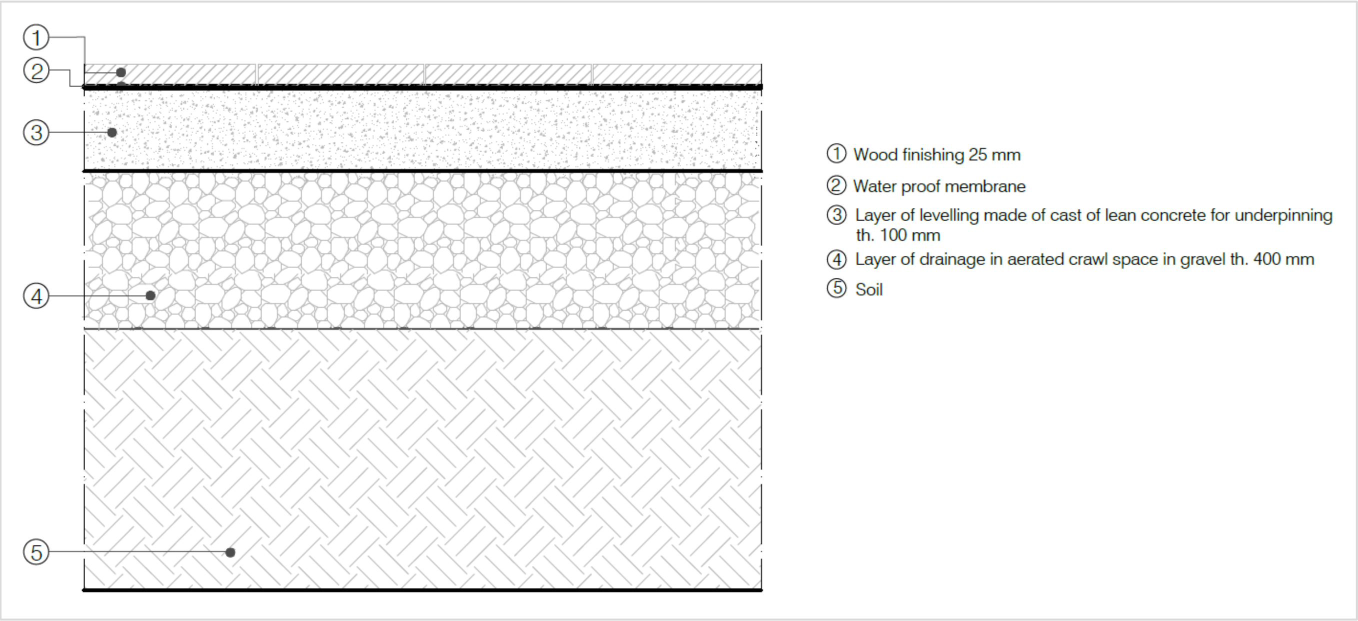


Figure 90. Floor type 1 made of wood finishing

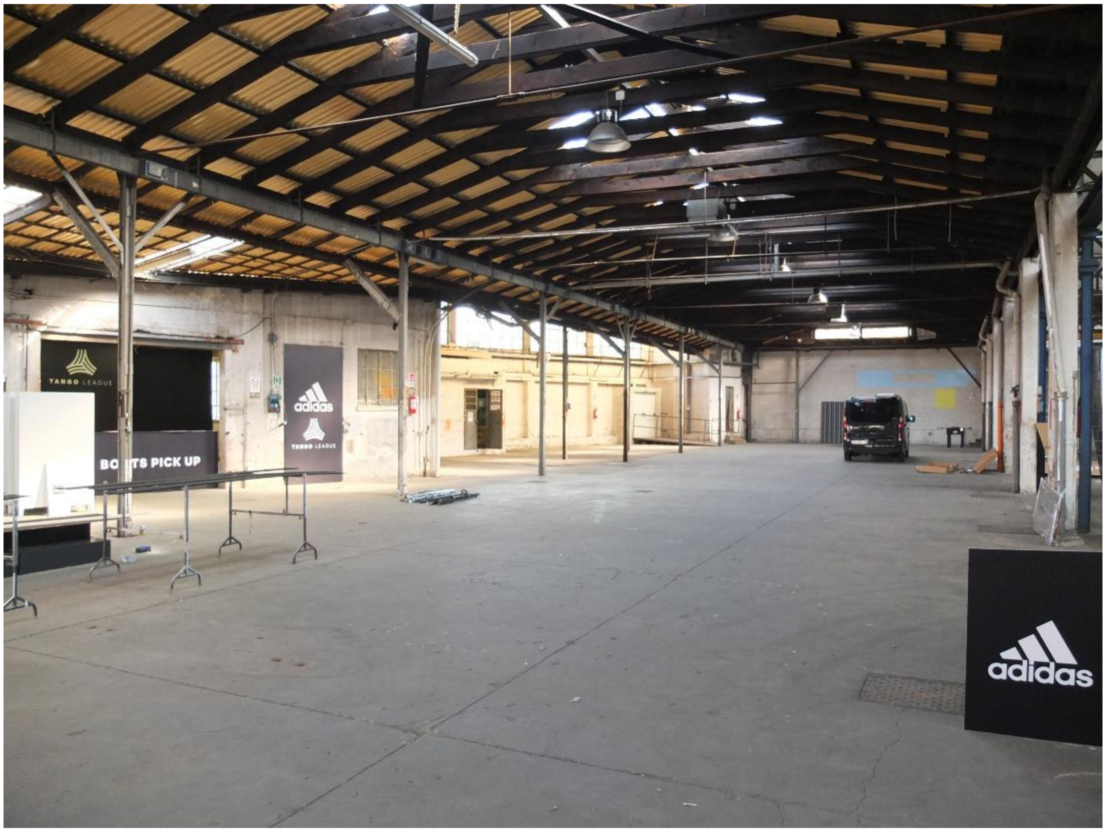


Figure 91. Floor type 1 in the building

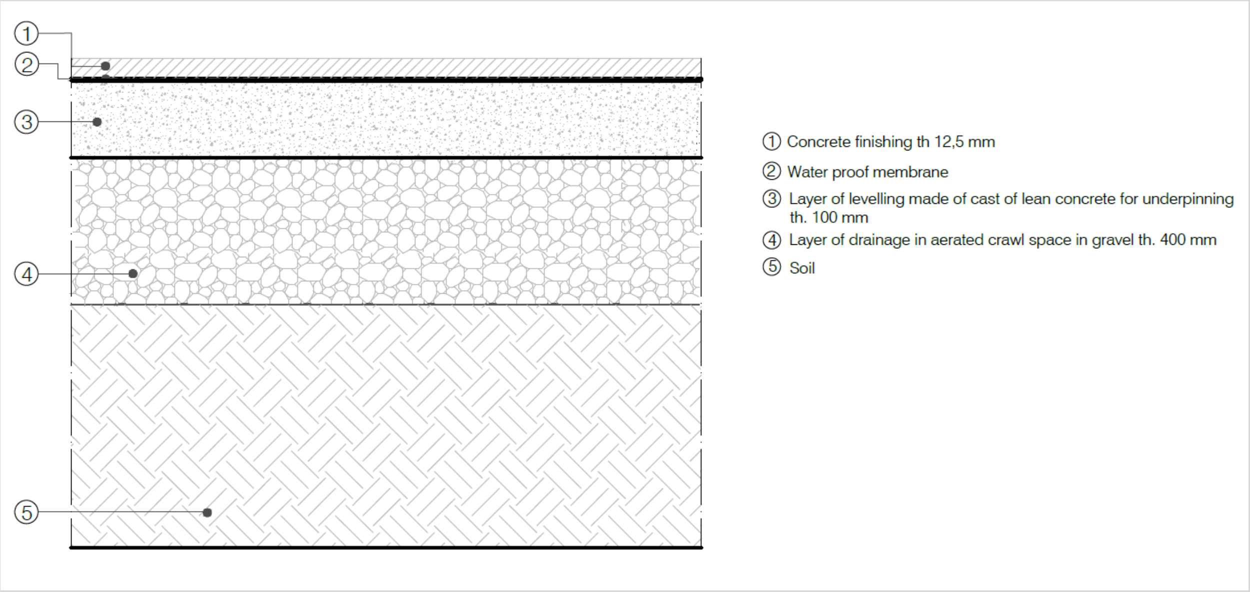


Figure 92. Floor type 2 made of concrete finishing in the building

Figure 93. Floor type 2 in the building

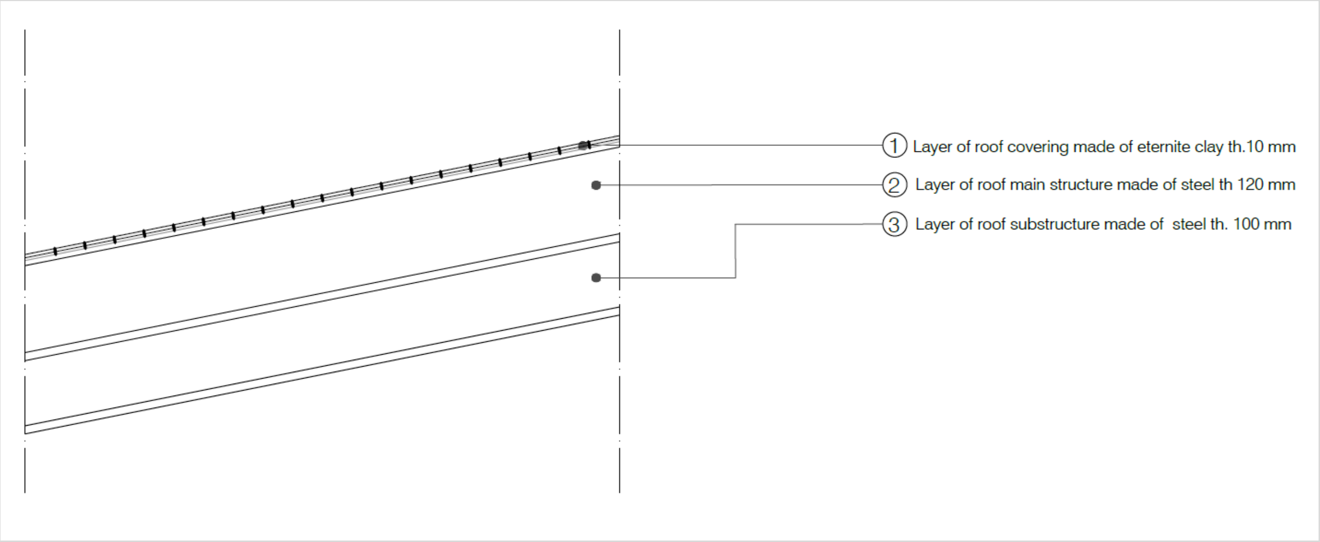


Figure 94. The layer of inclined roof in the building

Figure 95. The layer of inclined roof in the building

7.3.2 Occupant Behaviour

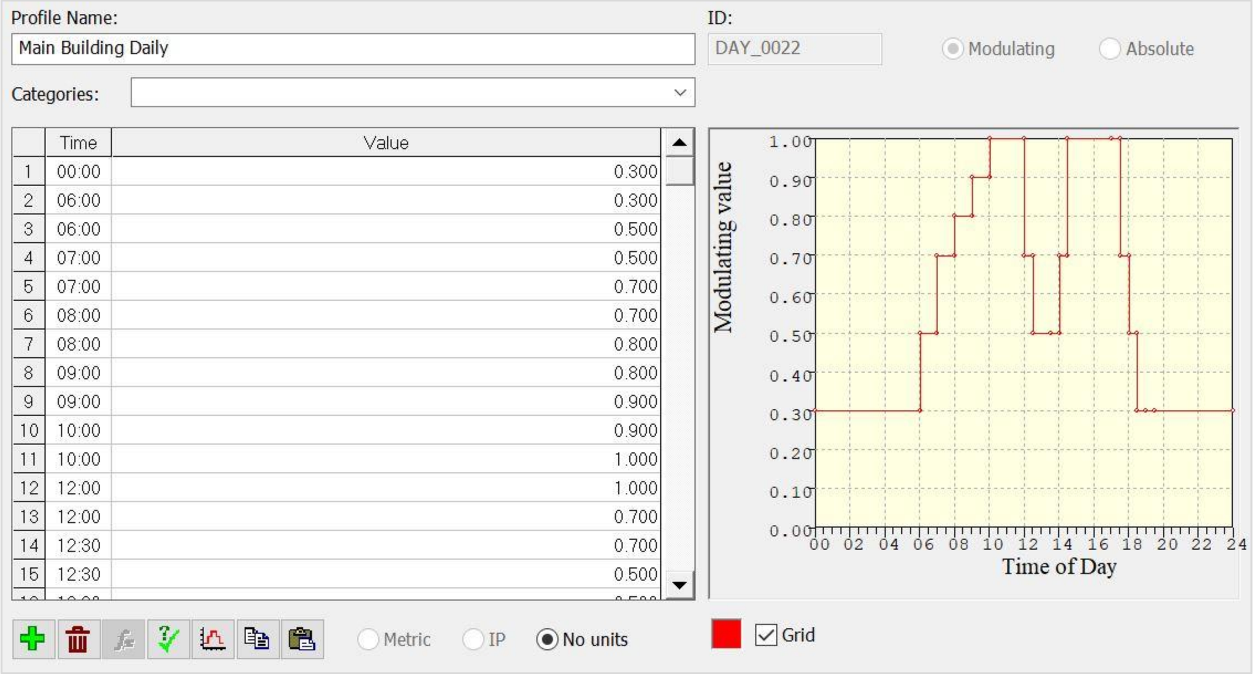
The internal loads in a building consist of people and equipment. As the number of persons and the number of equipment will vary according to the function of the building, internal loads will also decrease. Likewise, depending on the intensity of the work done inside, the use of human flow or equipment may change. EU Energy Star is used for energy use of equipment such as computers in general.

Except from machinery and equipment energy loads, the occupant schedules were defined with different scenarios shaping with these questions:

- How many people come to building?
- What time do they arrive to building?
- How many hours do they work in the office boxes?

- What time is their lunch time? and do they stay in the building during lunch time or go out?
- What time they left these office boxes?
- How many people can stay in the boxes after work?
- What time do the cafés start to work?
- How many hours do they work?
- At weekends, are the boxes usable?
- What are the scenarios for using prefab units?
- Which scenarios are the best?

After brainstorming, the answers have finalized the occupancy schedule. The profiles have been determined as below.



Profile Name: Main Building Daily

ID: DAY_0022

● Modulating ○ Absolute

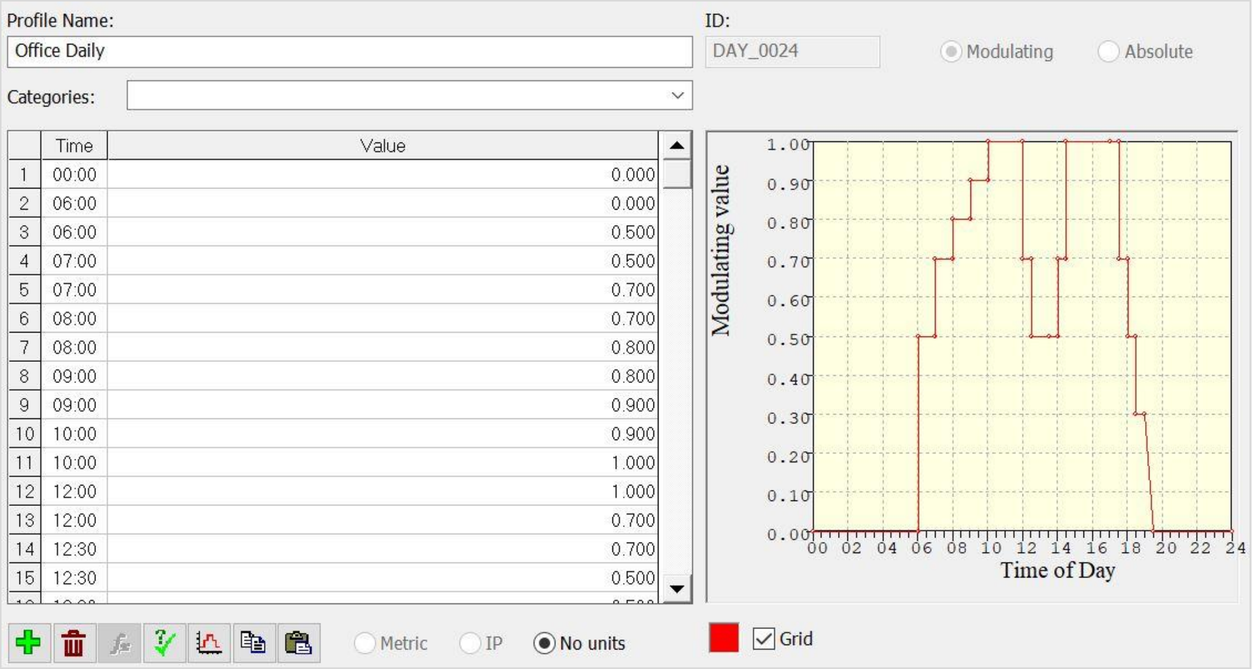
Categories:

	Time	Value
1	00:00	0.300
2	06:00	0.300
3	06:00	0.500
4	07:00	0.500
5	07:00	0.700
6	08:00	0.700
7	08:00	0.800
8	09:00	0.800
9	09:00	0.900
10	10:00	0.900
11	10:00	1.000
12	12:00	1.000
13	12:00	0.700
14	12:30	0.700
15	12:30	0.500

○ Metric ○ IP ● No units

☑ Grid

Figure 96. Housing profile



Profile Name: Office Daily

ID: DAY_0024

● Modulating ○ Absolute

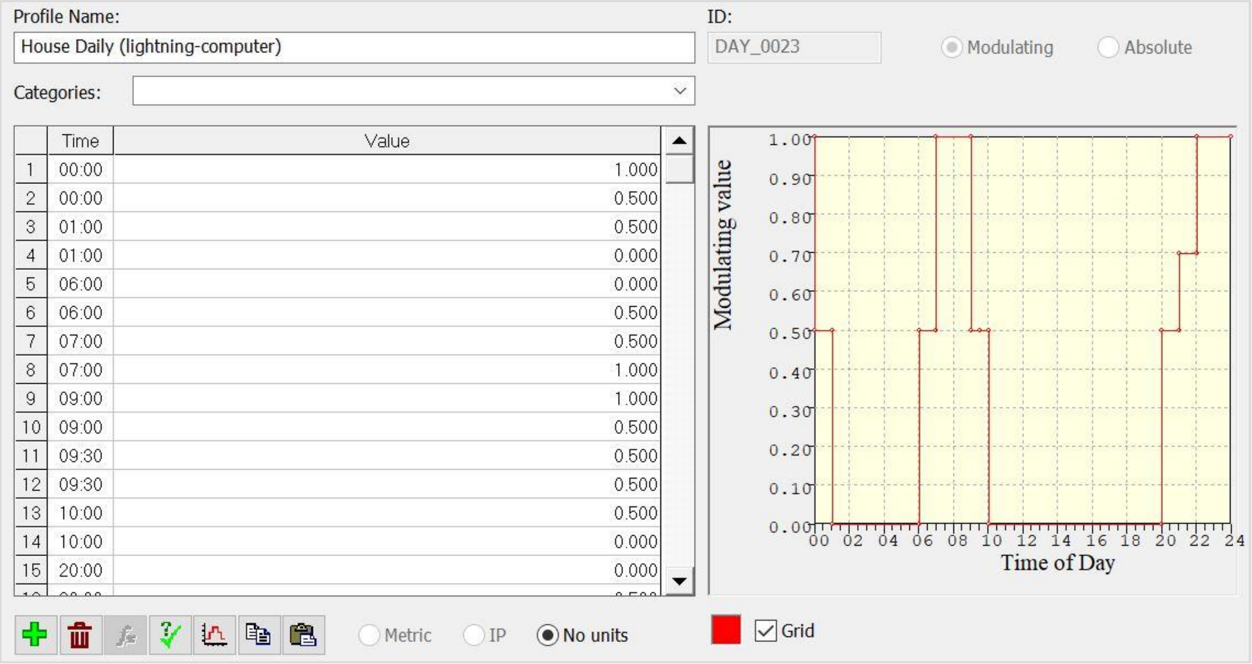
Categories:

	Time	Value
1	00:00	0.000
2	06:00	0.000
3	06:00	0.500
4	07:00	0.500
5	07:00	0.700
6	08:00	0.700
7	08:00	0.800
8	09:00	0.800
9	09:00	0.900
10	10:00	0.900
11	10:00	1.000
12	12:00	1.000
13	12:00	0.700
14	12:30	0.700
15	12:30	0.500

○ Metric ○ IP ● No units

☑ Grid

Figure 97. Main building profile



Profile Name: House Daily (lightning-computer)

ID: DAY_0023

● Modulating ○ Absolute

Categories:

	Time	Value
1	00:00	1.000
2	00:00	0.500
3	01:00	0.500
4	01:00	0.000
5	06:00	0.000
6	06:00	0.500
7	07:00	0.500
8	07:00	1.000
9	09:00	1.000
10	09:00	0.500
11	09:30	0.500
12	09:30	0.500
13	10:00	0.500
14	10:00	0.000
15	20:00	0.000

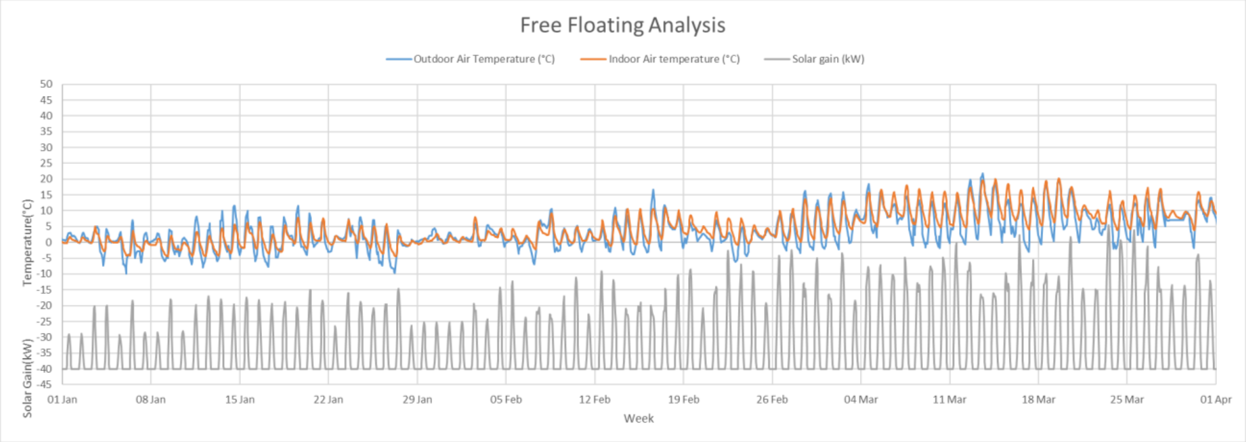
○ Metric ○ IP ● No units

☑ Grid

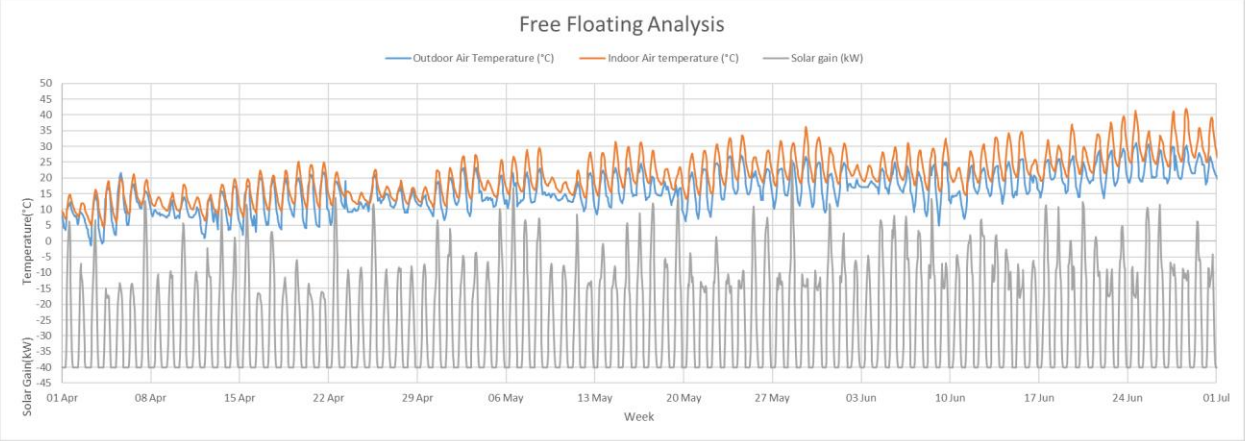
Figure 98. Office profile

7.3.3 Thermal loads in free-floating conditions

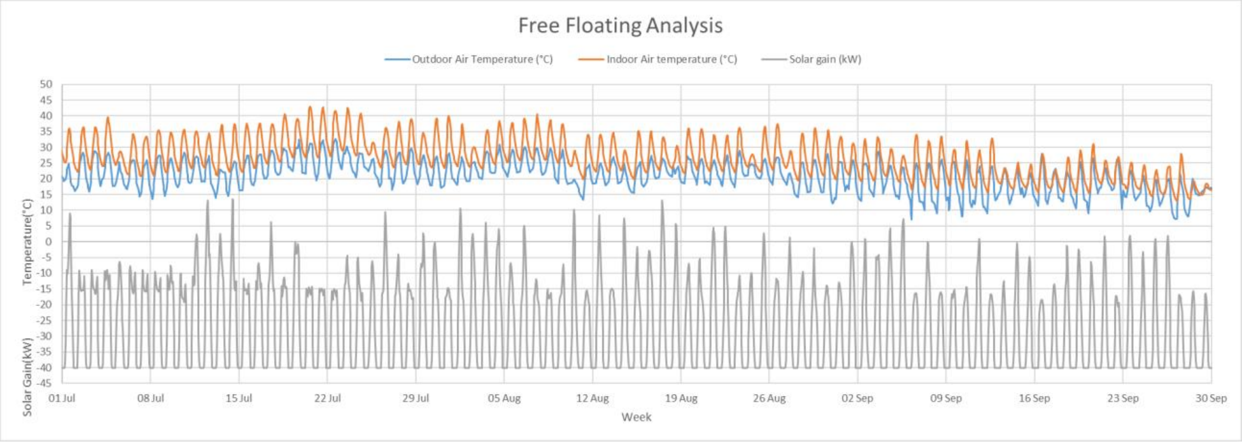
The analyses started with free-floating conditions since the building didn't have any existing equipment and user profile. The actual building conditions with its envelope including wall, slab and roof were analysed in IESVE.



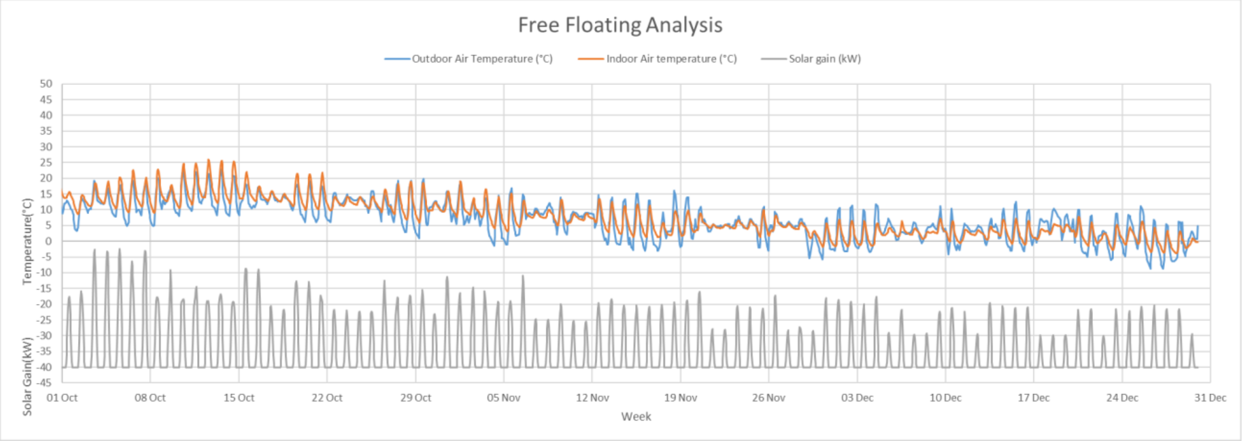
Graph 1. Outdoor, indoor dry bulb, solar gain in hotel between January and March



Graph 2. Outdoor, indoor dry bulb, and solar gain in hotel between April and June



Graph 3.. Outdoor, indoor dry bulb, solar gain in hotel between July and September

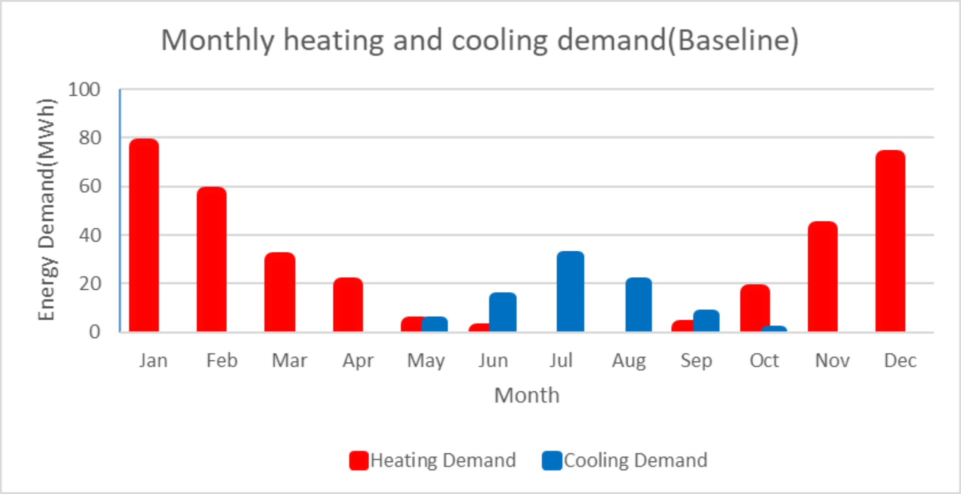


Graph 4. Outdoor, indoor dry bulb, solar gain in hotel between October and December

Because of the weak building envelope due to absence of insulation, the variations of indoor temperature were occurred by solar gain. When the solar gain was examined, the deviation of solar gains is seen daily in parallel with rising of sun rise and down. Winter season, sun is coming with lower angles; however, in summer season, it has higher angle. Because of that reason, the highest point of solar gains is observed more in January-March and October-December, but this is seen as strictly rising and fall in diurnal variation. Therefore, the total amount of solar gain in a day is more in April-June and July-September.

7.3.4 Energy demands

After the outdoor temperature, indoor temperature and solar gains were examined, the heating and cooling demands were analysed to decide energy need in the building. As the boundary conditions were defined as 21-26 °C, indoor temperature should be set that causes to energy demands in the building. In the winter season, indoor temperature remains down 21 °C, and the building requires to heat. In the summer season, indoor temperature goes up 26 °C, the building should be cooled. When the monthly needs were analysed, from January to April and from October to December, the heating need was occurred in high amount. The coldest month is January which needs to heat more. Besides, the building should be cooled more in months from June to August. The highest temperature is observed in July and during this month, cooling consume energy more than the other months to set indoor comfort.



Graph 5. Monthly heating and cooling demand considering baseline

As the looking at the *table 8*, the total energy demand is 396,3521 MWh. Since the heating demand is higher among than cooling demand, indoor conditions become more challengeable in winter times. In this case, it is understood that the structure of the wall definitely needs insulation.

Table 8. Monthly heating and cooling demand (MWh) considering baseline

	Heating Demand	Cooling Demand
Jan	76.8221	0
Feb	56.9258	0
Mar	29.7342	0
Apr	19.4478	0
May	3.3894	4.1317
Jun	0.2301	14.1592
Jul	0	31.0038
Aug	0	20.0637
Sep	2.1846	6.9674
Oct	16.5449	0.0297
Nov	42.7275	0
Dec	71.9901	0
TOTAL	**319.9966**	**76.3555**

7.3.5 Thermal mass improvement

The need for heating resulted in the current situation analysis for the building showed that the building envelope definitely needed insulation. In this case, the 4 different type of section were applied to two walls with different main body including 28 cm brick and 17 cm brick. First one was designed with air cavity without insulation. Other three cases have insulation layer but were differentiated with placing of it inside or outside.

Wall:

- ➢ Wall case 1
    - 28 cm brick body – U-value: 0.70 W/m^{2}K
    - 17 cm brick body – U-value: 0.79 W/m^{2}K
- ➢ Wall case 2
    - 28 cm brick body – U-value: 0.31 W/m^{2}K
    - 17 cm brick body – U-value: 0.32 W/m^{2}K
- ➢ Wall case 3

- 28 cm brick body – U-value: 0.31 W/m^{2}K
- 17 cm brick body – U-value: 0.32 W/m^{2}K

➢ Wall case 4

- 28 cm brick body – U-value: 0.21 W/m^{2}K
- 17 cm brick body – U-value: 0.21 W/m^{2}K

Slab:

➢ Slab with electrical cables and piping system – U-value: 0.20 W/m^{2}K

Roof:

➢ Inclined roof with sandwich panel – U-value: 0.18 W/m^{2}K

Wall

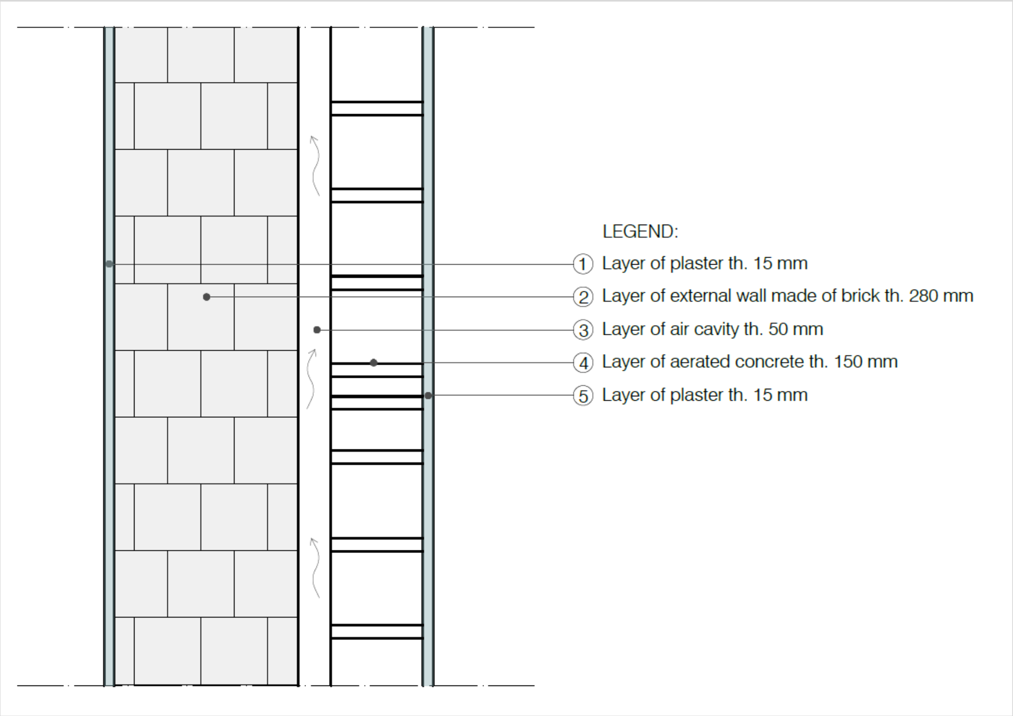


Figure 99. Designed layers of external wall 1

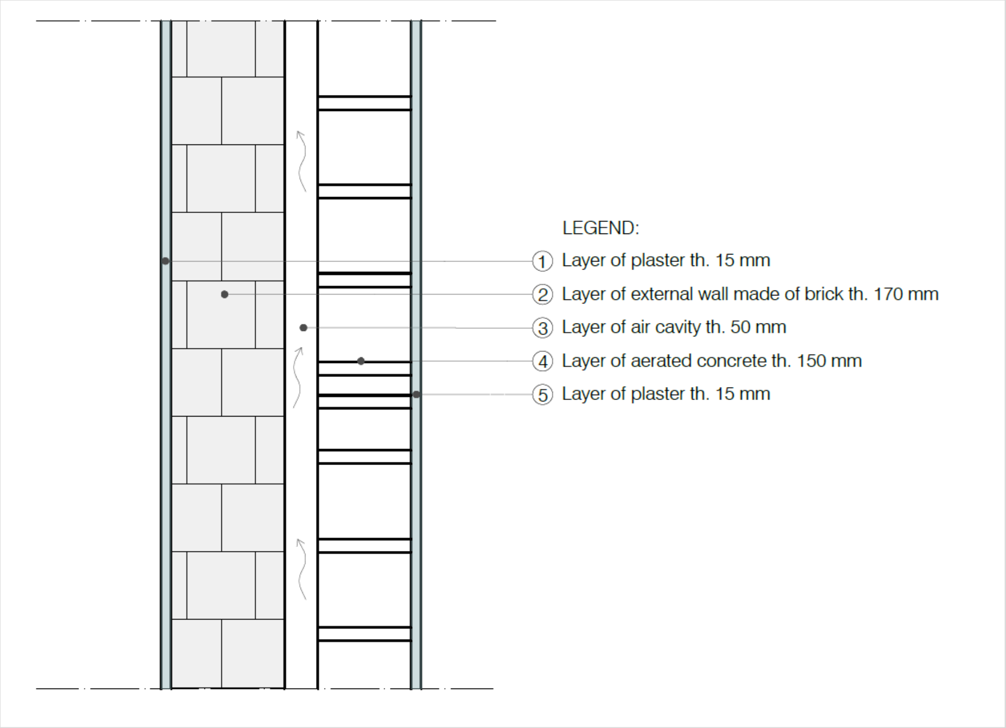


Figure 100. Designed layers of external wall 2

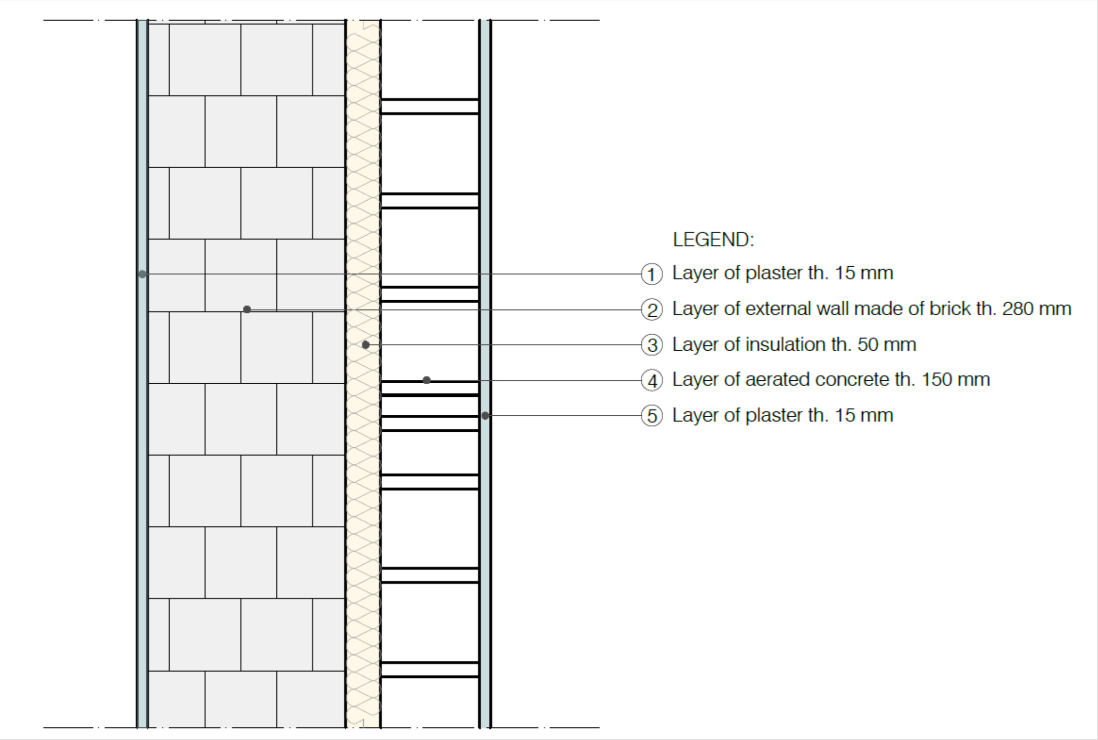


Figure 101. Designed layers of external wall 3

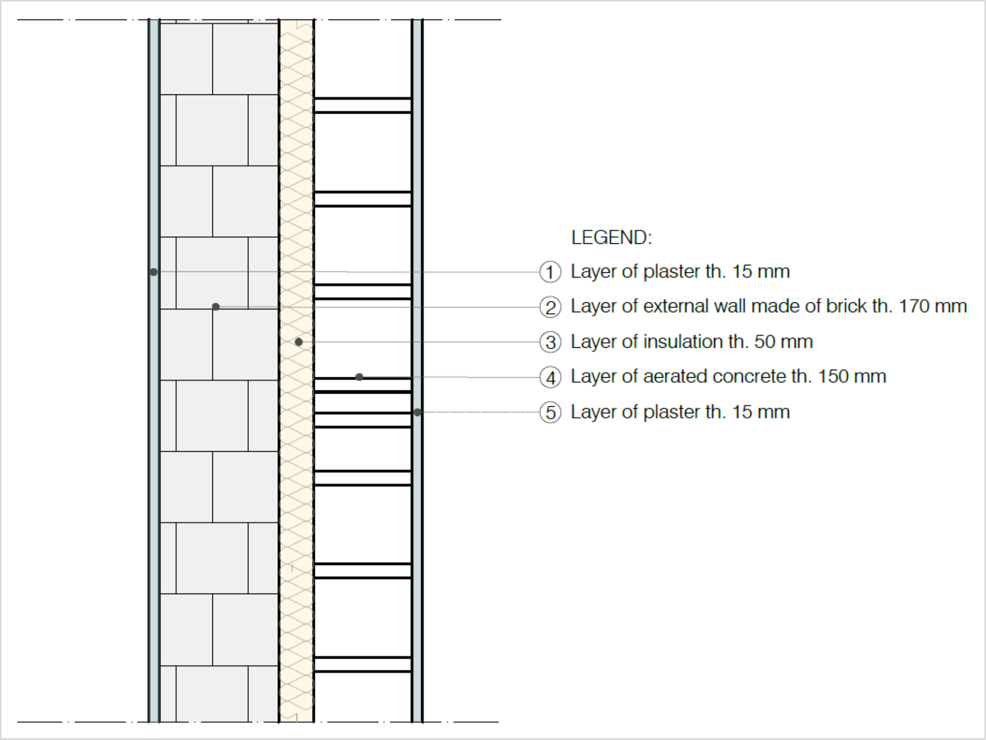


Figure 102. Designed layers of external wall 4

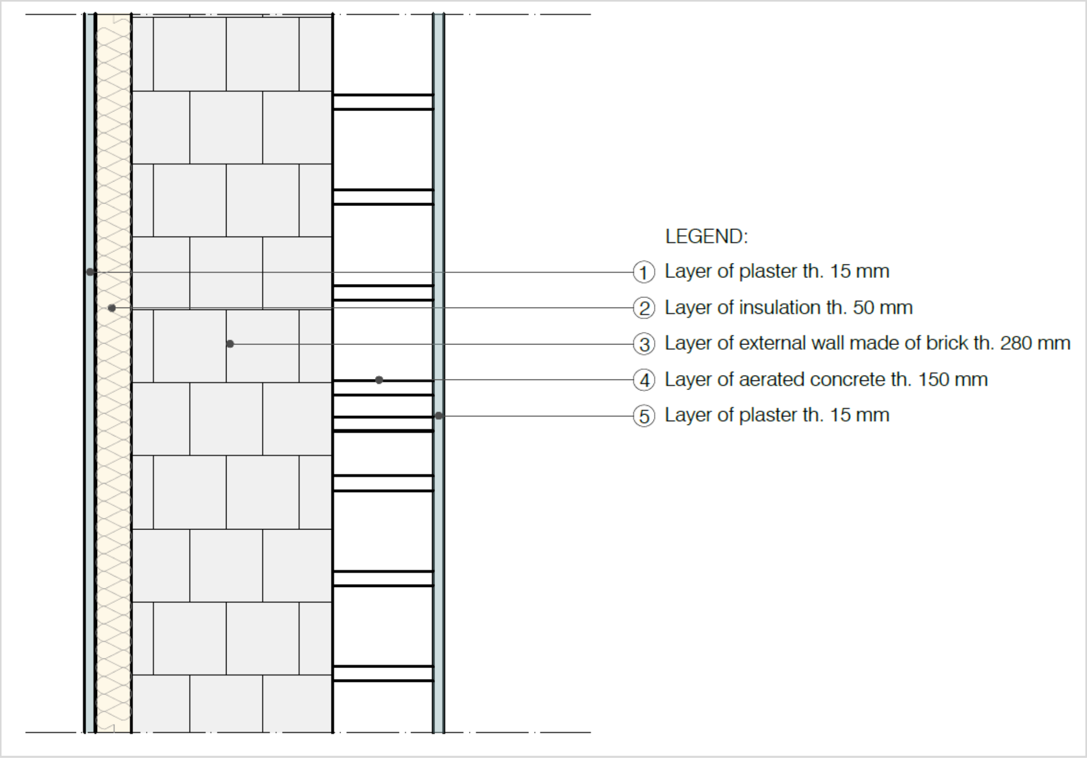


Figure 103. Designed layers of external wall 5

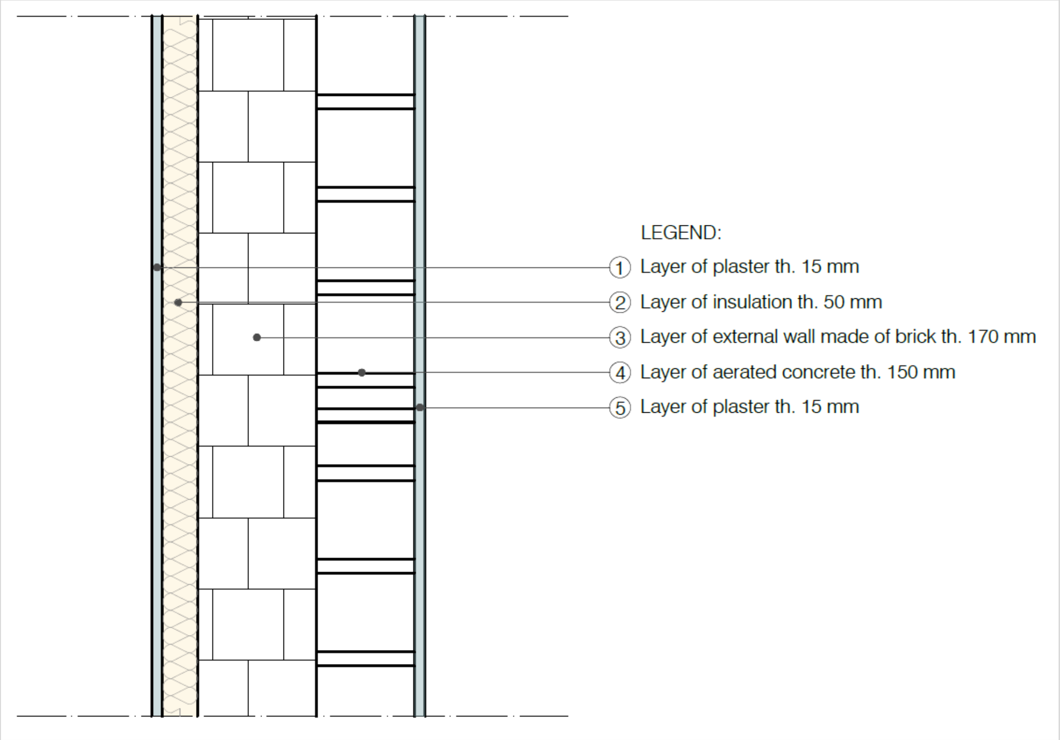


Figure 104. Designed layers of external wall 6

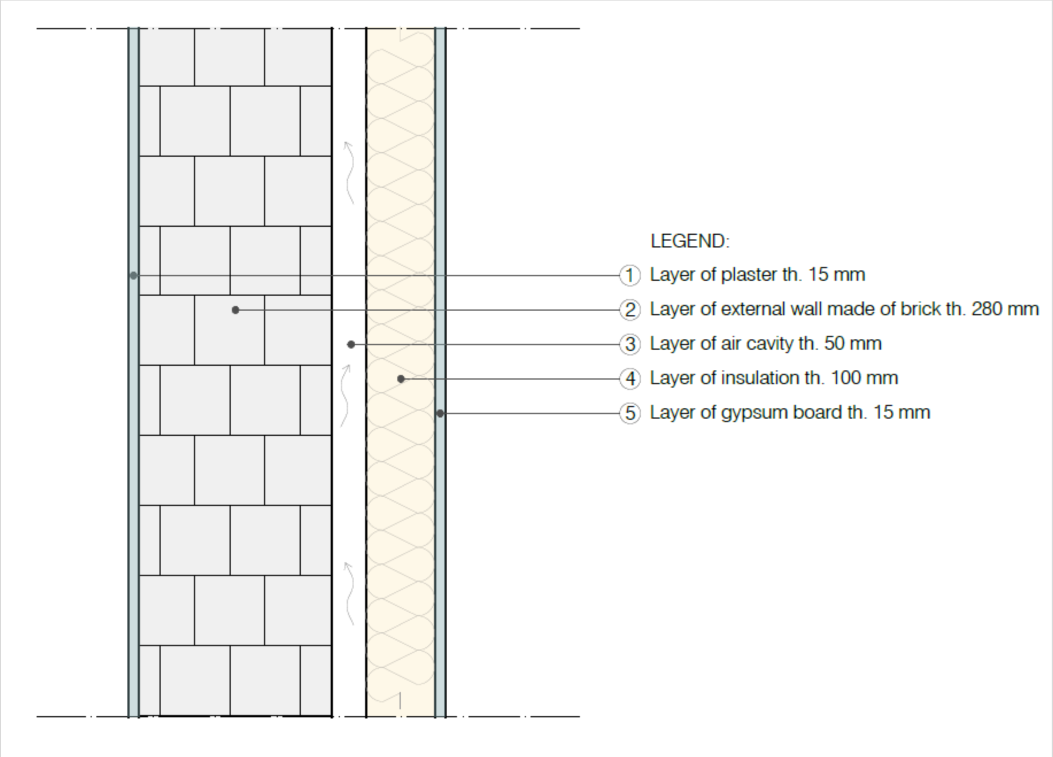


Figure 105. Designed layers of external wall 7

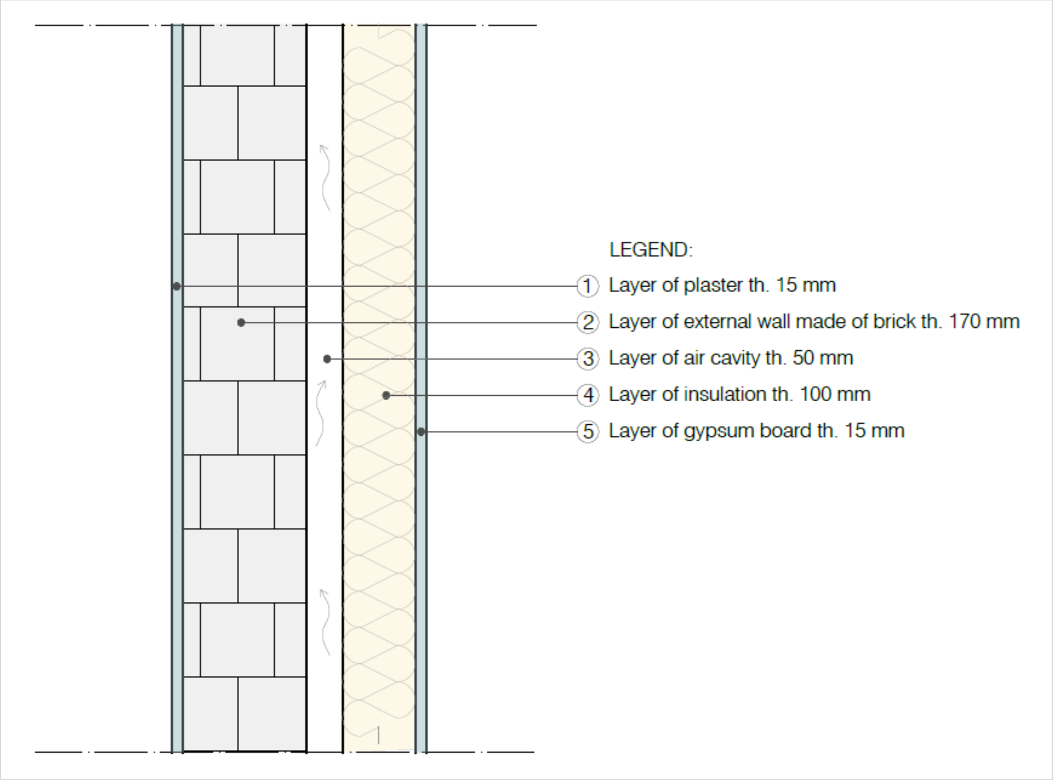
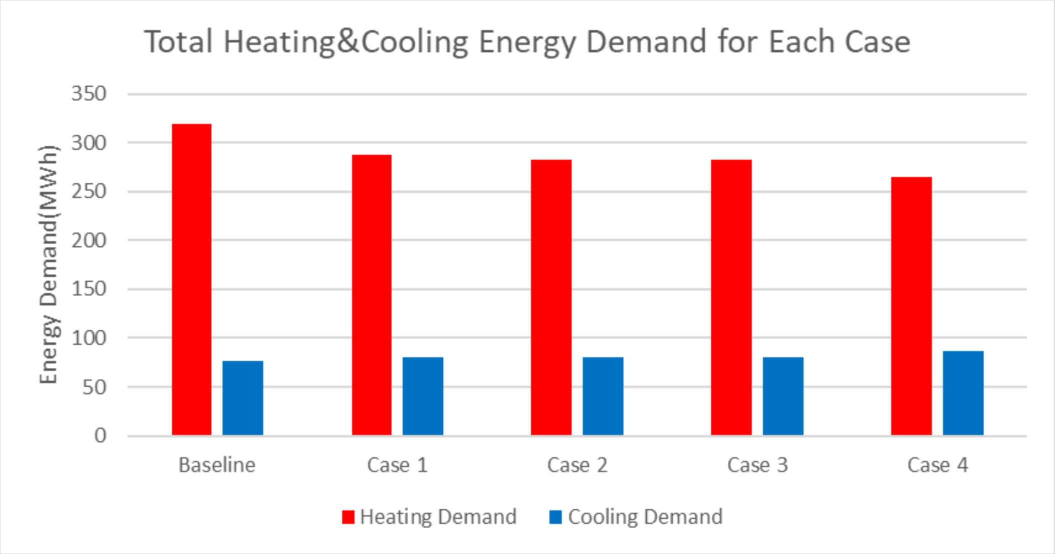


Figure 106. Designed layers of external wall 8

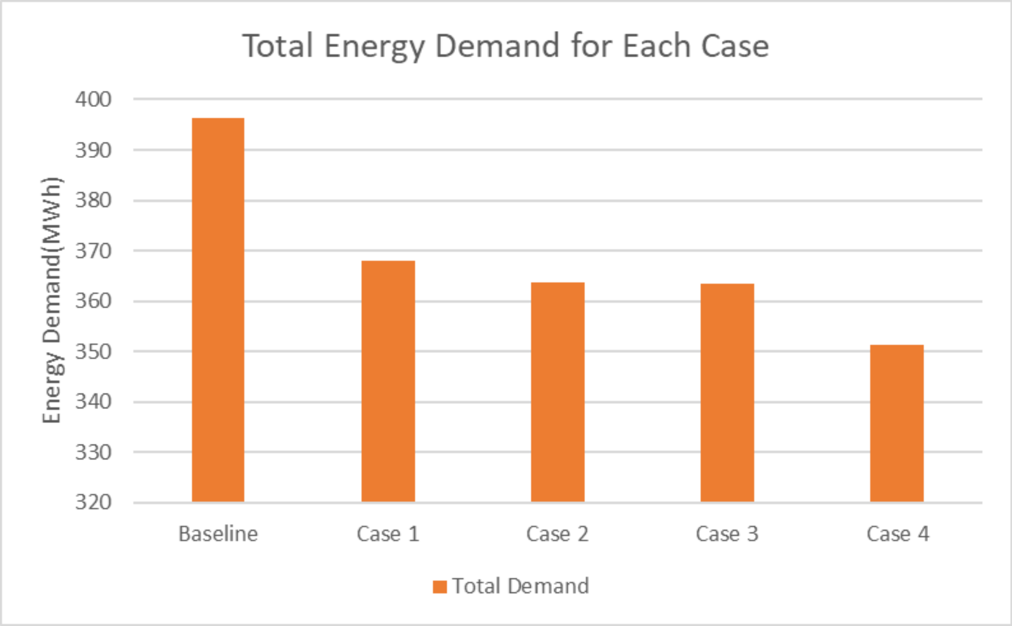


Graph 6. Heating and cooling demands of each wall case

According to cases, the heating and cooling demands are shown in the *graph 6* and *table 9*. Except for case 1, the other cases have insulation layer. The air cavity instead of insulation layer didn't provide good solution for heating while it works well for cooling because of decreasing effect of hot air. Consideration of heating need, placing insulation inner side of wall is the best solution with decreasing conductivity and heating demand. Besides, when the other layers on the wall section increase the thickness and decrease the conductivity, the solution didn't perform well for decrease heating load.

Table 9. Heating, cooling and total demand of cases

	Heating Demand	Cooling Demand	**Total Demand**
Baseline	319.9966	76.3555	**396.3521**
Case 1	287.4797	80.4078	**367.8875**
Case 2	283.2383	80.4141	**363.6524**
Case 3	282.7972	80.628	**363.4252**
Case 4	265.032	86.3693	**351.4013**

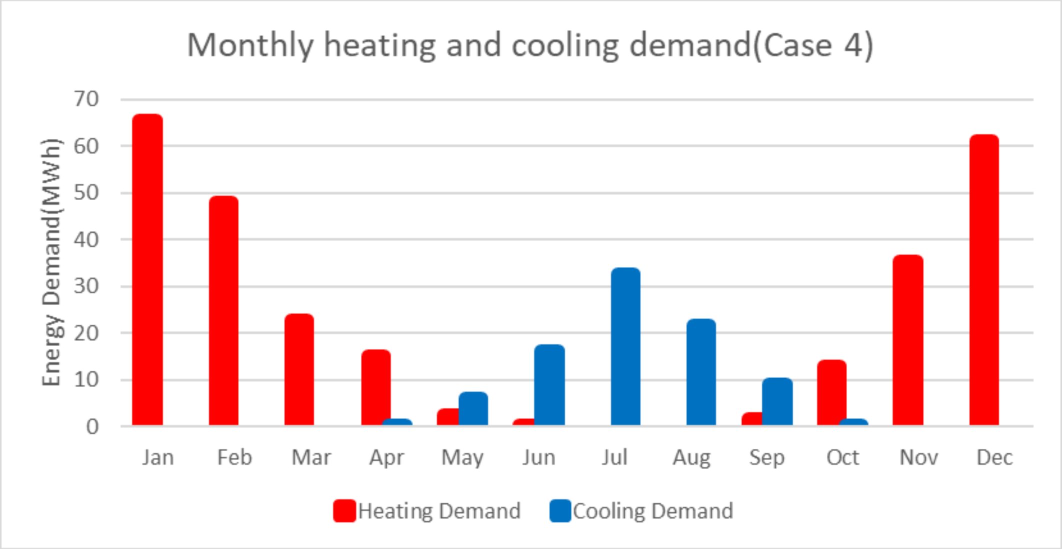


Graph 7. Total energy demand of each wall cases

Total energy demands were compared to see exact difference baseline and among cases, the values are orderly, 396 MWh, 368 MWh, 364 MWh, 363 MWh and 351 MWh as variation seen in *graph 7*. At least demand is seen in case 4.

Table 10. Heating, cooling and total demand of wall case 4 (MWh)

	Heating Demand	Cooling Demand
Jan	65.4164	0
Feb	47.8854	0
Mar	22.8165	0
Apr	15.0528	0.128
May	2.4706	6.2147
Jun	0.1632	16.1093
Jul	0	32.6062
Aug	0	21.8239
Sep	1.6965	9.0431
Oct	12.9669	0.4441
Nov	35.5001	0
Dec	61.0636	0
TOTAL	**265.032**	**86.3693**



Graph 8. Heating and cooling demands of wall case 4

The case 4 was decided as the best solution and chosen for wall design. The total improvement rate of case 4 can be seen below.

Table 11. Improvement rate of wall case 4

	Heating Demand	Cooling Demand	Total Demand	**Improvement**
Baseline	319.9966	76.3555	396.3521	**-11%**
Case 4	265.032	86.3693	351.4013	

Roof

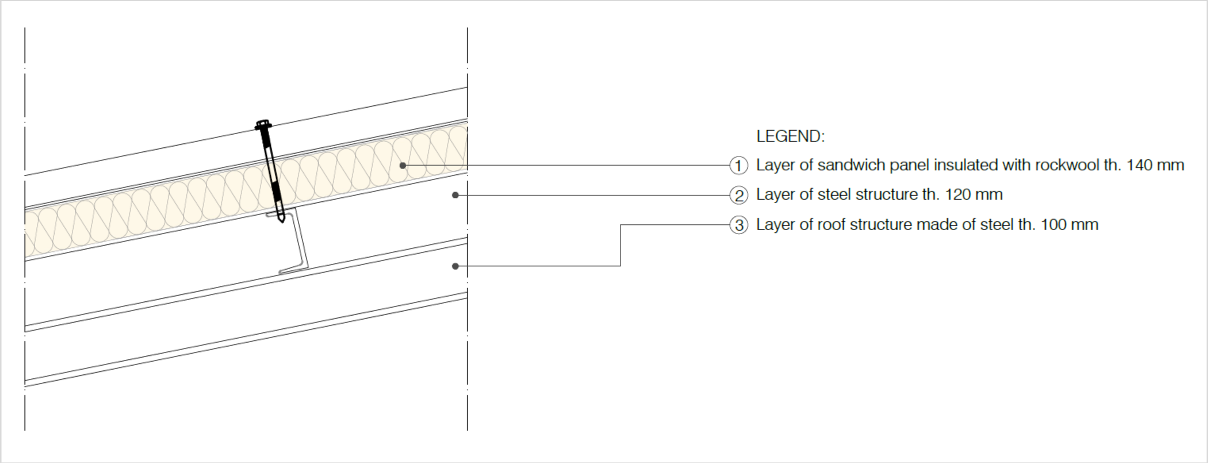
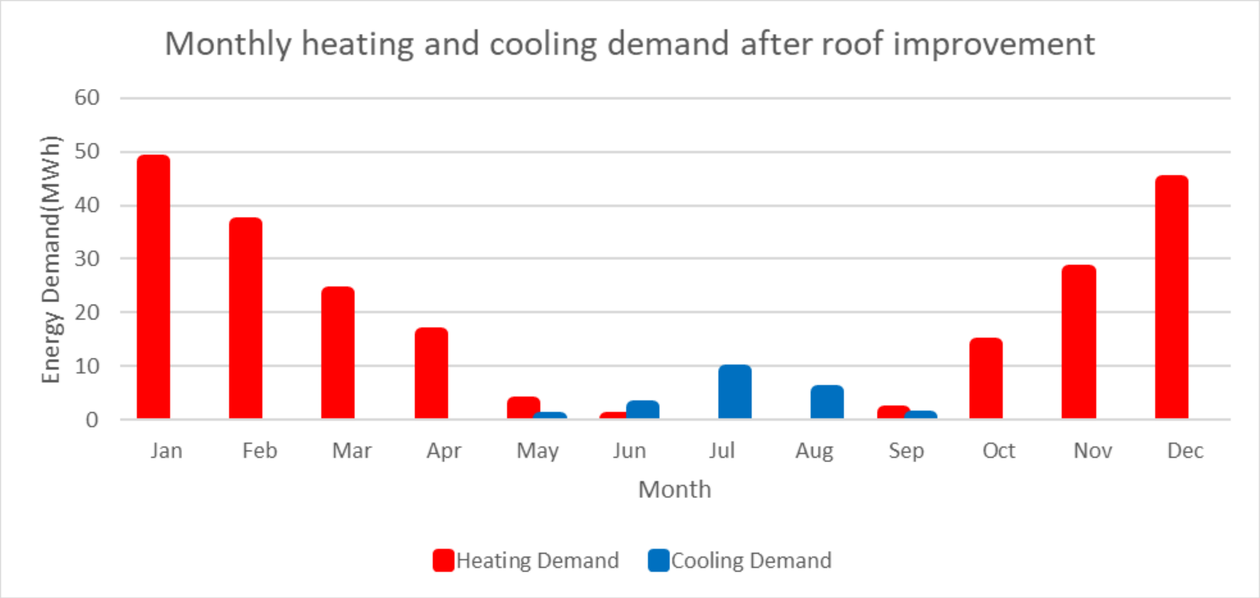


Figure 107. New roof design made of sandwich panel



Graph 9. Heating and cooling demands of new roof

Building new roof system was designed with 14 cm thick-rockwool insulated sandwich panel. The results of previous graph were analysed, the new design of roof affect on heating and cooling demand clearly. In the coldest month January, the heating demand has dropped to 48.21 MWh, while in the hottest month July, the cooling need has decreased to 9.14 MWh.

Table 12. Heating, cooling and total demand of roof (MWh)

	Heating Demand	Cooling Demand
Jan	48.2147	0
Feb	36.6052	0
Mar	23.5357	0
Apr	15.9117	0
May	2.9823	0.0715
Jun	0.0483	2.4844
Jul	0	9.1447
Aug	0	5.1469
Sep	1.4735	0.4656
Oct	14.0883	0
Nov	27.8072	0
Dec	44.4278	0
TOTAL	**215.0947**	**17.3132**

Table 13. Improvement rate of wall and roof

	Heating Demand	Cooling Demand	Total Demand	**Improvement**
Baseline	319.9966	76.3555	396.3521	
Wall	265.032	86.3693	351.4013	**-11%**
Roof	215.0947	17.3132	232.4079	**-41%**

When compared with baseline, roof improvement has changed results significantly. While total energy demand was eliminated to 351.40 MWh with wall improvement, with roof improvement, the total demand was decrease more and seen as 232.41 MWh. This final improvement of the envelope is 41% after new design of wall and roof.

Slab

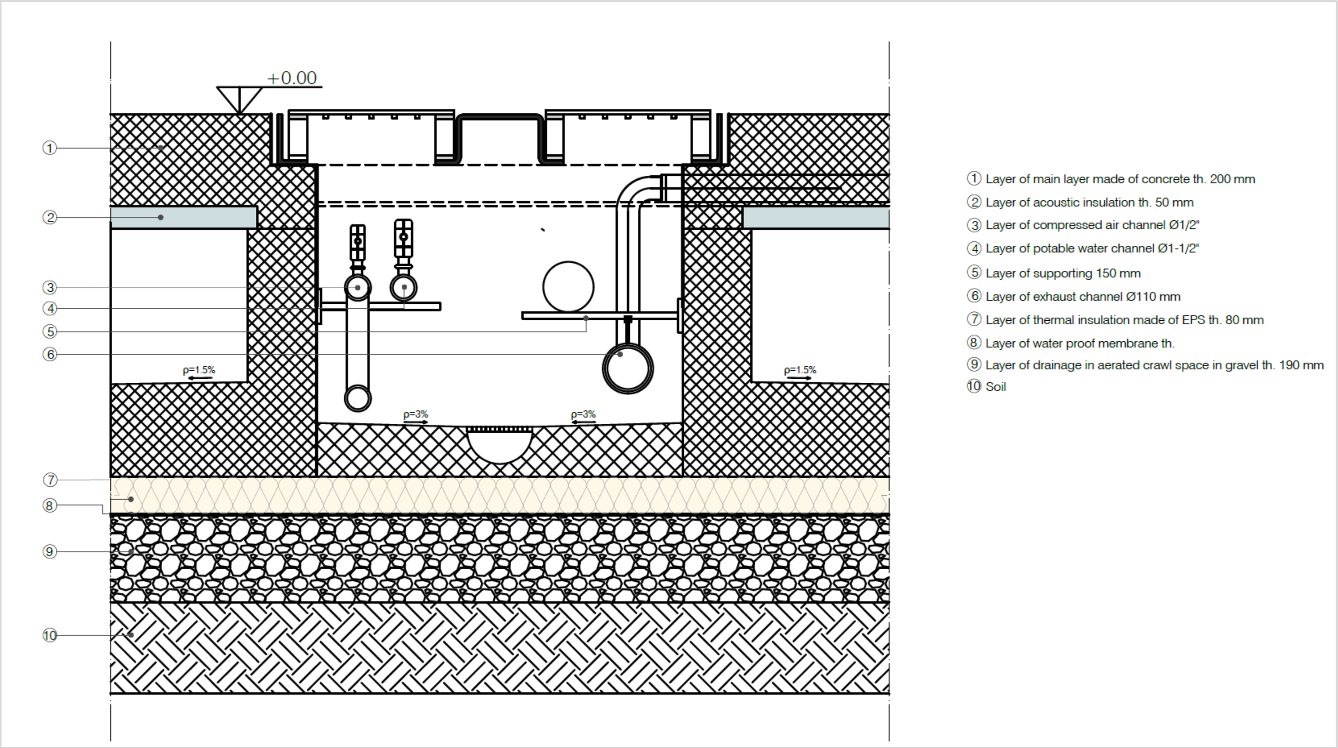
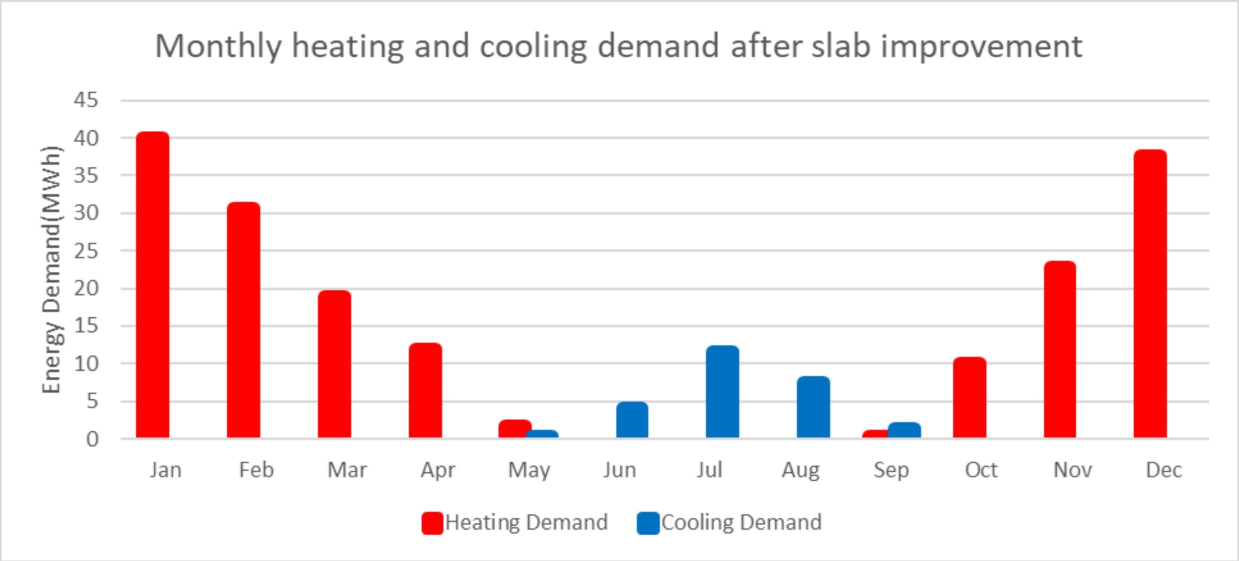


Figure 108. Designed suspended slab with underfloor piping



Graph 10. Heating and cooling demands of new slab design

The slab was improved with new technology which was constructed underfloor heating system for meeting requirement and electrical cables for machinery. This design solution provides modular and flexible design and heating to reach comfort conditions. With new slab design, the heating demand is 173.70 MWh while cooling is 24.93 MWh.

Table 14. Monthly heating, cooling and total demand of slab (MWh)

	Heating Demand	Cooling Demand
Jan	39.9878	0
Feb	30.5698	0
Mar	18.8114	0
Apr	11.846	0
May	1.7314	0.3043
Jun	0	4.1588
Jul	0	11.6497
Aug	0	7.5031
Sep	0.3808	1.3135
Oct	10.0456	0
Nov	22.7611	0
Dec	37.5711	0
TOTAL	**173.7049**	**24.9293**

Table 15. Improvement rate of wall, roof and slab

	Heating Demand	Cooling Demand	Total Demand	**Improvement**
Baseline	319.9966	76.3555	396.3521	
Wall	265.032	86.3693	351.4013	**-11%**
Roof	215.0947	17.3132	232.4079	**-41%**
Slab	173.7049	24.9293	198.6342	**-50%**

After roof improvement, the building conditions has enhanced again with slab design. While the improvement rate was 41% with wall and roof improvement, the total demand was decreased by 50% in comparison with baseline of building.

7.3.6 Glazing improvement

As a glazing design, four different cases were analysed. The window factors were gathered by LBNL Window which has specific glass data from manufacturers. The U-values were also calculated in this software by decision of window thicknesses, glass type and cavity.

Two different glass types were analysed: Float glass and low-E glass. The coating of low-e glass reflects radiation to prevent transferring inside of room, and allow heat coming from sun.

In addition, as a cavity, two different gasses were used. First one is air, the other one is argon. The cavity leads to convection and transfer less heat. Since thermal conductivity of air is lower than argon, using argon in cavity decreases the heat transfer that effects on U-value of glazing.

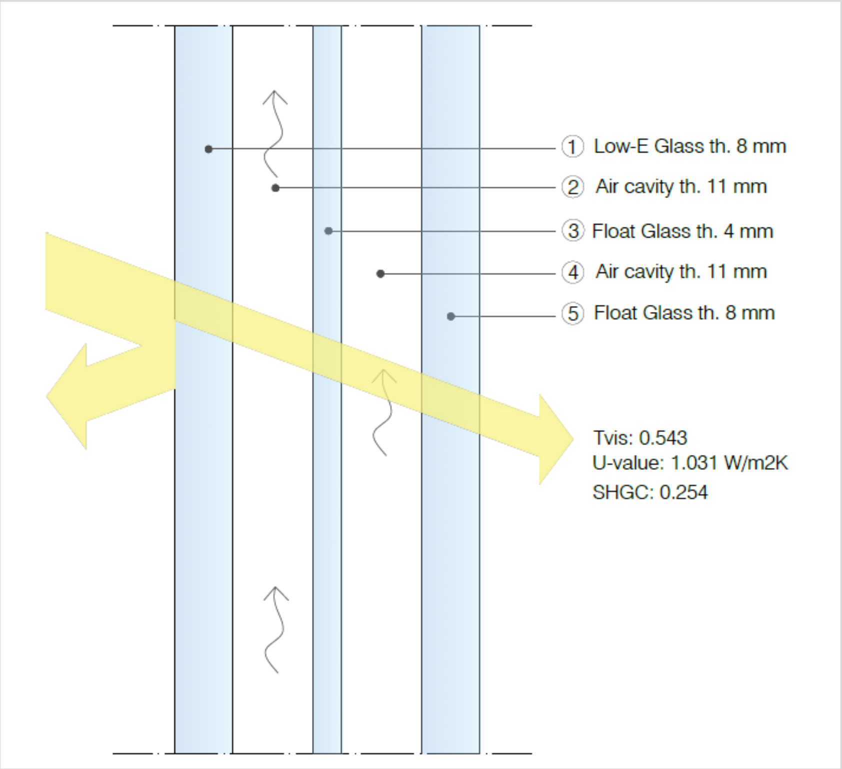


Figure 109. Window layers of case 1

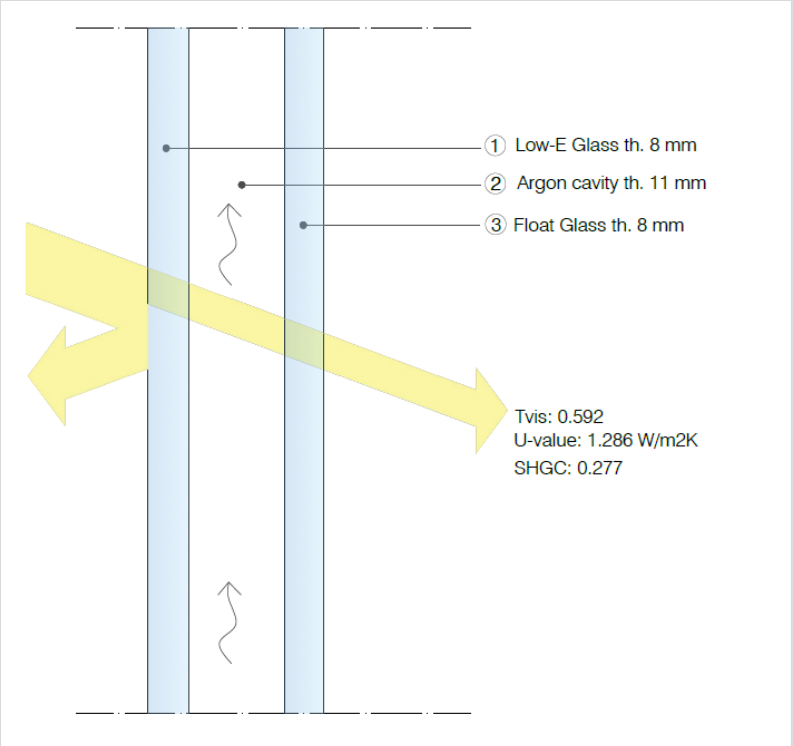


Figure 110. Window layers of case 2

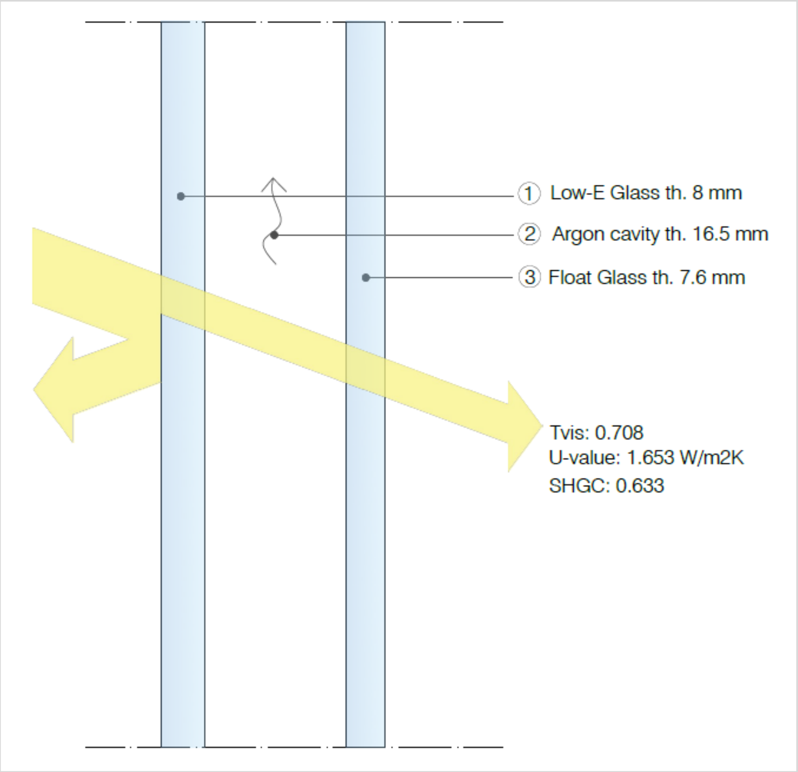


Figure 111. Window layers of case 3

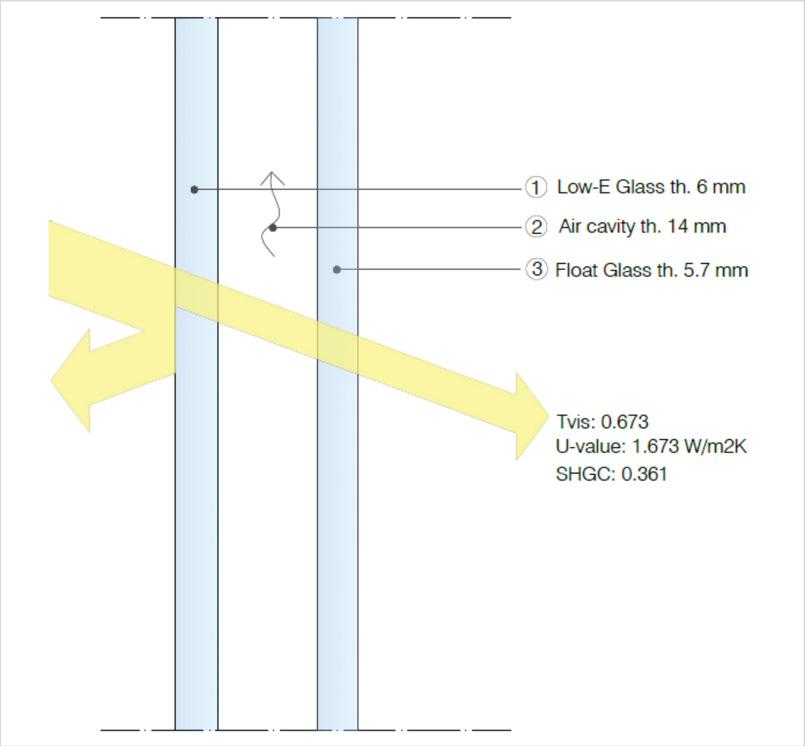
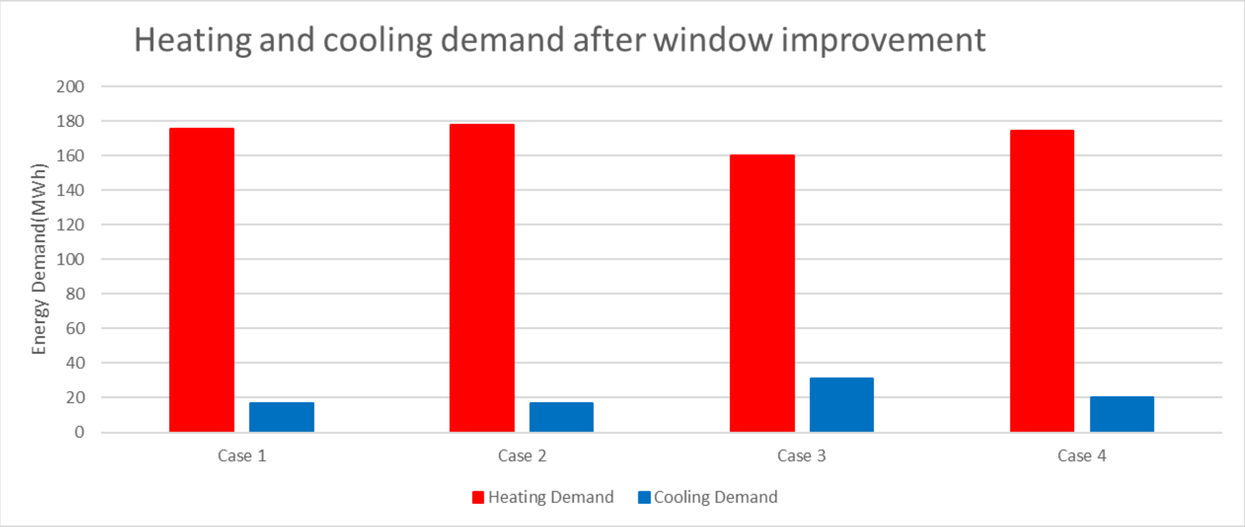


Figure 112. Window layers of case 4



Graph 11. Heating and cooling demand of each window cases

First case consists of 8 mm low-e glass, 11 mm air cavity, 4 mm float glass, 11 mm air cavity, and 8 mm float glass. The U-value of baseline is 1.031 W/m^{2}K, visible transmittance of the glazing is 0.543 and the solar heat gain coefficient – SHGC is 0.254. For this glazing, total plant load is 192.515 MWh. Second case is composed of 8 mm low-e glass, 11 mm cavity infilled with argon gas, and 8 mm float glass. The U-value of baseline is 1.286 W/m^{2}K, visible transmittance of the glazing is 0.592 and the solar heat gain coefficient – SHGC is 0.277. For this glazing, total plant load is 194.645 MWh. Third case is high solar gain double glazing system which is composed of 8 mm low-e glass, 16.5 mm cavity infilled with argon gas, and 7.6 mm float glass. The U-value of baseline is 1.653 W/m^{2}K, visible transmittance of the glazing is 0.708 and the solar heat gain coefficient – SHGC is 0.633. For this glazing, total plant load is 191.614 MWh. Fourth case is composed of 6 mm low-e glass, 14 mm air cavity, and 5.7 mm float glass. The U-value of baseline is 1.673 W/m^{2}K, visible transmittance of the glazing is 0.673 and the solar heat gain coefficient – SHGC is 0.361. For this glazing, total plant load is 194.622 MWh.

The glazing case results show the best option for minimum total demand is case which has to double glazing system with low-e glass and argon filled cavity of 16.5 mm. The case 3 has 160.283 MWh heating need while the cooling is 31.330 MWh. Although the cooling demand was higher than other cases, total value of energy need was decreased.

Table 16. Heating, cooling and total demand of each window cases (MWh)

	Heating Demand	Cooling Demand	**Total Demand**
	173.7049	24.9293	**198.6342**
Case 1	175.5826	16.6689	**192.2515**
Case 2	177.8935	16.7517	**194.6452**
Case 3	160.2834	31.3301	**191.6135**
Case 4	174.5711	20.0507	**194.6218**

Table 17. Improvement rate of wall, roof, slab and glazing

	Heating Demand	Cooling Demand	Total Demand	**Improvement**
Baseline	319.9966	76.3555	396.3521	
Wall	265.032	86.3693	351.4013	**-11%**
Roof	215.0947	17.3132	232.4079	**-41%**
Slab	173.7049	24.9293	198.6342	**-50%**
Glazing	160.2834	31.3301	191.6135	**-52%**

The glazing enhancement was compared with other situations, the total demand was decreased by 52% in comparison with baseline of building.

7.3.7 Internal gains

Internal gains were defined for office and accommodation use for the building. These are machinery, equipment, and people. The analyses were gathered according to occupant scenarios as mentioned in 7.3.2.

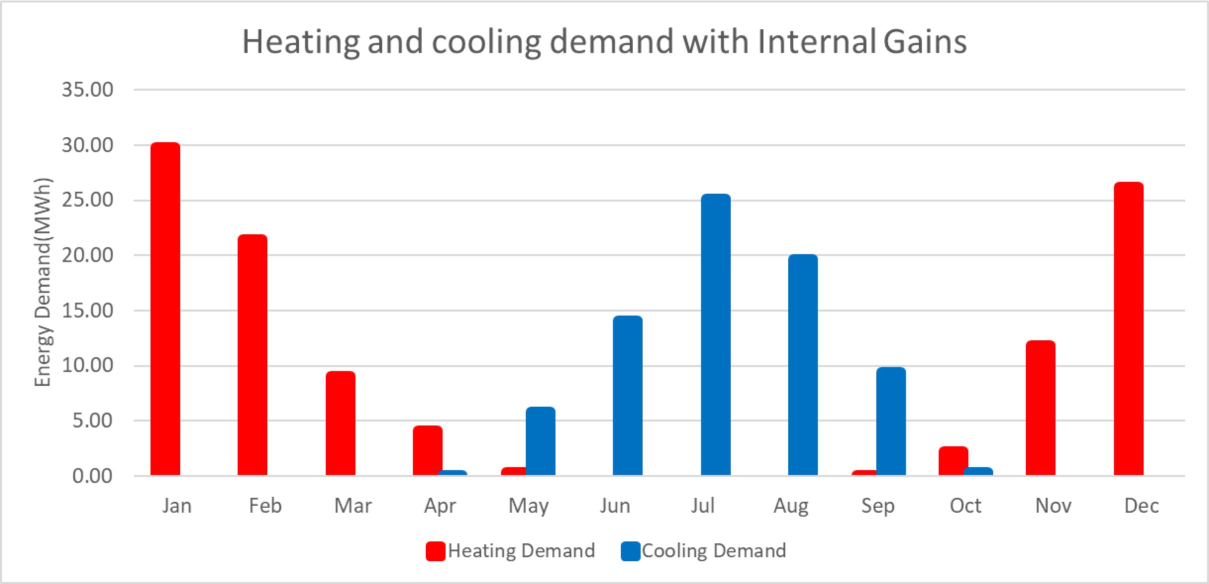


Figure 113. Heating and cooling demand with internal gains

Table 18. Heating and cooling demand after loading internal gains on the building

	Heating Demand	Cooling Demand
Jan	29.7805	0
Feb	21.4789	0
Mar	9.0632	0
Apr	4.1209	0.059
May	0.3604	5.8297
Jun	0	14.1297
Jul	0	25.1406
Aug	0	19.7046
Sep	0.0727	9.4528
Oct	2.2046	0.3179
Nov	11.8445	0
Dec	26.2173	0
TOTAL	**105.1431**	**74.6343**

Table 19. Improvement rate after combining new envelope design and internal gains

	Heating Demand	Cooling Demand	Total Demand	**Improvement**
Baseline	319.9966	76.3555	396.3521	
Wall	265.032	86.3693	351.4013	**-11%**
Roof	215.0947	17.3132	232.4079	**-41%**
Slab	173.7049	24.9293	198.6342	**-50%**
Glazing	160.2834	31.3301	191.6135	**-52%**
Internal Gains	105.1431	74.6343	179.7774	**-55%**

Internal gains affected on indoor temperature, and this caused to decrease heating demand while cooling demand decreased that reduced by 55% of baseline energy demand.

7.3.8 Heating, cooling and ventilation design

The industrial function of the building led to the absence of heating and cooling under the conditions of that day. Since the function change will increase with the time, people spend inside of the building, it is clearly seen that there is a need for heating, cooling and ventilation. In the free-floating analysis, energy need of the building could be reduced by 52% when the building envelope was improved. In this part of study, heating, cooling and ventilation solutions were discussed and they were designed in CAD.

In order to realize the flexible design concept, the office function had to be fully operational when the office boxes were moved. For this to happen, the office equipment and the power line that would meet the needs of employees had to be able to reach the boxes in any way. Therefore, based on the design axis specified in 7.2, an underground electrical system was created *figure 110*. The electrical cables passing through the floor are made accessible in boxes and inside the building with the cover system in the file.

Figure 114. Underfloor electric plan

The electrical cables reach the boxes so that they can be used for lighting, sockets and USB inputs inside the boxes. The power lines, that continue along the horizontal lines, are collected into a single line and reach the electric room. This is a good solution to have a centralized system to control it in the event of a major failure. In addition to this, the ability to interfere with the caps in the boxes and in the building improves its solvability and controllability for minor faults. As electrical cables, heat-resistant cable is preferred because there will be floor heating.

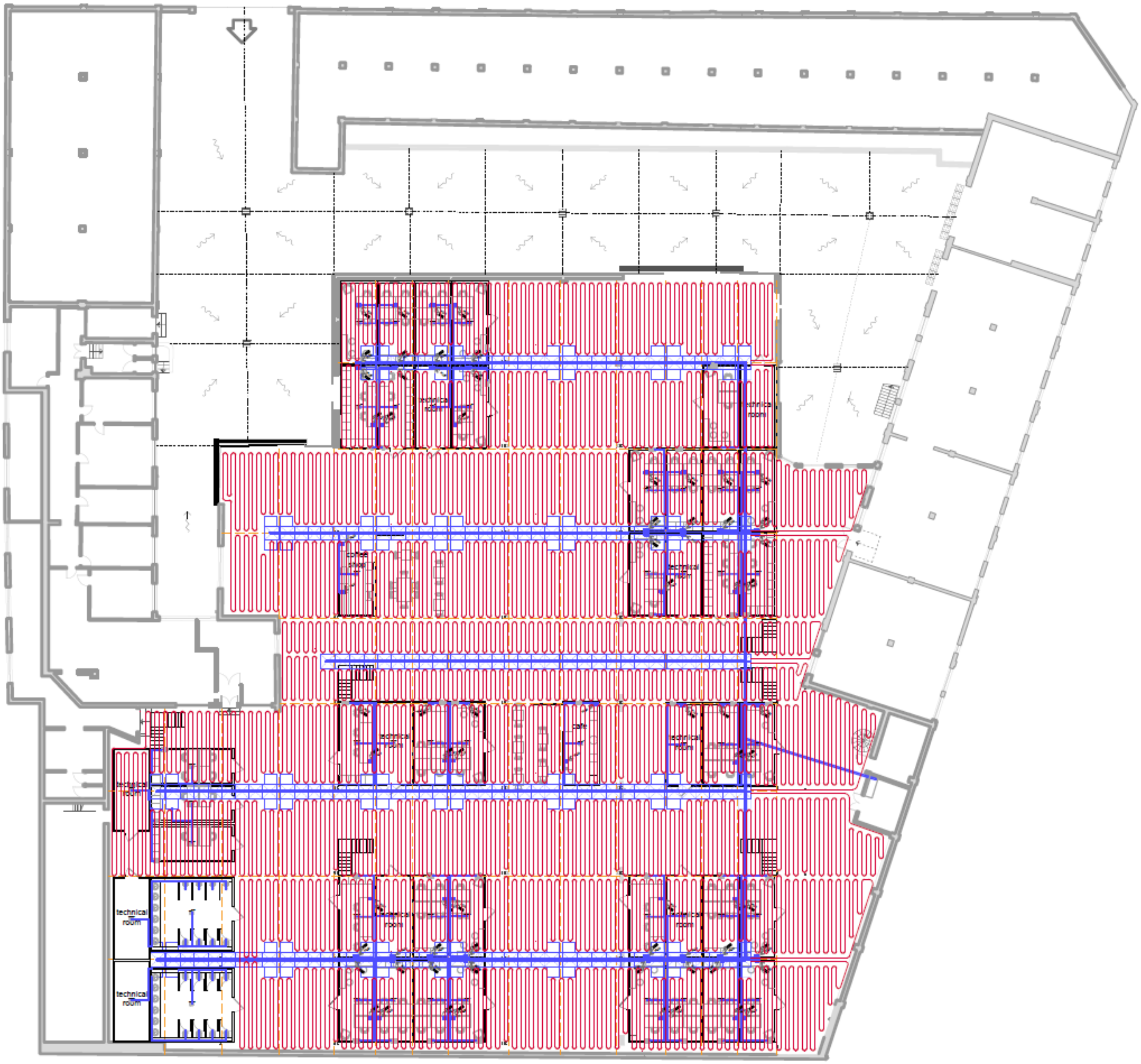


Figure 115. Underfloor heating plan

The floor heating system has been preferred to a more technological design rather than a traditional solution. Considering the covers with electrical lines, a system was designed for heating the whole building. Instead of heating each box separately, heating the building is expected to be a more economical solution. The heating pipes pass underfloor at different heights so as not to damage the electrical cables.

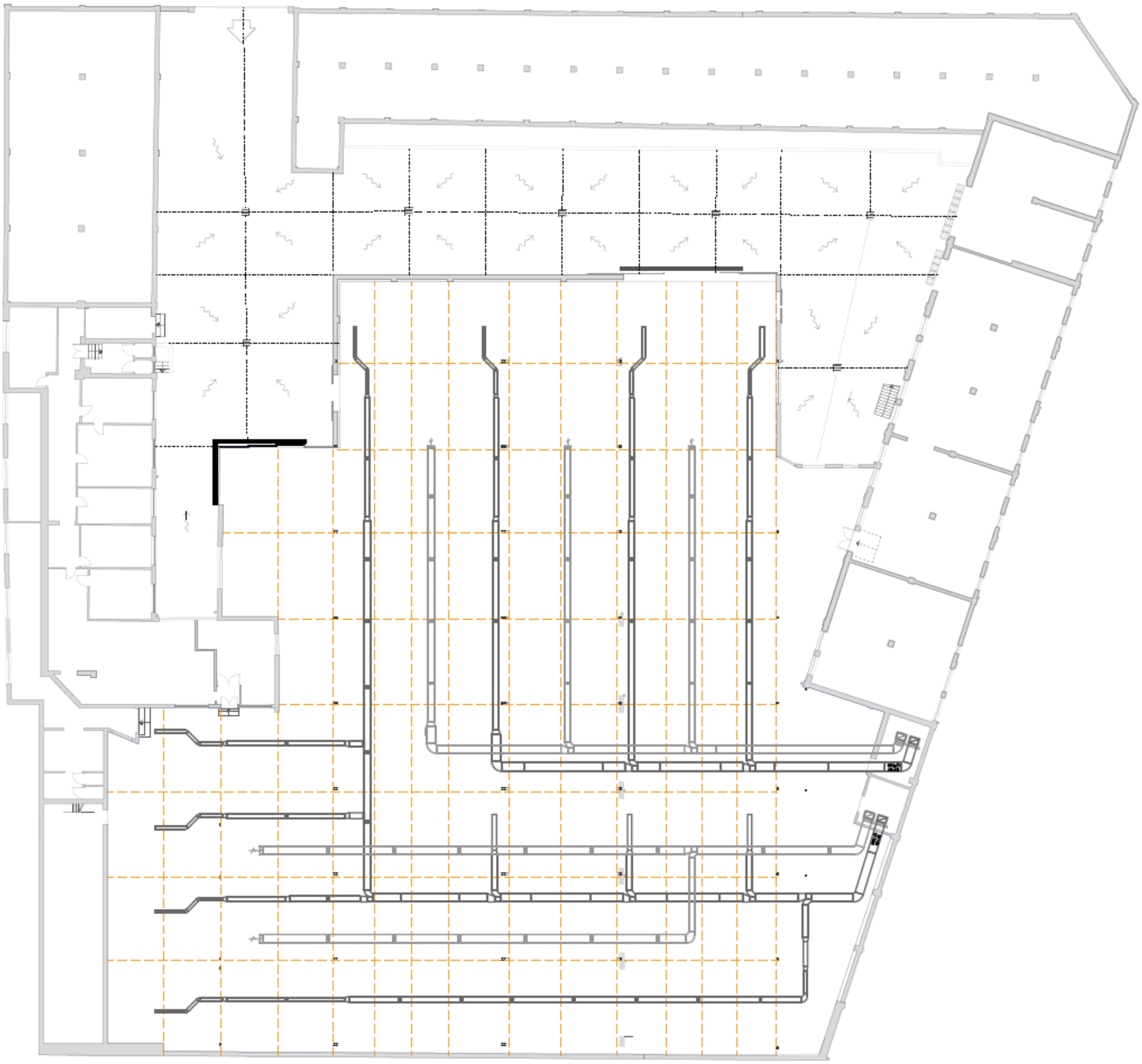
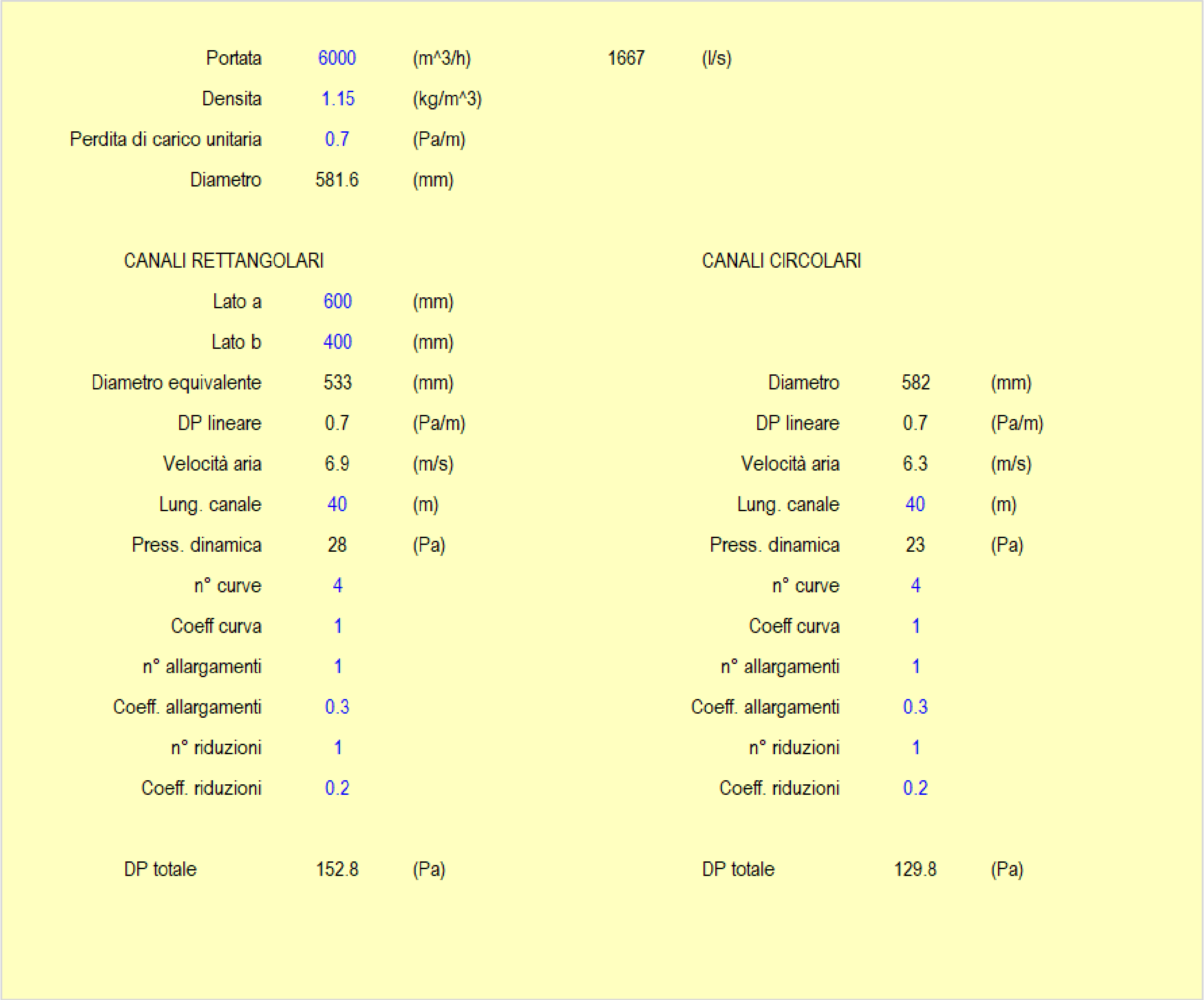


Figure 116. Ventilation plan

As the ventilation design, inlet air and exhaust air were calculated according to requirements. When the ventilation was designed, 40 m^3/h is considered per person according to UNI10339. This is assumed as 100 people in the building, the total requirement is 4000 m^3/h. air change is also provided 4/h for office buildings. On the other hand, there are decentralised ventilation systems in boxes and their outlet air goes to building and outlet comes to boxes. This requires additional fresh air in the building that is also considered in the calculations. Total 6000 m^3/h air capacity was taken into account by using rectangular ducts with 600x400 mm section. Air separation around inside of building is designed with smaller section in the building.



Portata	6000	(m^3/h)	1667	(l/s)	
Densita	1.15	(kg/m^3)			
Perdita di carico unitaria	0.7	(Pa/m)			
Diametro	581.6	(mm)			
CANALI RETTANGOLARI			CANALI CIRCOLARI		
Lato a	600	(mm)			
Lato b	400	(mm)			
Diametro equivalente	533	(mm)	Diametro	582	(mm)
DP lineare	0.7	(Pa/m)	DP lineare	0.7	(Pa/m)
Velocità aria	6.9	(m/s)	Velocità aria	6.3	(m/s)
Lung. canale	40	(m)	Lung. canale	40	(m)
Press. dinamica	28	(Pa)	Press. dinamica	23	(Pa)
n° curve	4		n° curve	4	
Coeff curva	1		Coeff curva	1	
n° allargamenti	1		n° allargamenti	1	
Coeff. allargamenti	0.3		Coeff. allargamenti	0.3	
n° riduzioni	1		n° riduzioni	1	
Coeff. riduzioni	0.2		Coeff. riduzioni	0.2	
DP totale	152.8	(Pa)	DP totale	129.8	(Pa)

Figure 117. Calculation of sections in excel

Then, the ventilation was modelled in BIM with mechanical template which allows to draw ducts easier than the cad because REVIT contains many sections and their connections inside the library.

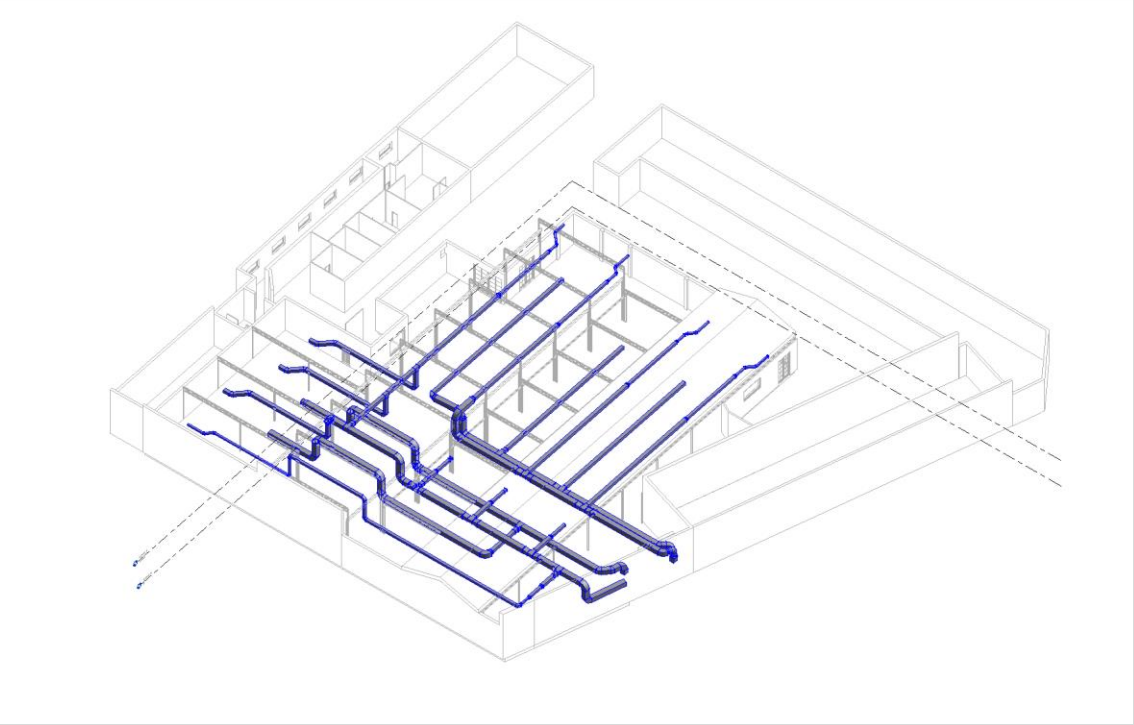


Figure 118. Ventilation design in BIM

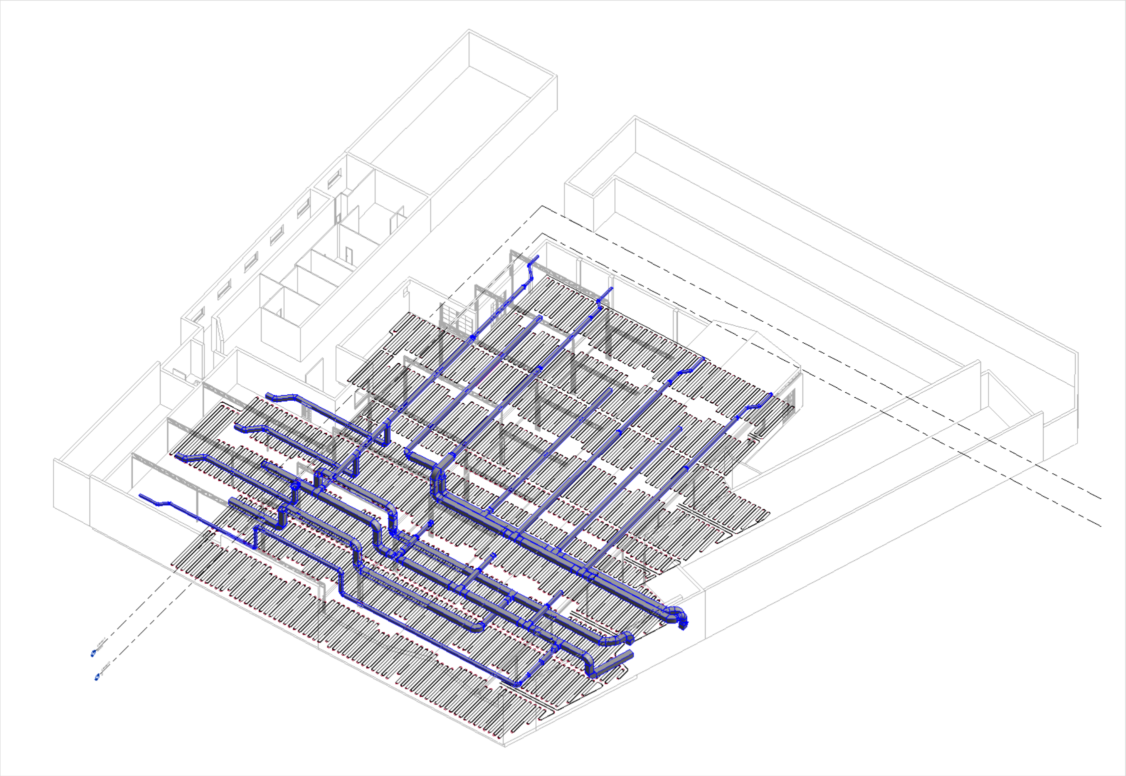


Figure 119. Underfloor heating and ventilation system in BIM

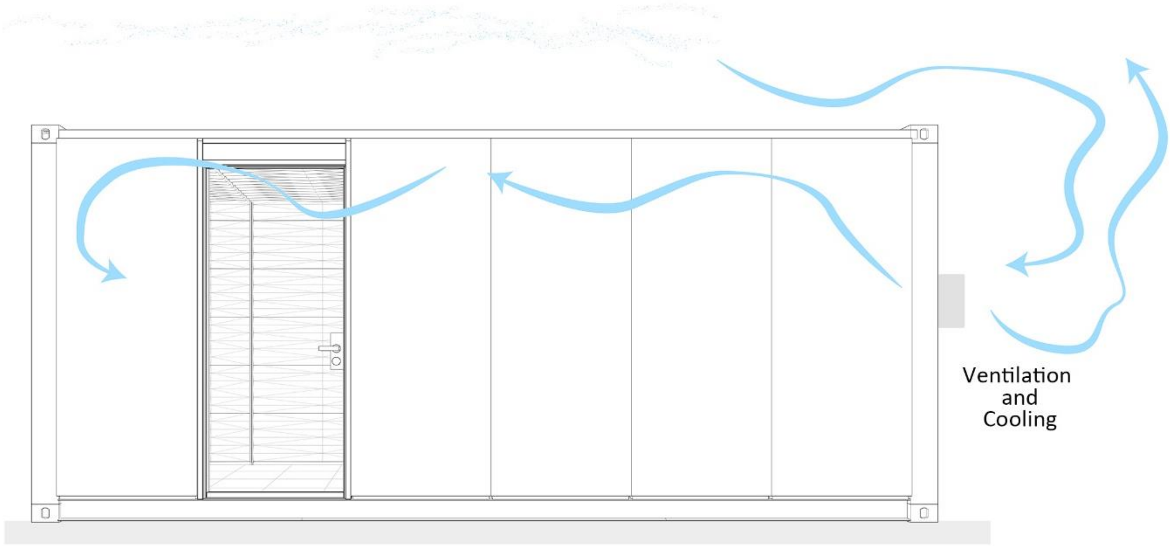


Figure 120. Air circulation in the box

Except from ventilation of building, prefabricated units were also conditioned with decentralized ventilation units. These units have dimension in 409 mm x 388 mm x 196 mm and air flow rate is 15, 30,60 and 100 m^3/h according to working level I, II, III and max.

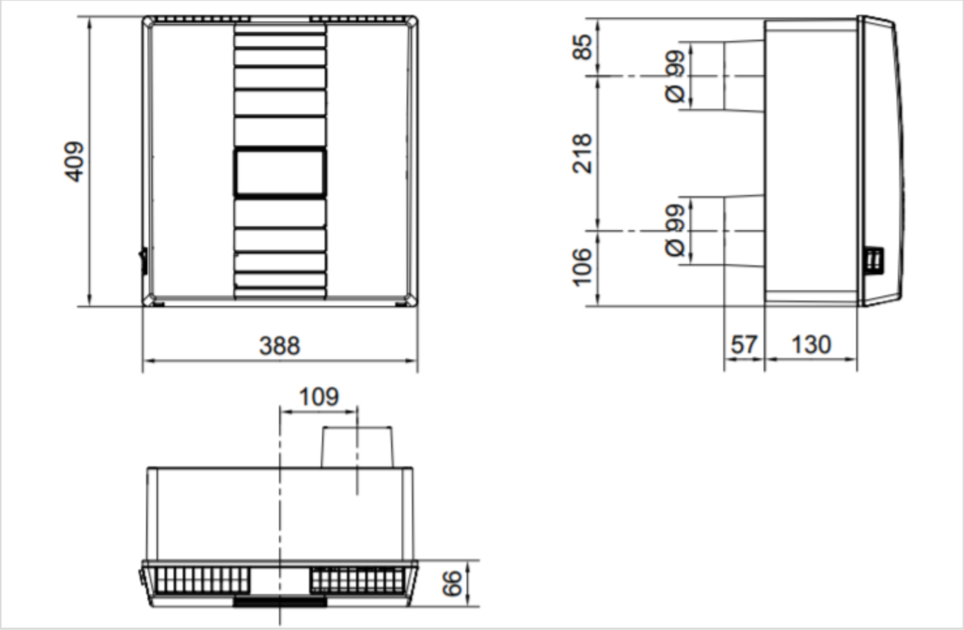


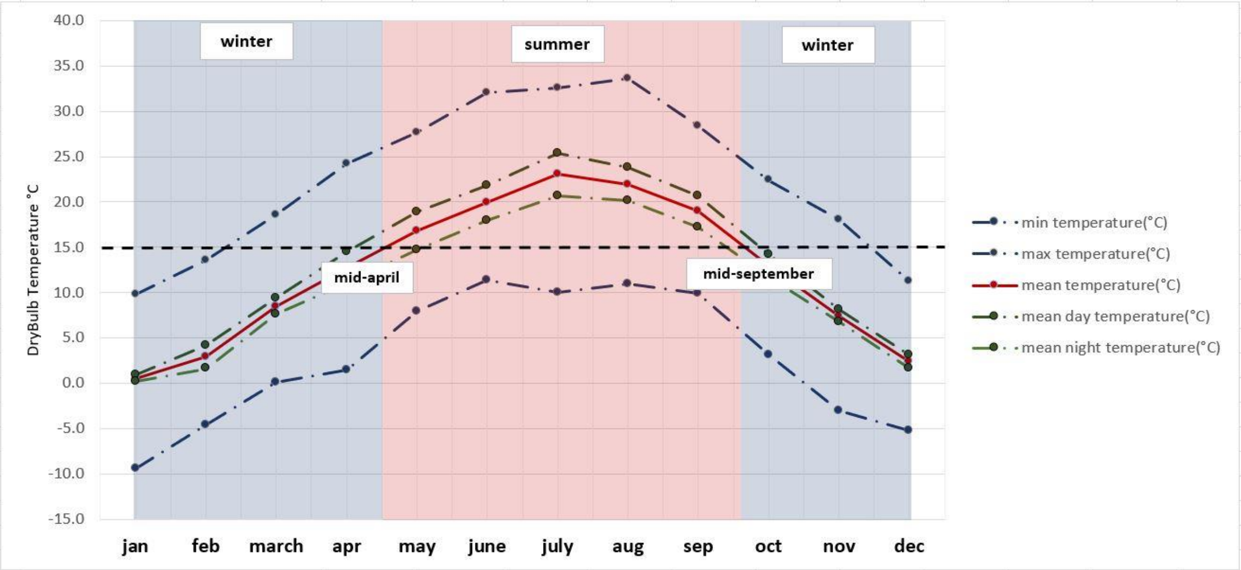
Figure 121. Ventilation units of modular boxes (Source: Meltem VMC)

Accordingly, it was seen that the energy requirements of the building decreased by entering the appropriate values for the heating and cooling systems designed respectively.

7.3.9 Final Improvement of Building

7.3.9.1 Weather Analysis

In *graph 12*, Milan’s dry bulb temperature for all months by specifying average, minimum and maximum values are shown. As it can be seen, on average, July is the hottest month and January is the coldest month. By considering temperature of 15°C, summer starts from mid-April and ends on mid-September.

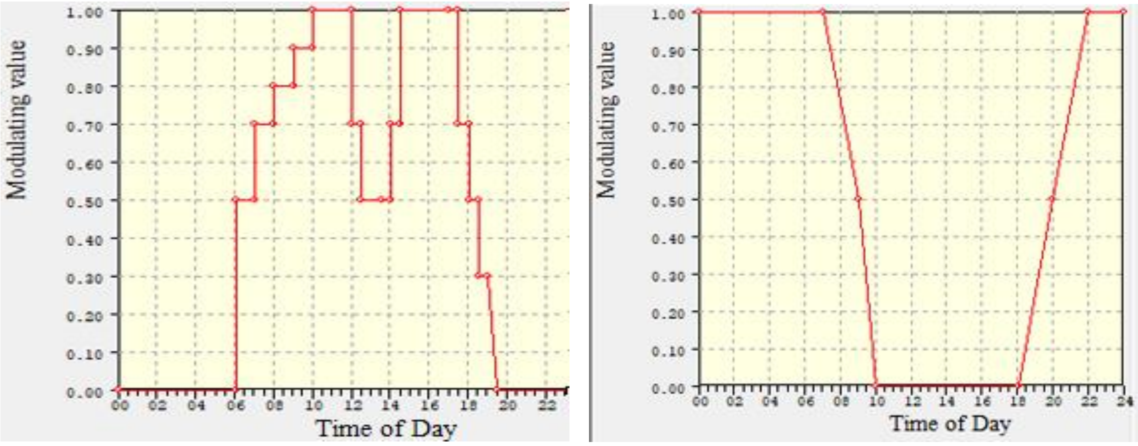


Graph 12. Wheather Analysis

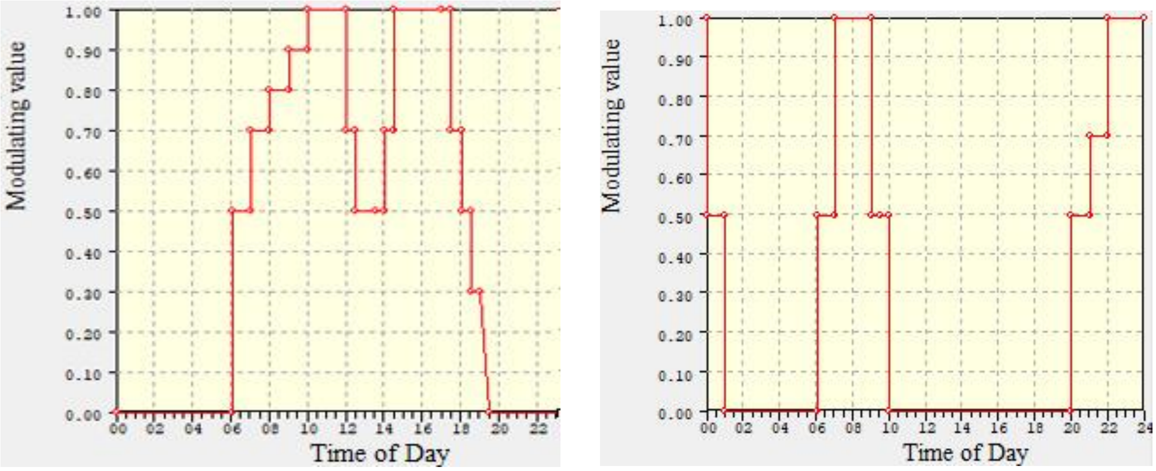
In this chapter, the whole building is modelled in IES-VE simulation software in the manner of energy. The main building is conditioned with HVAC system and internal prefabricated boxes has free floating condition which are ventilated with air inside the main building.

7.3.9.2 Internal Gain

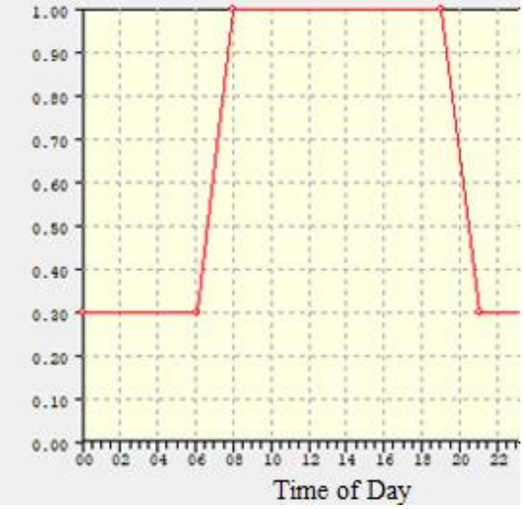
In the *graph 13*, occupancy profile of prefabricated buildings is shown, also in *graph 14* internal gain for the relative zones can be seen. Finally, *graph 15* shows general lighting profile of the main building.



Graph 13. Occupancy profile for office on left and housing on right



Graph 14. Equipment heat gain profile for office on left and housing on right



Graph 15. General lighting heat gain profile for the main building

Room	Infiltration	Ventilation	General Lighting	People		Computer	Machinery	Fluorescent Lighting
	Max Flow(ach)	Max Flow	Sensible Gain (W/m2)	Sensible Gain (W/m2)	Latent Gain (W/Person)	Sensible Gain (W/m2)	Sensible Gain (W/m2)	Sensible Gain (W/m2)
Offices	0.25	0.6 ach	0	60	50	15	10	5
House	0.25	0.6 ach	0	60	50	15	15	5
Service room	0.25	0	0	0	0	0	15	5
Main Building	0.25	0.6 ach	10	0				

Table 20. Internal gains

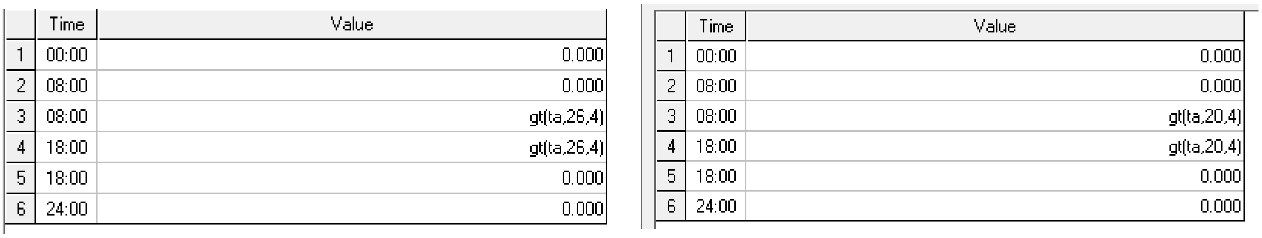
In table below, HVAC setting points are shown, for heating and cooling purpose. As it is shown, the main building is conditioned by set point of 20°C in winter and 26°C in summer. Also, the timing of HVAC to be turned on is specified. Prefabricated units are not conditioned by HVAC and are free floating conditioned.

Room	Heating				Cooling			
	Set point (^{0}C)	Day	Week	Month	Set point (^{0}C)	Day	Week	Month
Main Building	20	8.30-18.30	5 Days	Sep to May	26	8.30-18.30	5 Days	Sep to May
Prefabricated Units	No Plant				No Plant			

Table 21. Heating and cooling - Boundary conditions and schedules

7.3.9.3 Ventilation

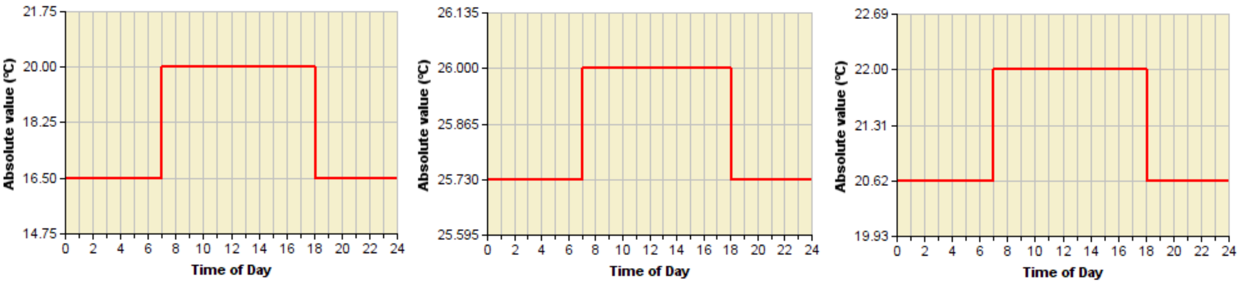
In this simulation, there are two ways of ventilation, one is mechanical ventilation simulated through auxiliary ventilation in the software. This mechanical ventilation is working in the whole year with flow rate of 0.6 ach and with altering temperature shown in graph xx, differing in different seasons. In the situations that temperature is more than 26 in summer and less than 20 in winter, there is a function applied to the Macro-Flo section in the software and make the doors of the boxes open to benefit from conditioned outdoor air. In tables xx function applied to door opening is shown, on left for summer and on right for winter.



	Time	Value
1	00:00	0.000
2	08:00	0.000
3	08:00	gt(ta,26,4)
4	18:00	gt(ta,26,4)
5	18:00	0.000
6	24:00	0.000

	Time	Value
1	00:00	0.000
2	08:00	0.000
3	08:00	gt(ta,20,4)
4	18:00	gt(ta,20,4)
5	18:00	0.000
6	24:00	0.000

Table 22. The profile of auxiliary ventilation air temperature coming from the main building to the prefabricated ones including offices and houses are shown.



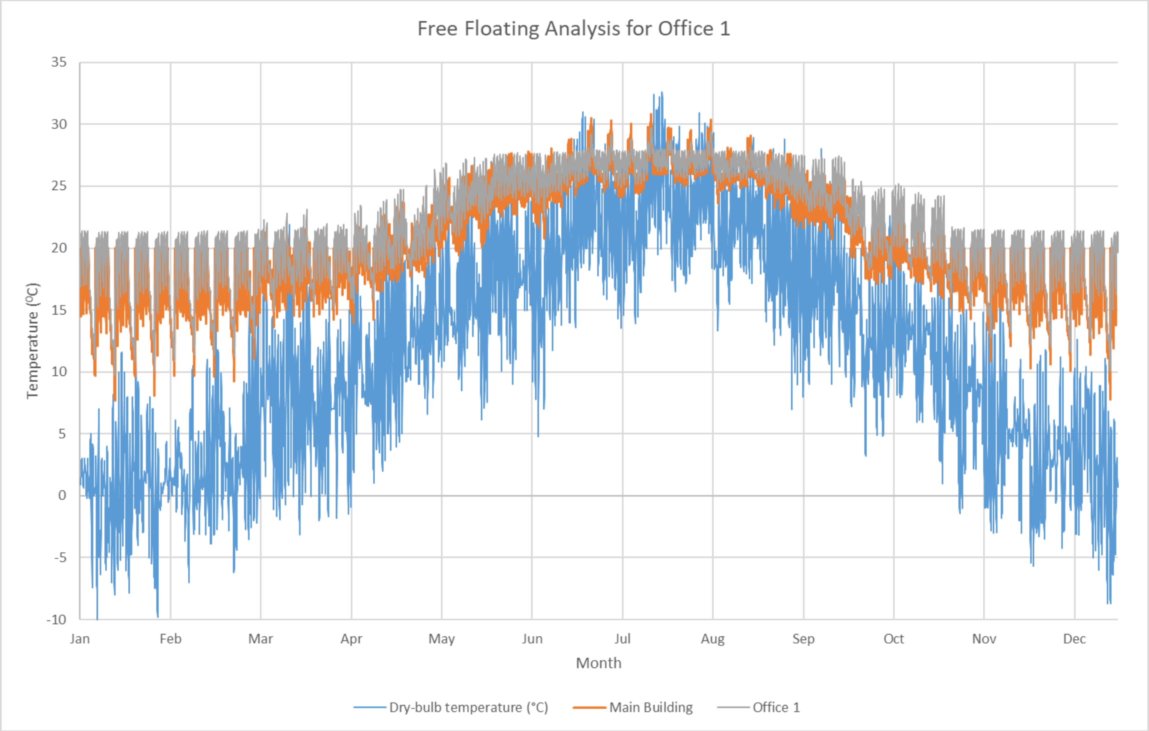
Graph 16. Auxiliary ventilation temperature for winter in left, summer in the middle and midseason on the right

Plan 3 Simulation

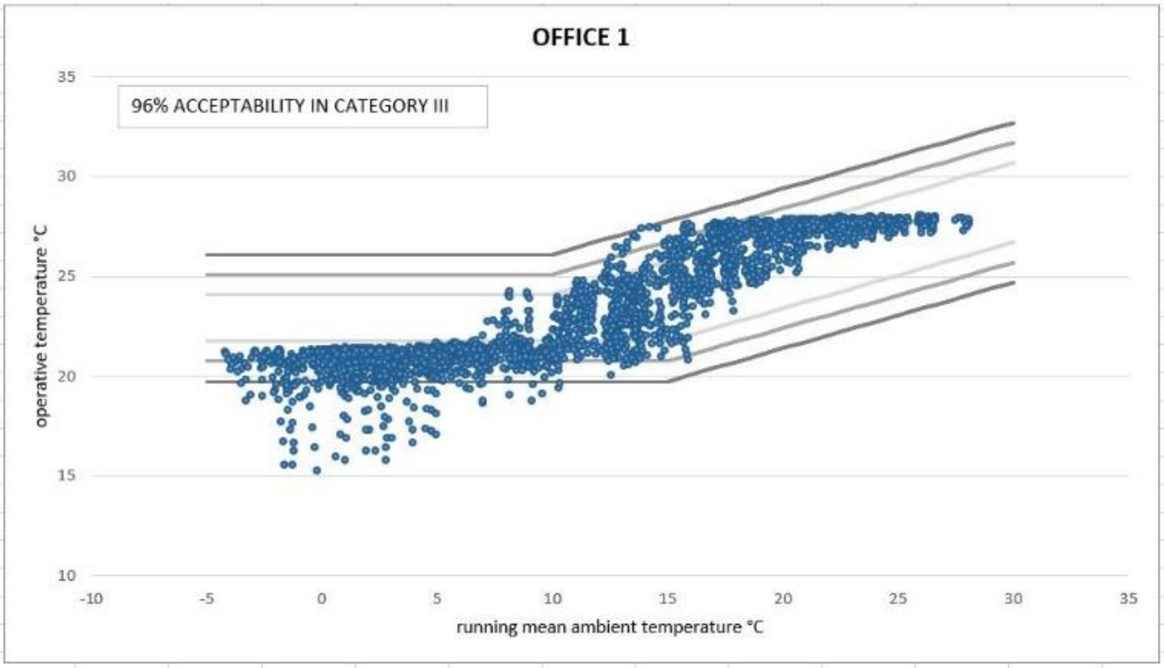
- Plan 3 is considered as typical plan for energy simulations.
- The simulations consider 5 offices and 2 housing units in the different locations in the building.
- For all thermal zones, there is graph showing outside dry bulb temperature, temperature of the main building and the temperature of the zone itself.
- There is also graph showing data of thermal zone temperature dispersion according to adaptive comfort zone and shows percentage of acceptability for category III.
- To have more detailed understanding of what happens inside each zone, situation of the zone in the first week of the hottest and coldest month through the whole year is studied.
- Housings are used from 6 p.m. to 8 a.m. when the main building HVAC system is off.

Figure 122. Number of zones in office left and housing right

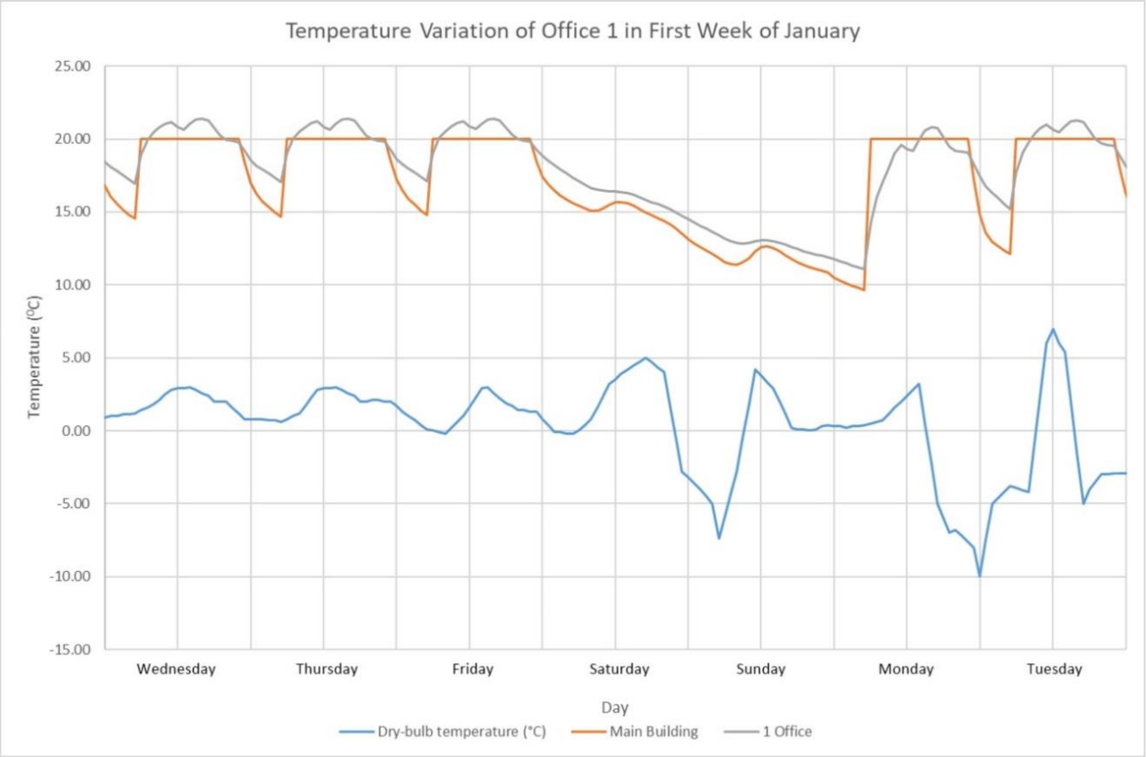
- **Office 1**



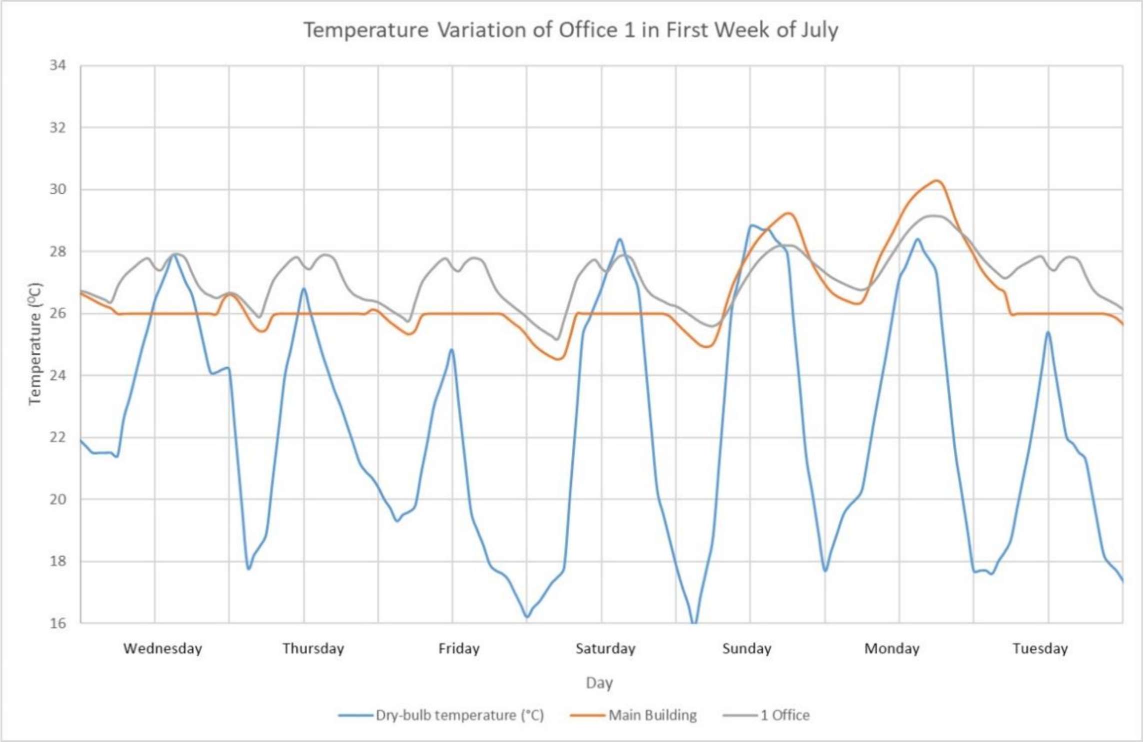
Graph 17. Free floating analysis for office 1



Graph 18. Adaptive running mean temperature of office 1



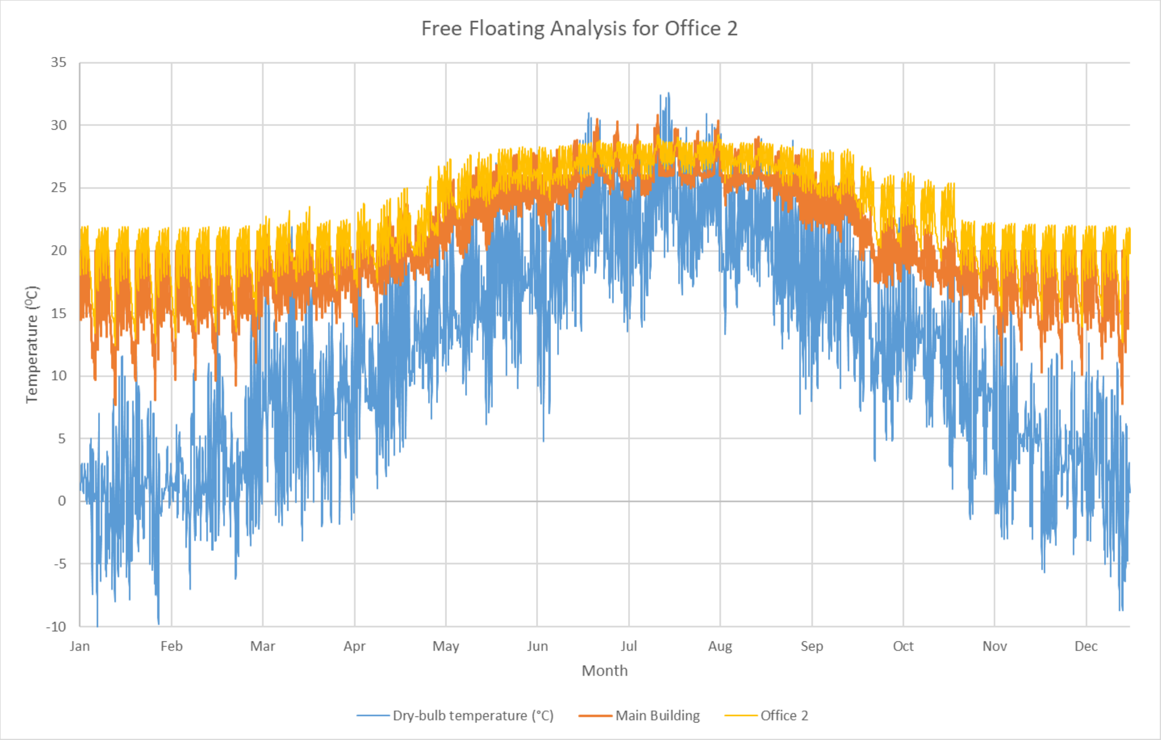
Graph 19. Temperature variation of office 1 in first week of January



Graph 20. Temperature variation of office 1 in first week of July

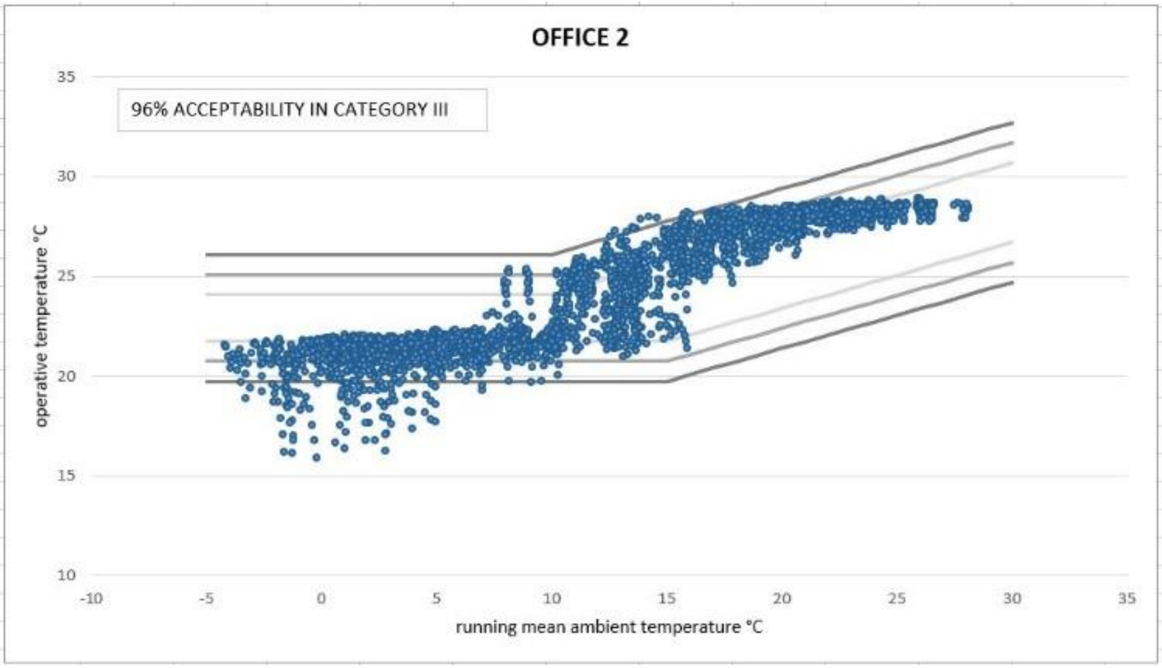
Office thermal zone 1 by considering adaptive comfort range of category III are 96% is comfortable result. The main problem would be in cold months that temperature reaches around 15°C. January, the coldest month, hours with low temperature are observed early in the morning around 8 a.m. when heating has just started working; however, there is no problem for other hours of the day.

- **Office 2**

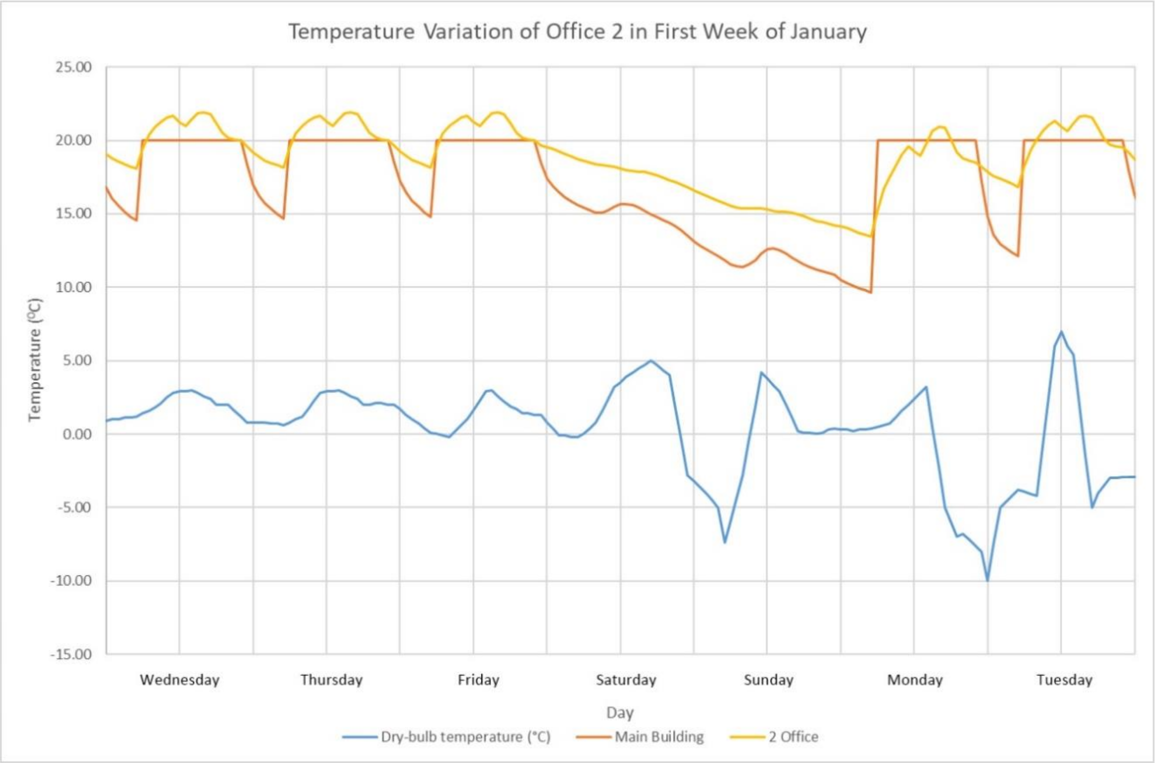


Graph 21. Free floating analysis for office 2

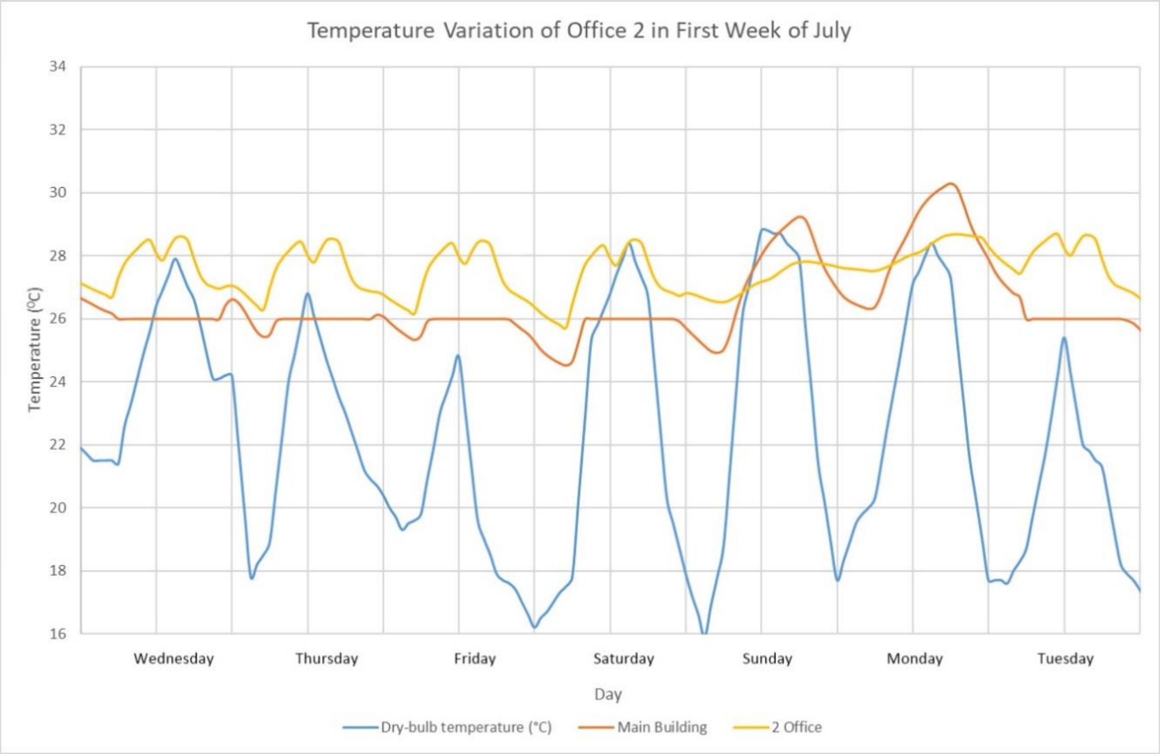
Office thermal zone 2 showed the similar results office 1 by considering adaptive comfort range of category III are 96% is comfortable result. In cold months that temperature reaches around 16-17°C. When the temperature variations were examined, in January temperature drops down 10ºC early in the morning before heating has started working.



Graph 22. Adaptive running mean temperature of office 2

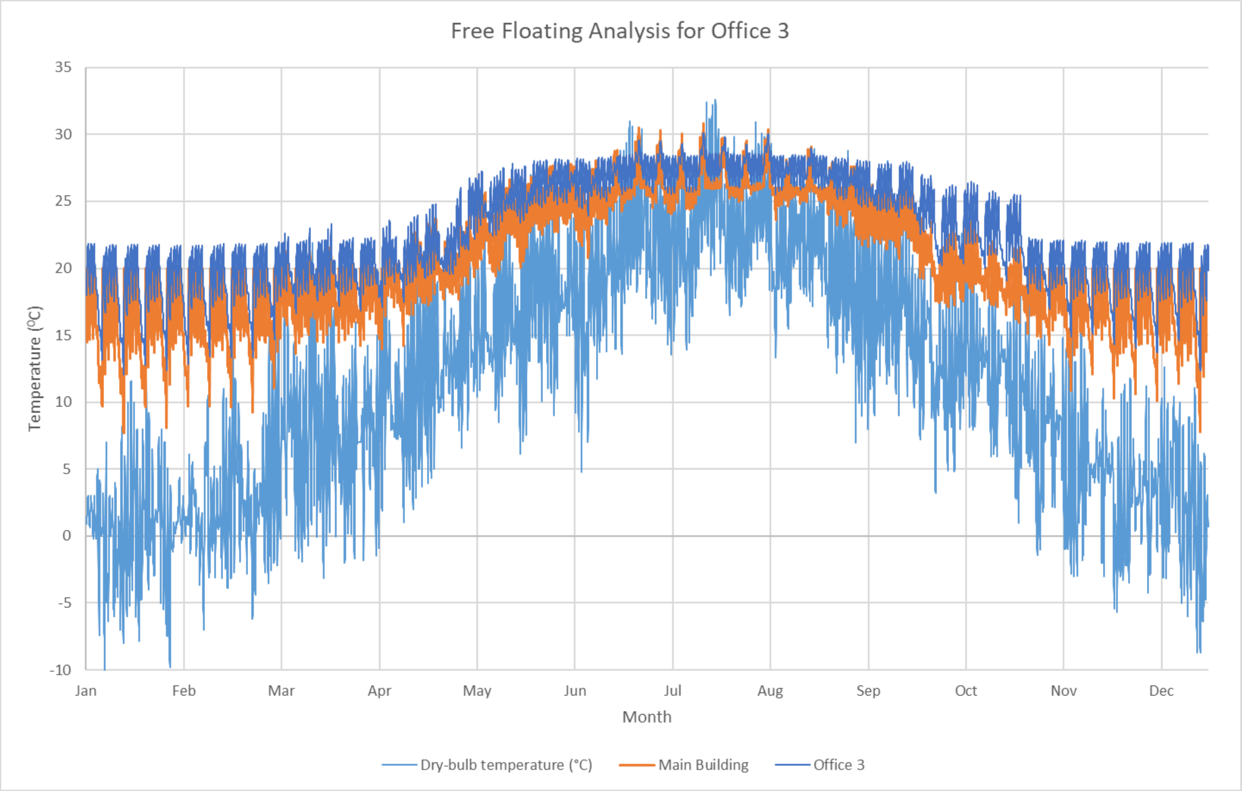


Graph 23. Temperature variation of office 2 in first week of January

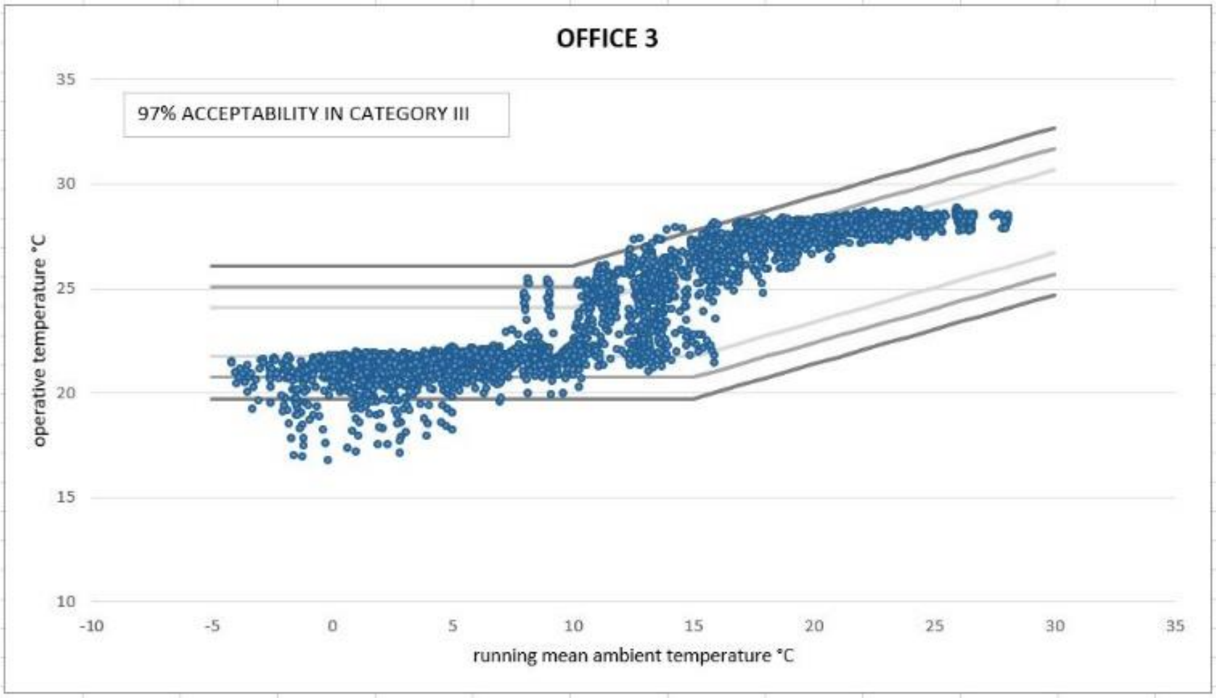


Graph 24. Temperature variation of office 2 in first week of July

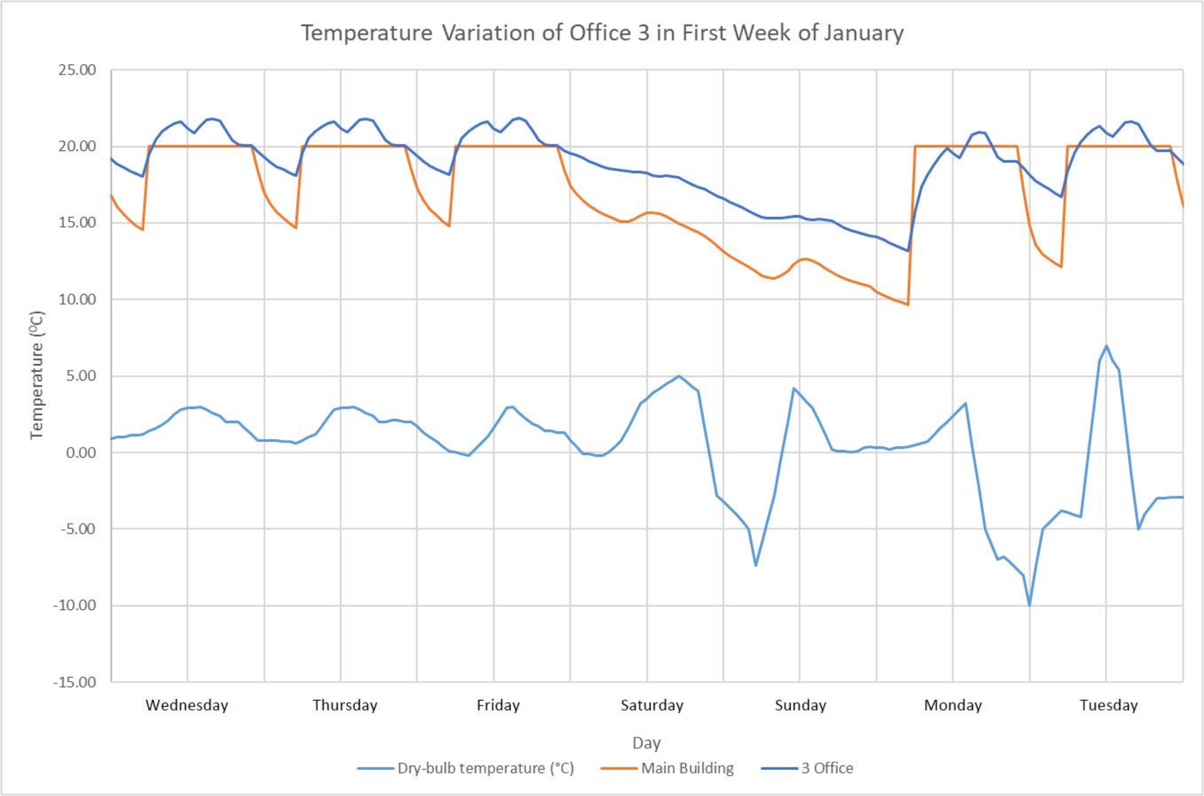
- **Office 3**



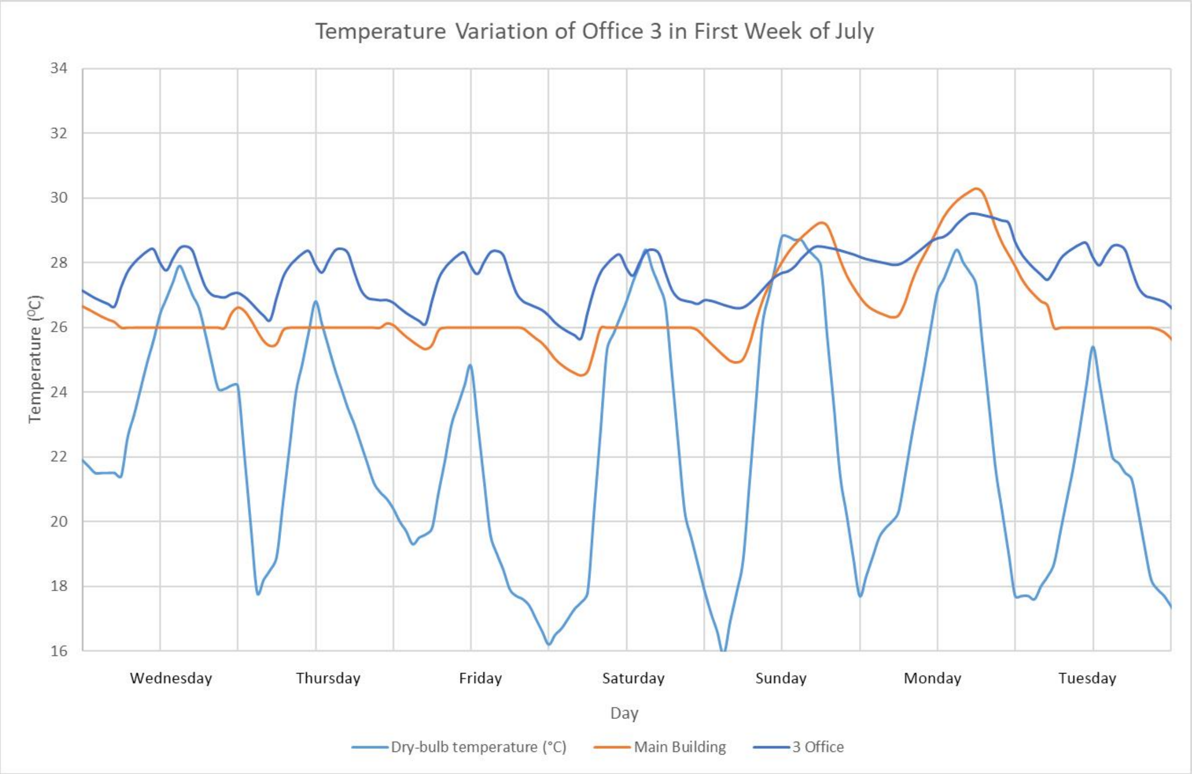
Graph 25. Free floating analysis for office 3



Graph 26. Adaptive running mean temperature of office 3



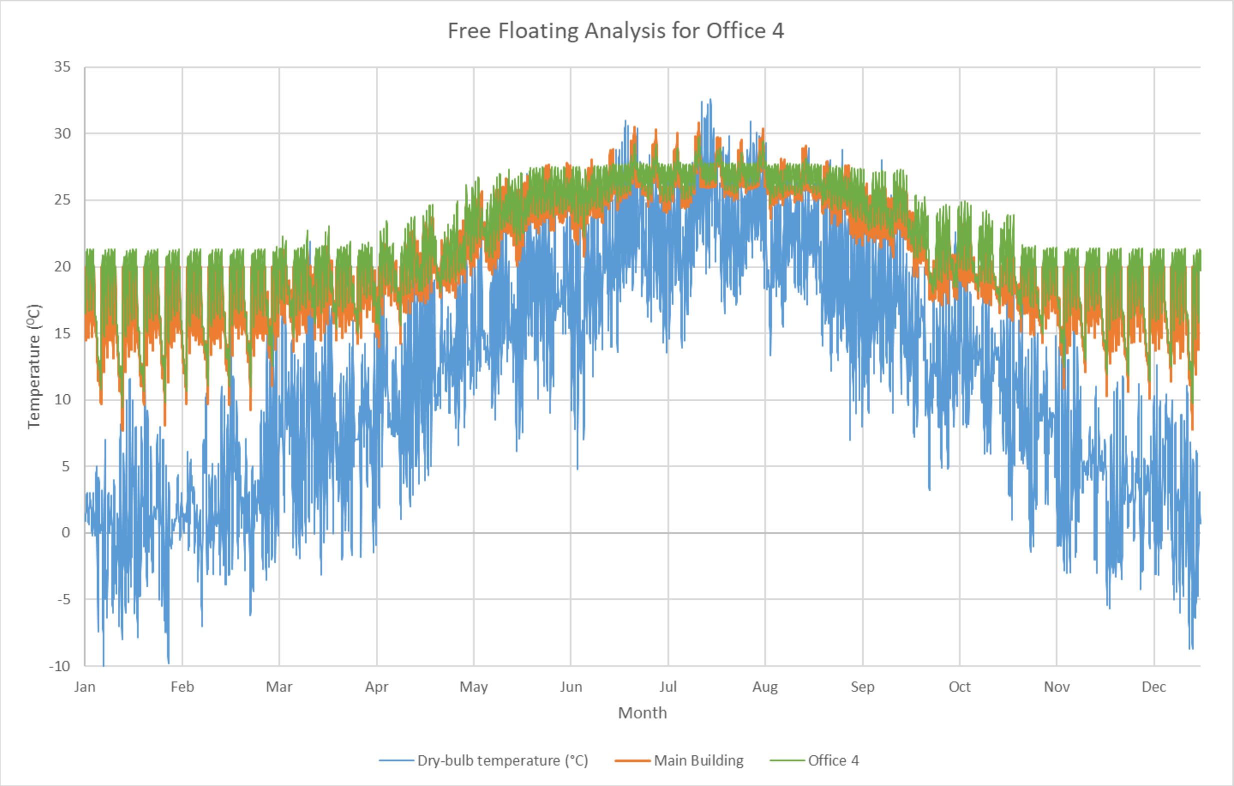
Graph 27. Temperature variation of office 3 in first week of January



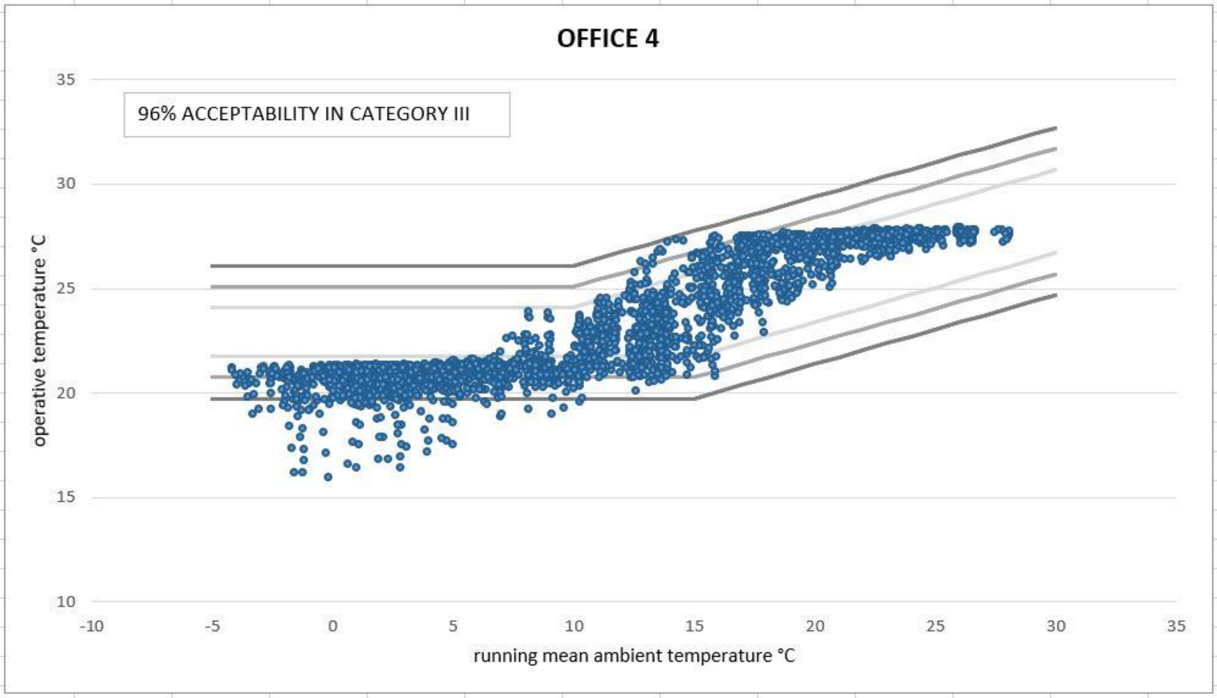
Graph 28. Temperature variation of office 3 in first week of July

Office thermal zone 3 has showed a bit difference than office 1 and 2 considering adaptive comfort range of category III are 97%. In winter especially January, temperature goes down around 17°C before heating. As the temperature variations, in January temperature drops down 10ºC early in the morning before heating has started working.

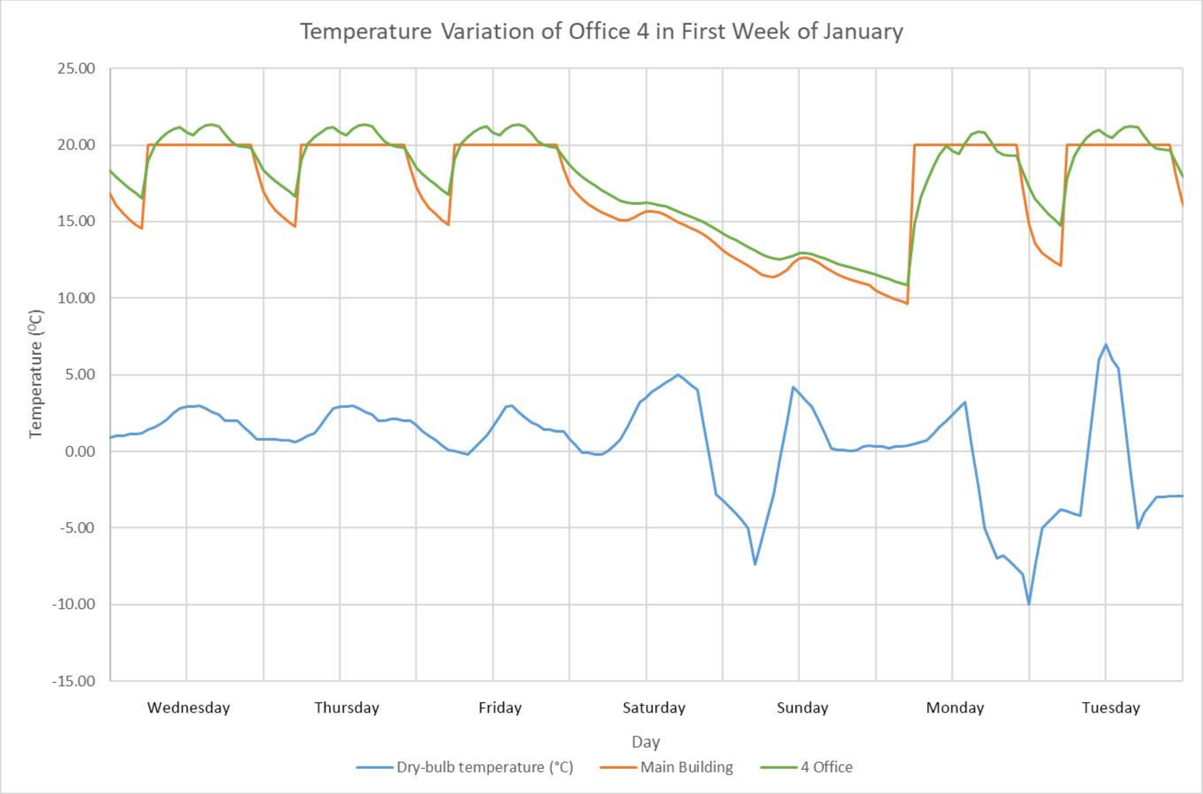
- **Office 4**



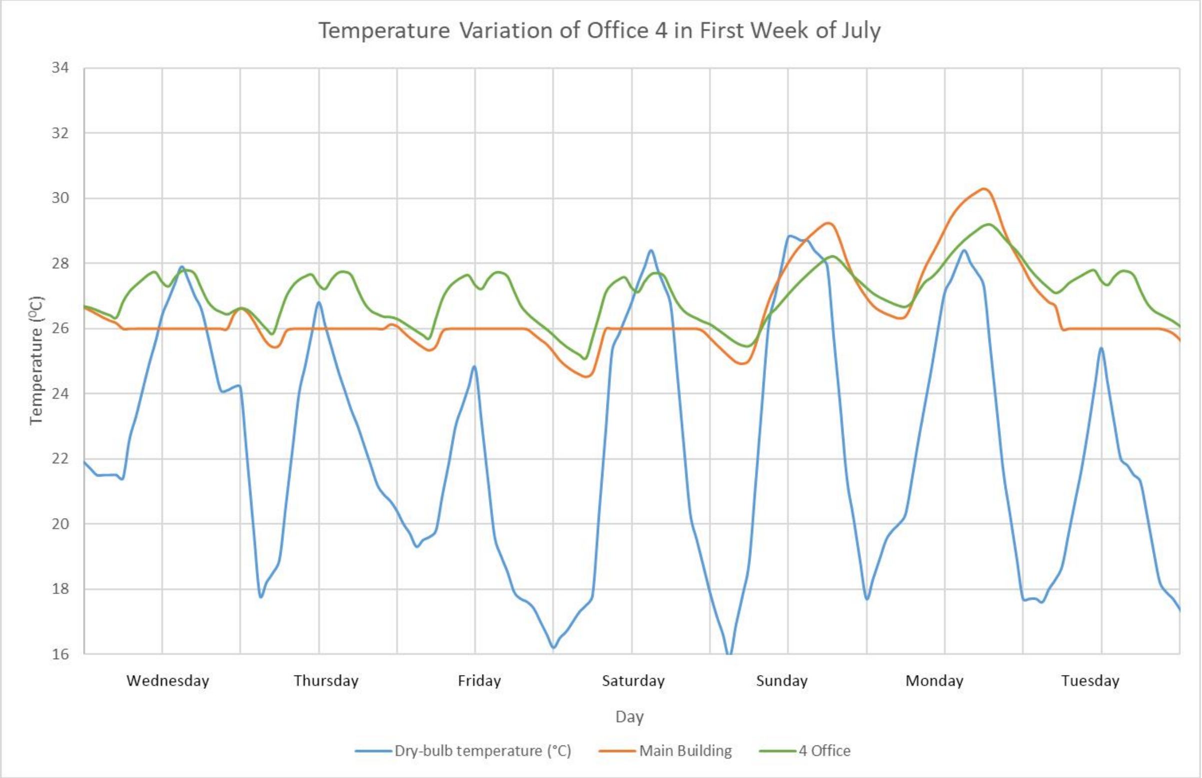
Graph 29. Free floating analysis for office 4



Graph 30. Adaptive running mean temperature of office 4



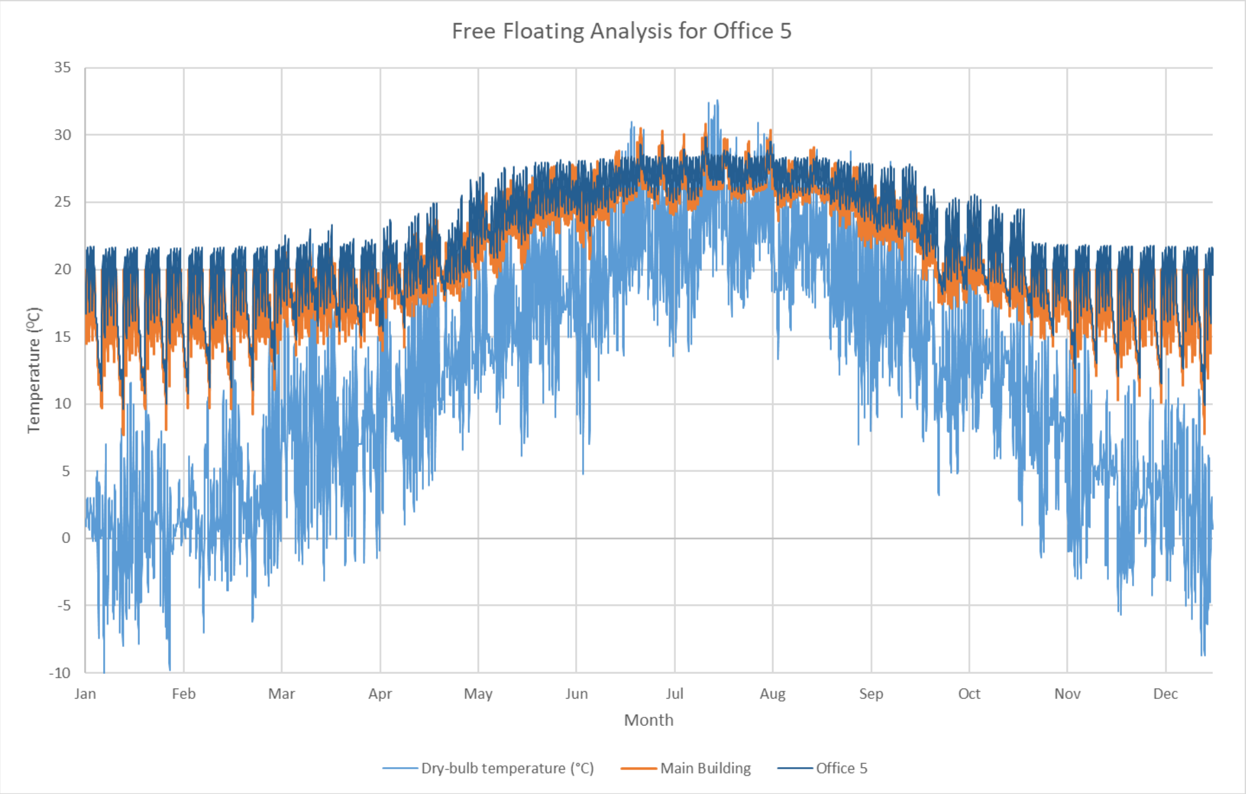
Graph 31. Temperature variation of office 4 in first week of January



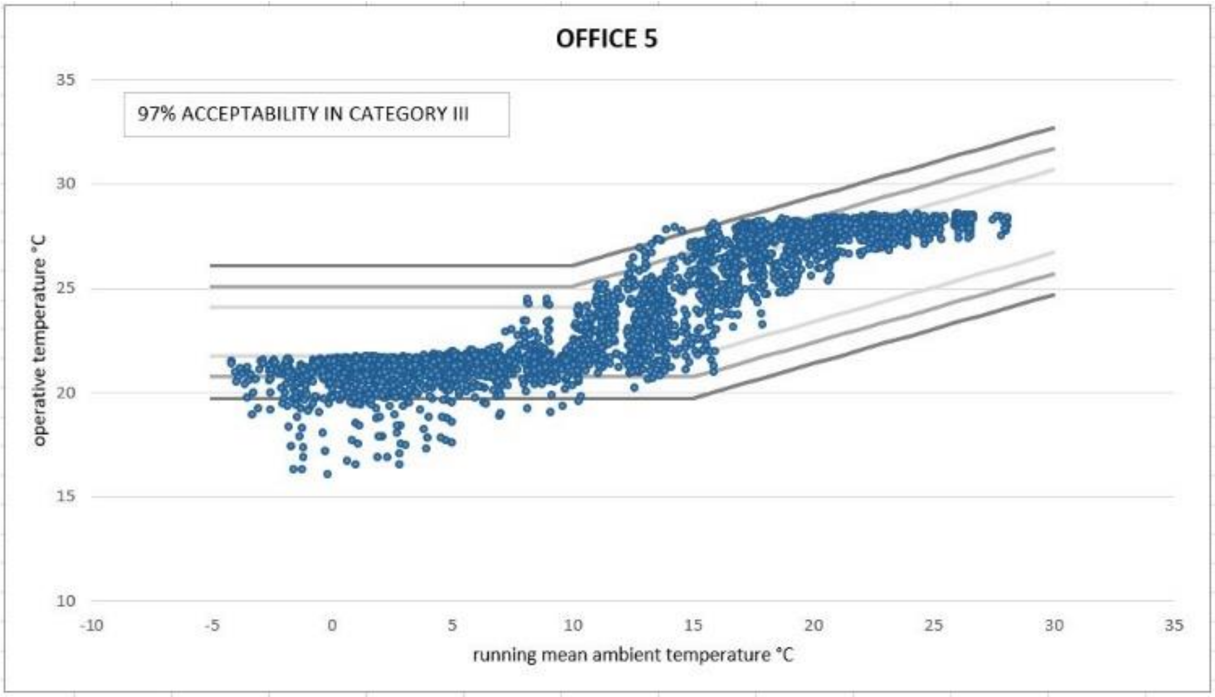
Graph 32. Temperature variation of office 4 in first week of July

Office thermal zone 4 showed the similar results office 1 and 2 by considering adaptive comfort range of category III are 96% is comfortable result. In winter especially January, temperature goes down around 17°C before heating. January morning before heating has started, temperature was observed under 10°C.

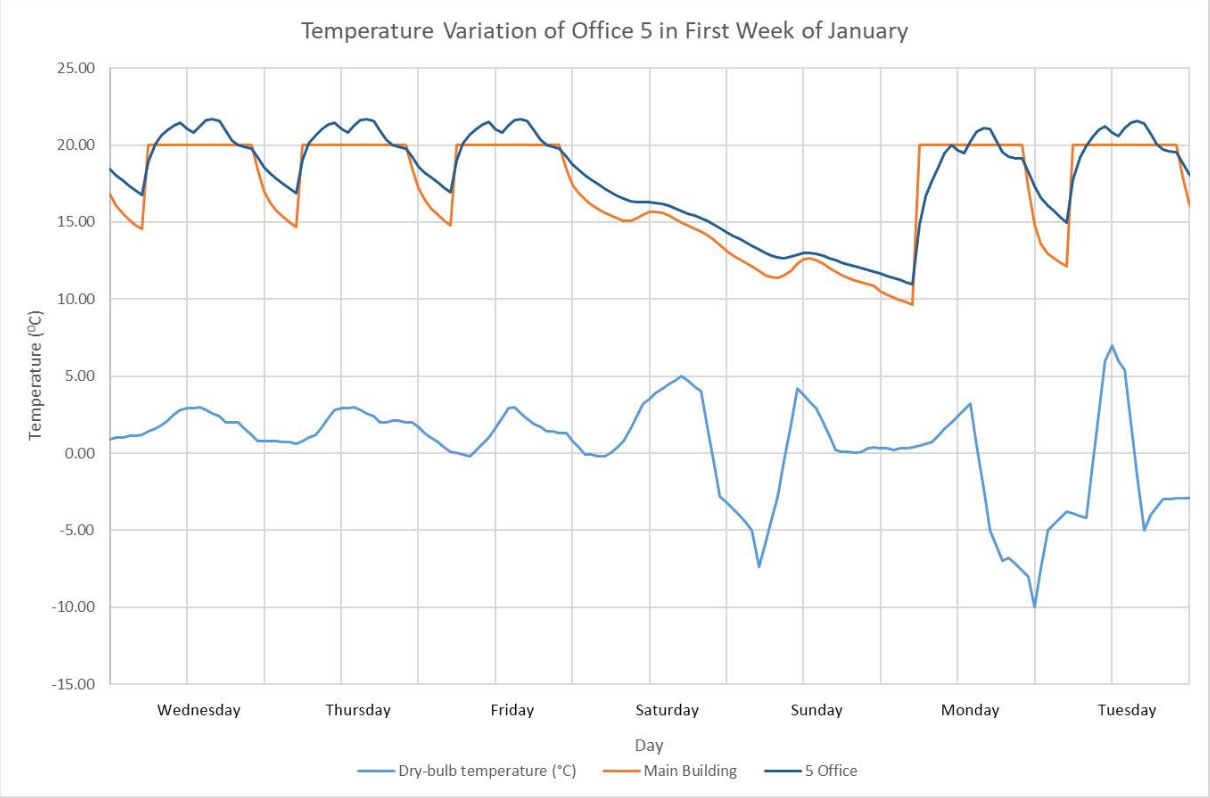
- **Office 5**



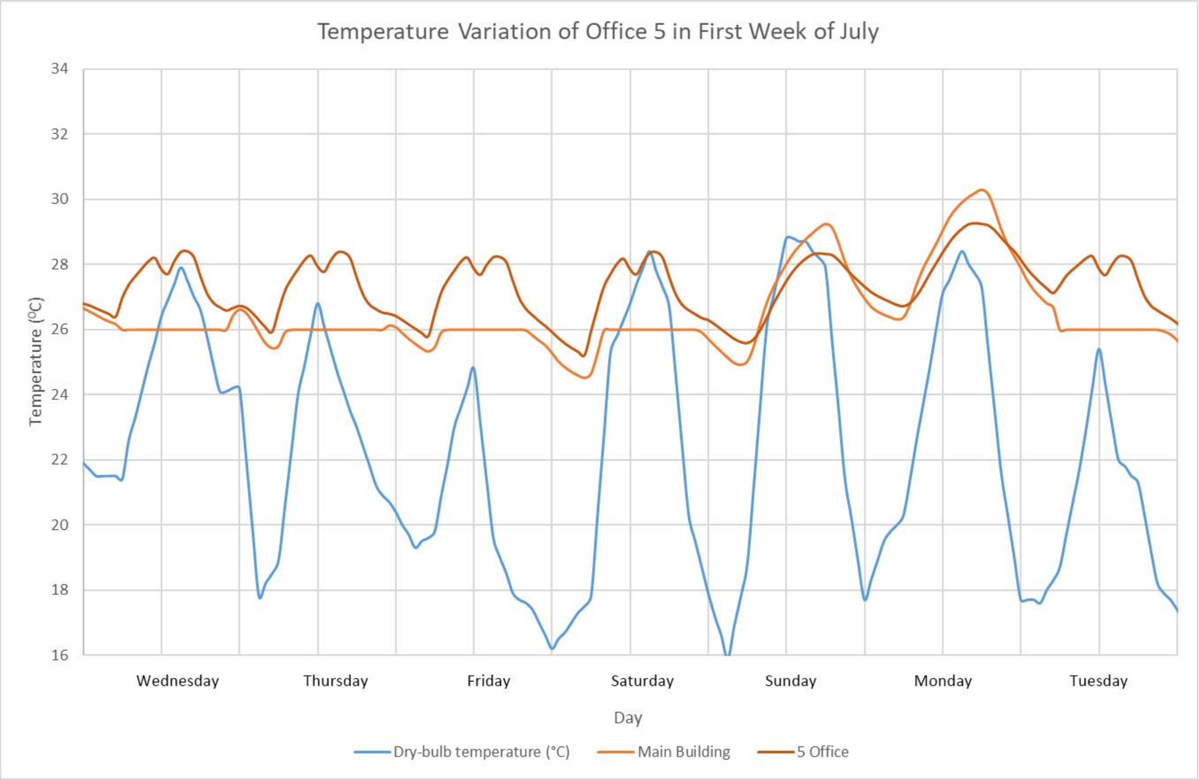
Graph 33. Free floating analysis for office 5



Graph 34. Adaptive running mean temperature of office 4



Graph 35. Temperature variation of office 5 in first week of January



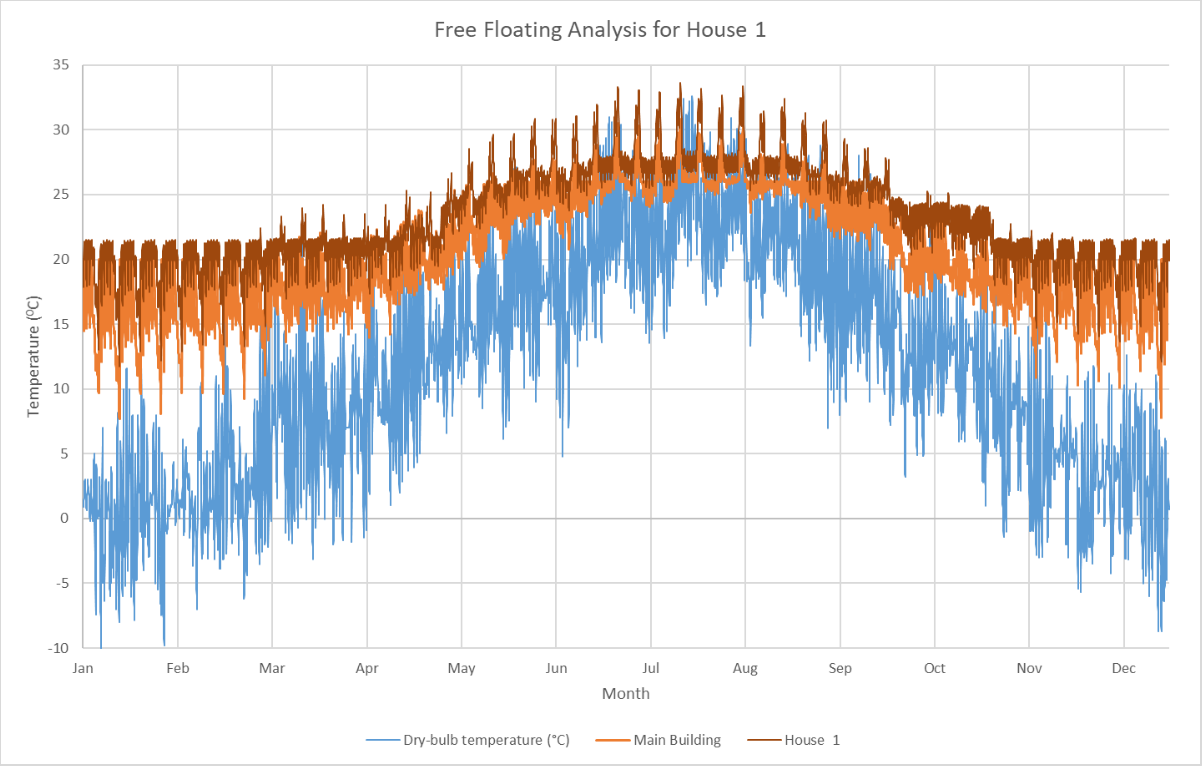
Graph 36. Temperature variation of office 5 in first week of July

Office thermal zone 5 has also adaptive comfort range of category III are 97% in similarity with office 3. In winter especially January, temperature goes down around 16-17°C before heating. As the temperature variations, in January temperature drops down 10ºC early in the morning before heating has started working.

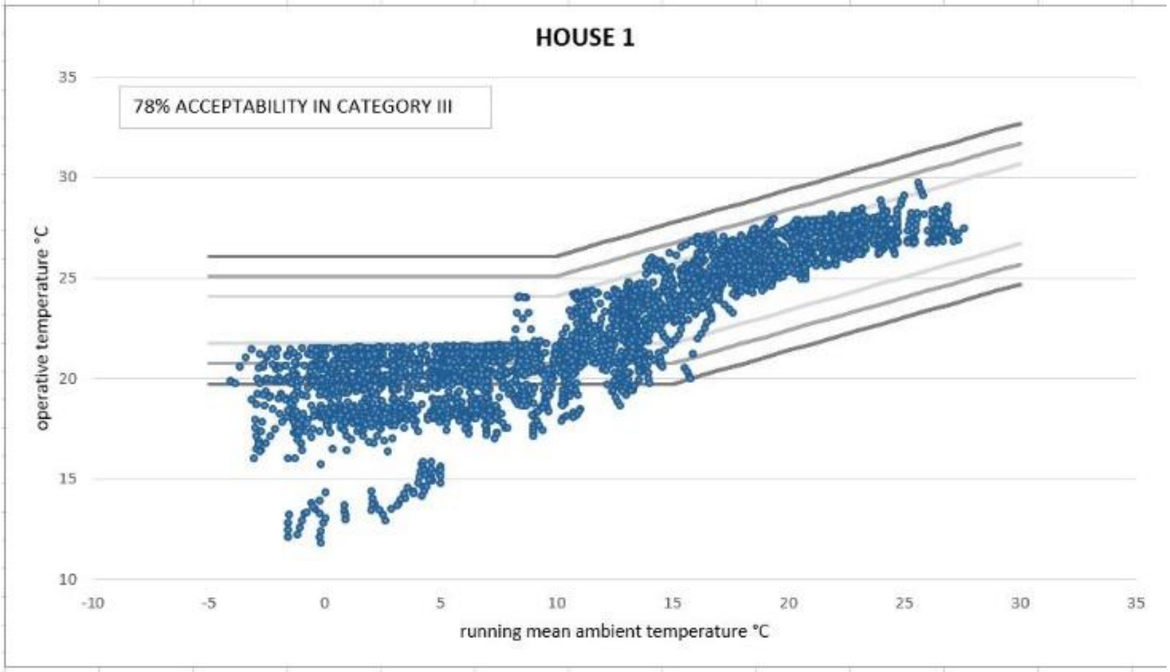
Results of office simulations:

- Office thermal zones by considering adaptive comfort range of category III are 96% to 97% comfortable which is a pretty good result.
- The main problem would be in cold months that temperature reaches around 16°C.
- Focusing on January which is the coldest month of the year in Milan, it is seen that cold hours relate to early in the morning around 8 a.m. when HVAC system of the main building has just started working and there is no problem for other hours of the day.

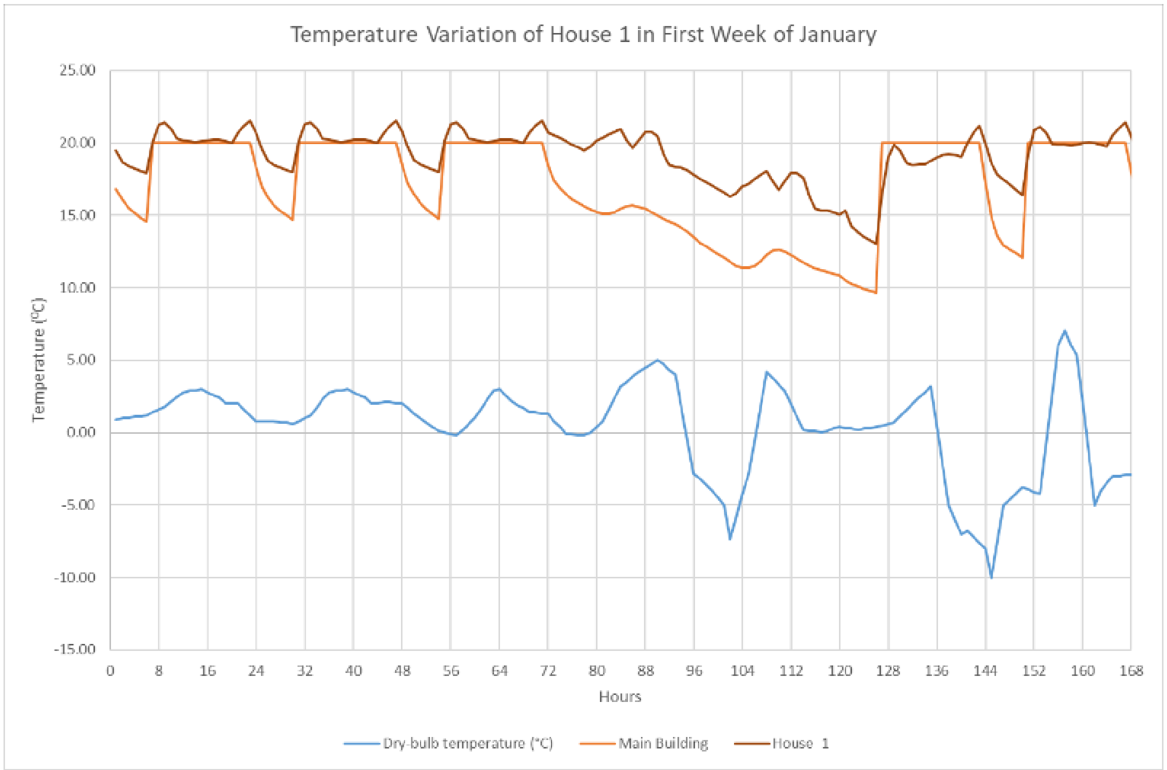
- **Housing 1**



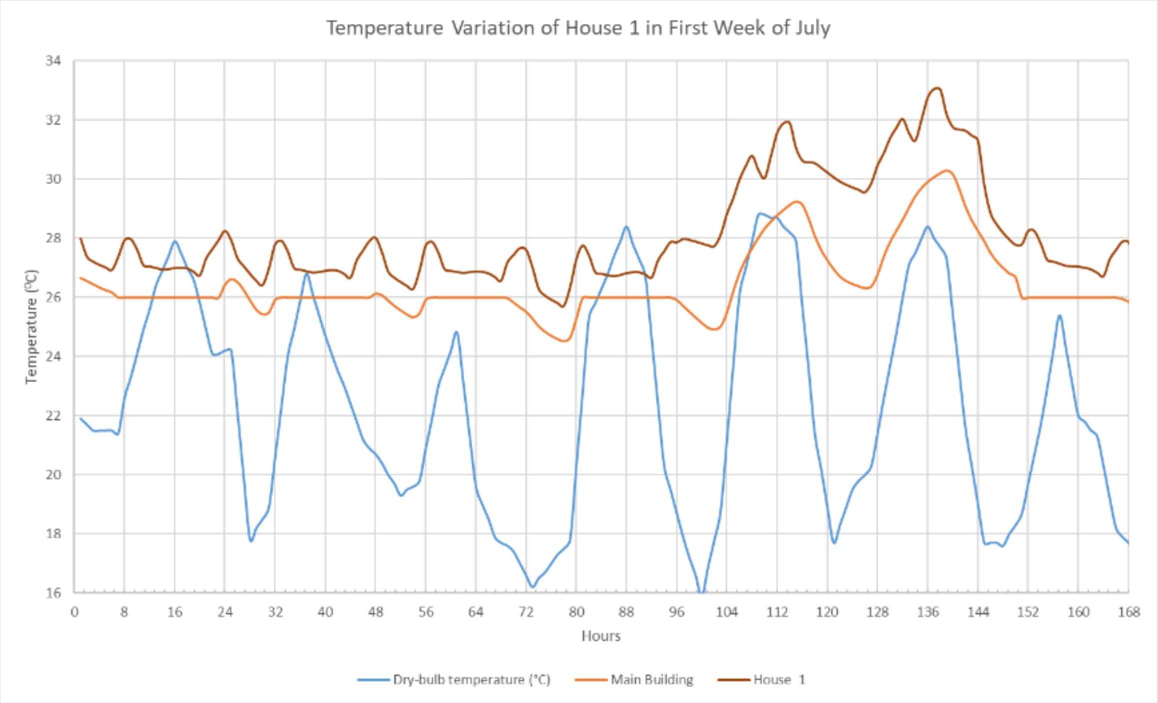
Graph 37. Free floating analysis for housing 1



Graph 38. Adaptive running mean temperature of housing 1

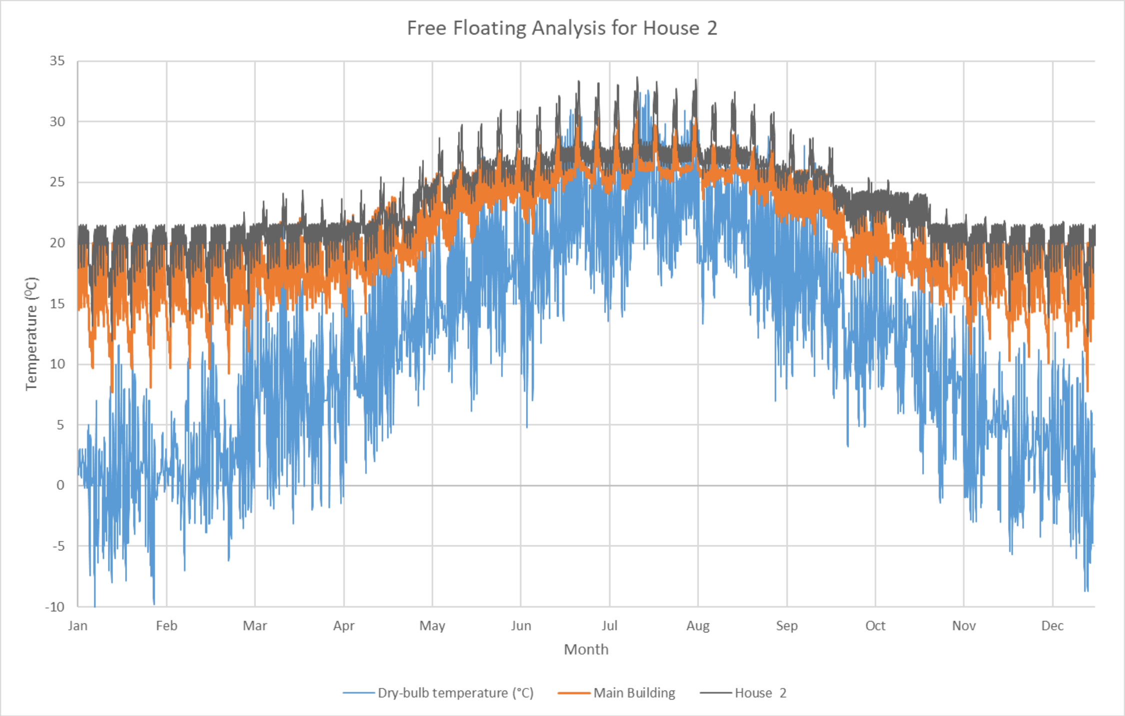


Graph 39. Temperature variation of housing 1 in first week of January

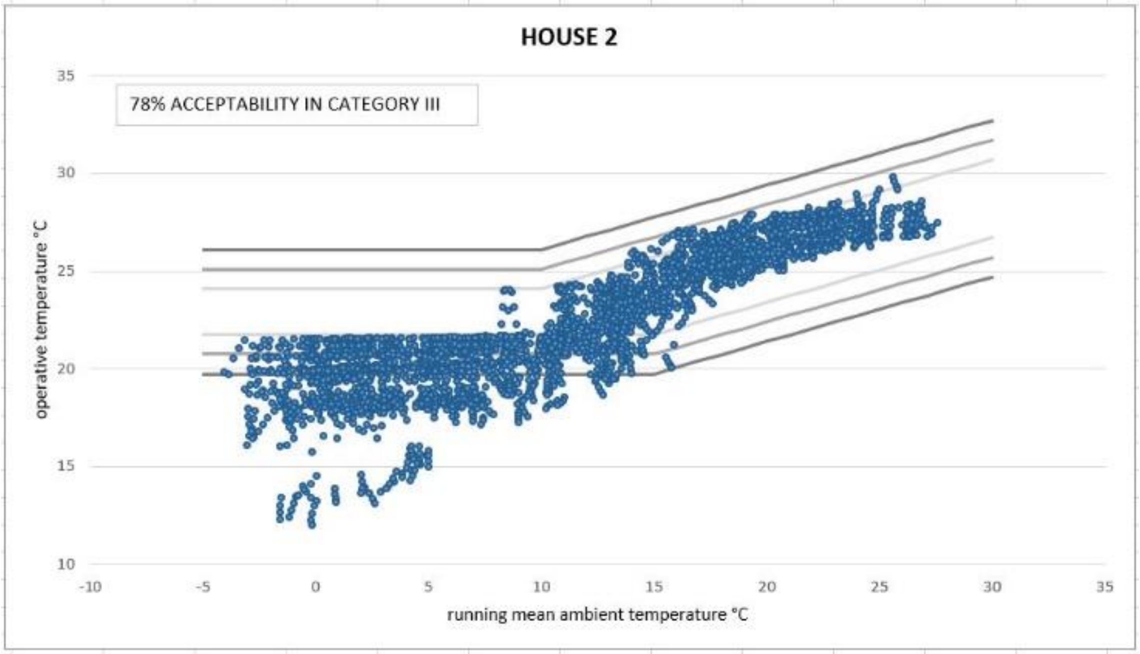


Graph 40. Temperature variation of housing 1 in first week of July

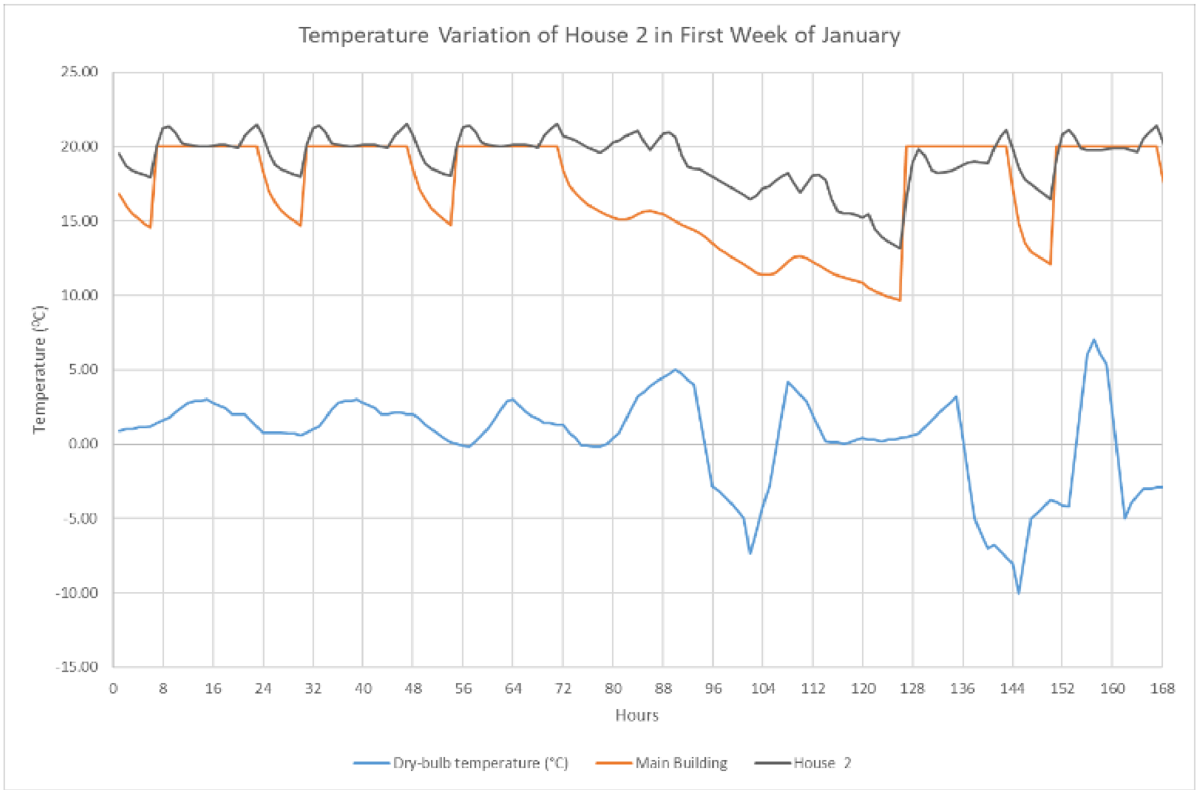
- **Housing 2**



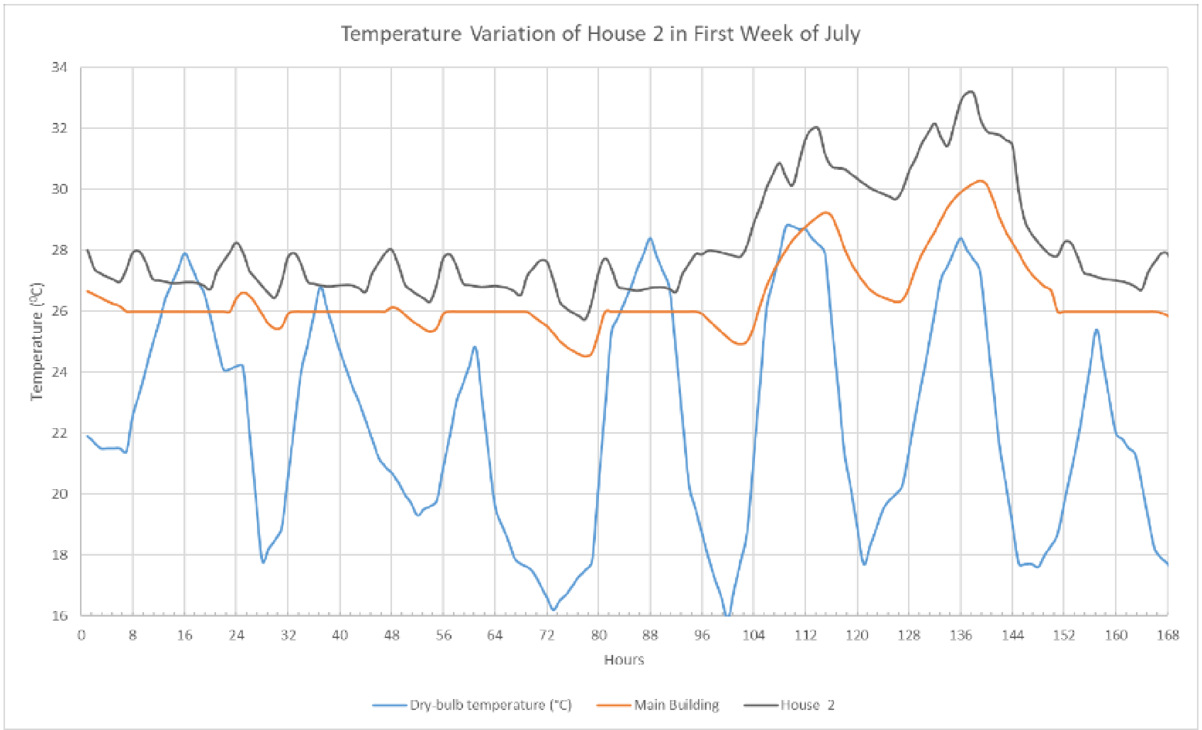
Graph 41. Free floating analysis for housing 2



Graph 42. Adaptive running mean temperature of housing 2



Graph 43. Temperature variation of housing 2 in first week of January



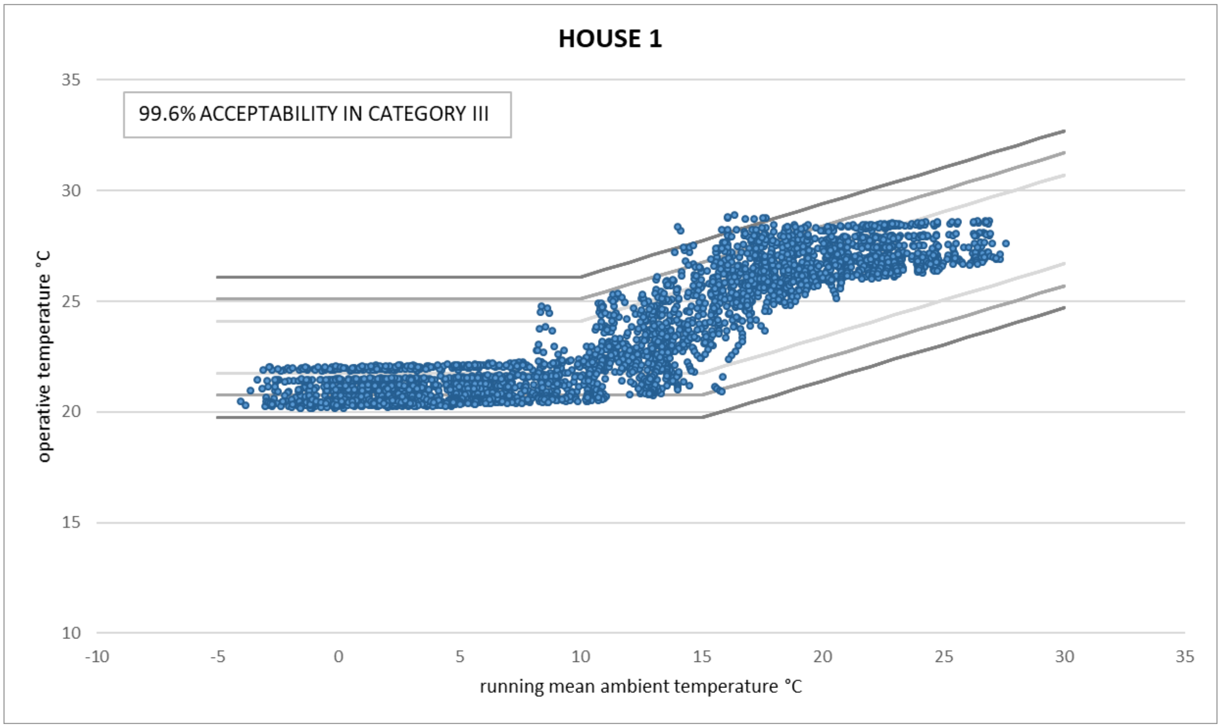
Graph 44. Temperature variation of housing 2 in first week of July

Results of housing simulations:

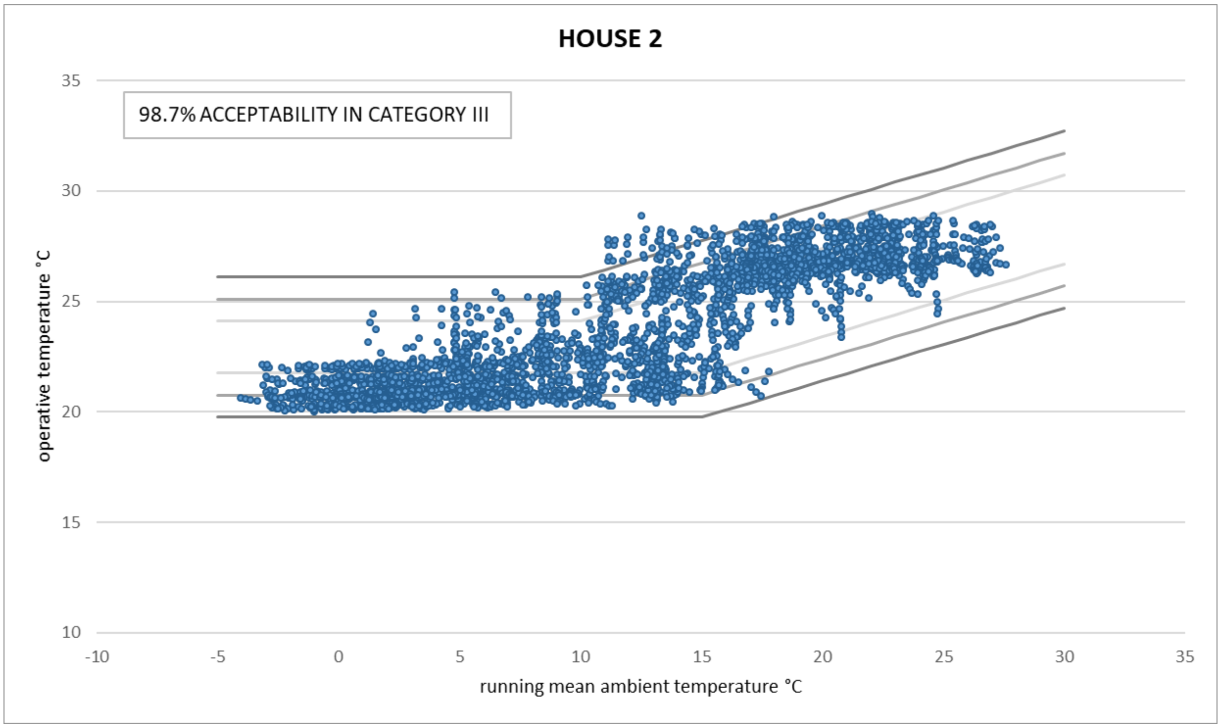
- Housing thermal zones have harsher situation in cold days because housings are used from 6 p.m. to 8 a.m. when the main building HVAC system is off.
- Comfort value for these zones are 78% that needs improvement. In what follows, there is simulation result of other scenario by considering HVAC works in winter all day long.

- **Changing the Scenario of Housing**

Since housing 1 and 2 temperatures are in 78% acceptability, the new scenarios were developed. It was due to the fact that the main building HVAC system is off. New scenarios accepted by considering HVAC works in winter all day long.



Graph 45. Adaptive running mean temperature for housing 1 – new



Graph 46. Adaptive running mean temperature for housing 2 – new

Considering HVAC works in winter all day in housing 1, the temperature in the houses increases and the acceptability rate was achieved 99.6% for house 1 and 98.7% for house 2.

- **Final Results**

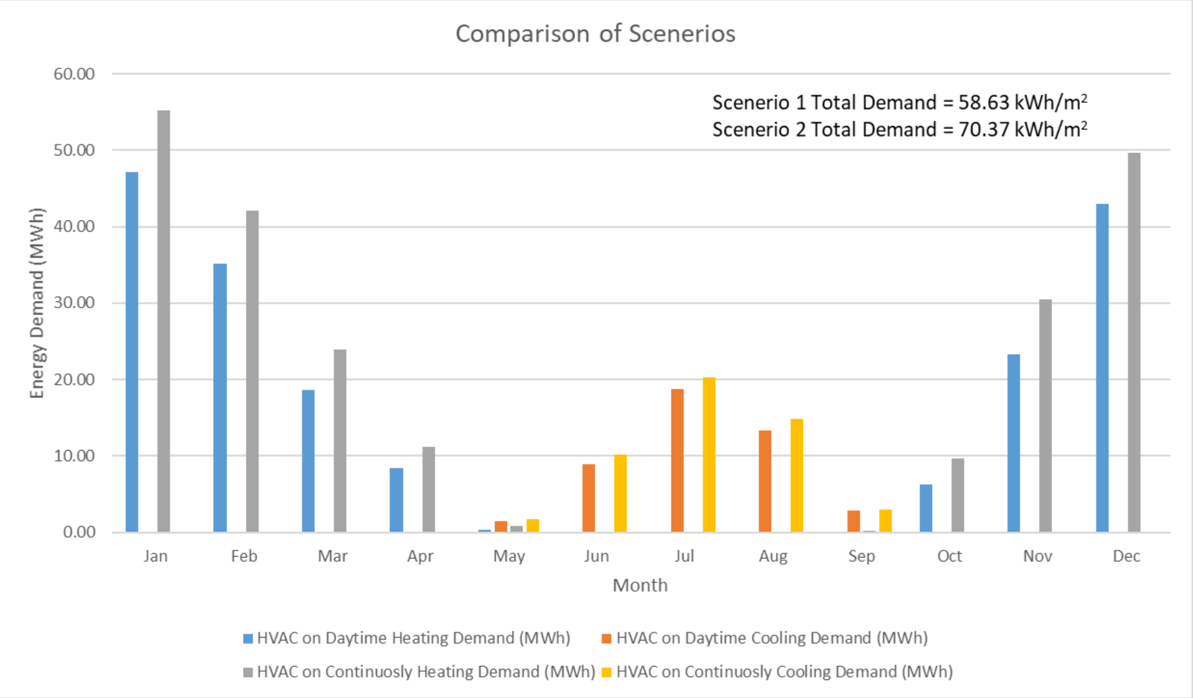
In the final step, energy demand for HVAC system is shown in *tables 23* separated in heating and cooling demands. Table on the left is showing energy demand for the first scenario where HVAC system is kept on from 8 a.m. to 6 p.m. on weekly days and table on the right is showing energy demand for the second scenario which keeps the HVAC system on during the whole day of weekdays. It is clear that the first scenario uses less energy of 46.95 kWh/m^2 for heating and 11.68kWh/m^2 of cooling while the second scenario consumes more energy of 57.52kWh/m^2 for heating and 12.85kWh/m^2 of cooling. The point is that, although second scenario uses more energy, it causes thermal zones of house to be 99% of times inside comfort zone.

Table 23.Monthly energy demands for two scenarios

Month	Heating Demand (MWh)	Cooling Demand (MWh)
Jan	47.19	0.00
Feb	35.18	0.00
Mar	18.61	0.00
Apr	8.37	0.00
May	0.36	1.42
Jun	0.00	8.96
Jul	0.00	18.76
Aug	0.00	13.32
Sep	0.05	2.91
Oct	6.31	0.00
Nov	23.30	0.00
Dec	42.94	0.00
Total	182.31	45.37
Total(kWh/m2)	46.95	11.68

Month	Heating Demand (MWh)	Cooling Demand (MWh)
Jan	55.27	0.00
Feb	42.14	0.00
Mar	23.96	0.00
Apr	11.19	0.00
May	0.79	1.71
Jun	0.00	10.19
Jul	0.00	20.26
Aug	0.00	14.79
Sep	0.16	2.96
Oct	9.65	0.00
Nov	30.50	0.00
Dec	49.70	0.00
Total	223.35	49.92
Total(kWh/m2)	57.52	12.85

In the *graph 47*, HVAC heating and cooling energy demands are shown together for two scenarios. What mentioned above can be seen graphically by specifying total energy demand for both scenarios together which is 58.63kWh/m^2 and 70.37kWh/m^2 for the first and second scenarios respectively. It will depend on what is expected from thermal behaviour of the building to choose from scenarios.



Graph 47. Comparison of scenarios

7.4 Renewable energy systems

7.4.1 Photovoltaic System

The old office building has inclined roof which is high potential for PV panels. After rebuilding new roof with sandwich panel, the PV panels were conditioned on the roof that is one of refurbishment strategy of the project. New functions of the building causes to more energy consumption because of increasing capacity of building which means people, equipment and plants. It was aimed that PV generated energy meet energy requirement of building. It seems to be hard for all year since the winter conditions make harder to do it.

The PV panels are placed directly on the existing slope of roof with joining to sandwich panels. Total 23 different roof parts has PV and 2000 PV panels with 1142 m^2.

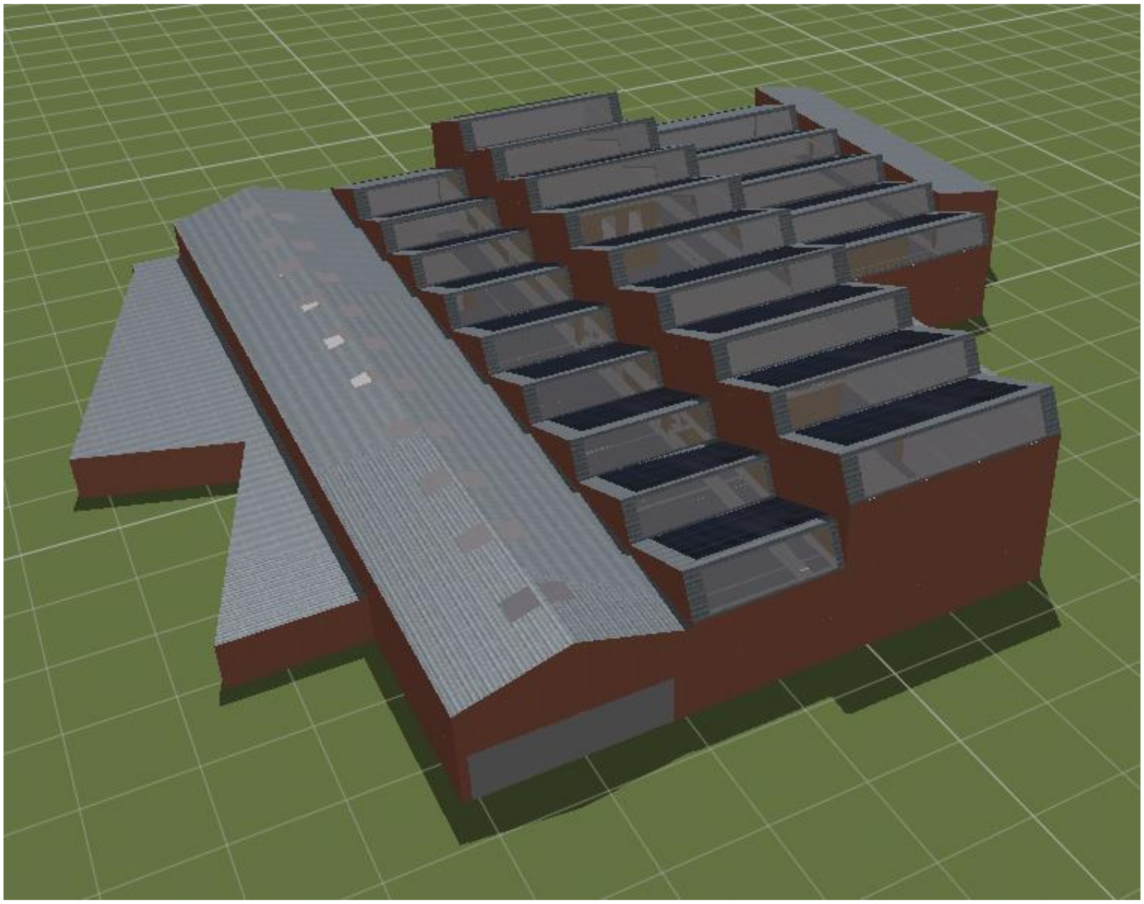
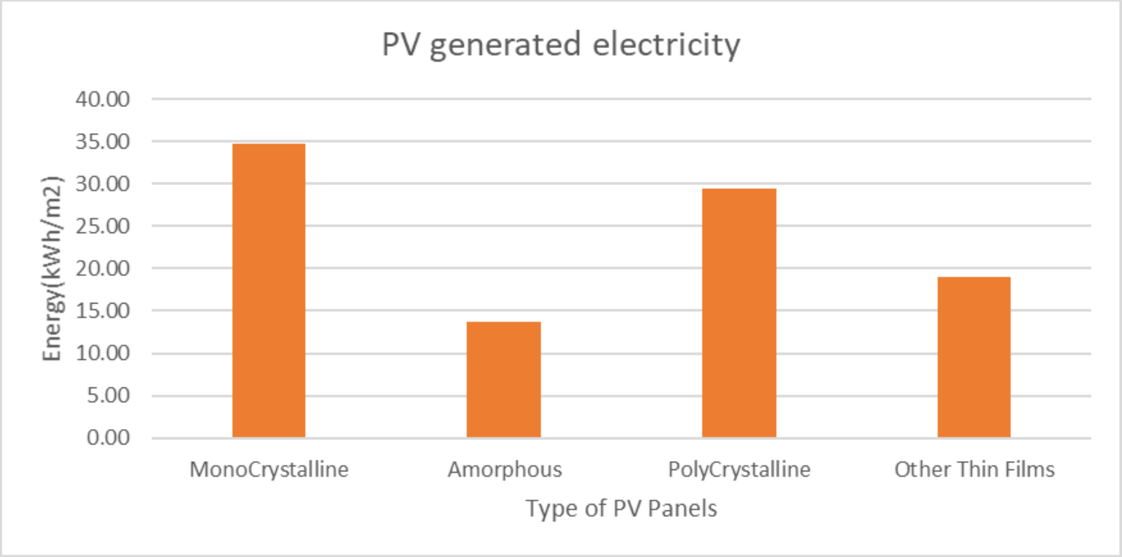


Figure 123. PV design in IESVE

Table 24. Electricity generate by PV types

Type of PV Panels	**PV generated electricity (kWh/m2)**
MonoCrystalline	34.73
Amorphous	13.77
PolyCrystalline	29.39
Other Thin Films	19.03

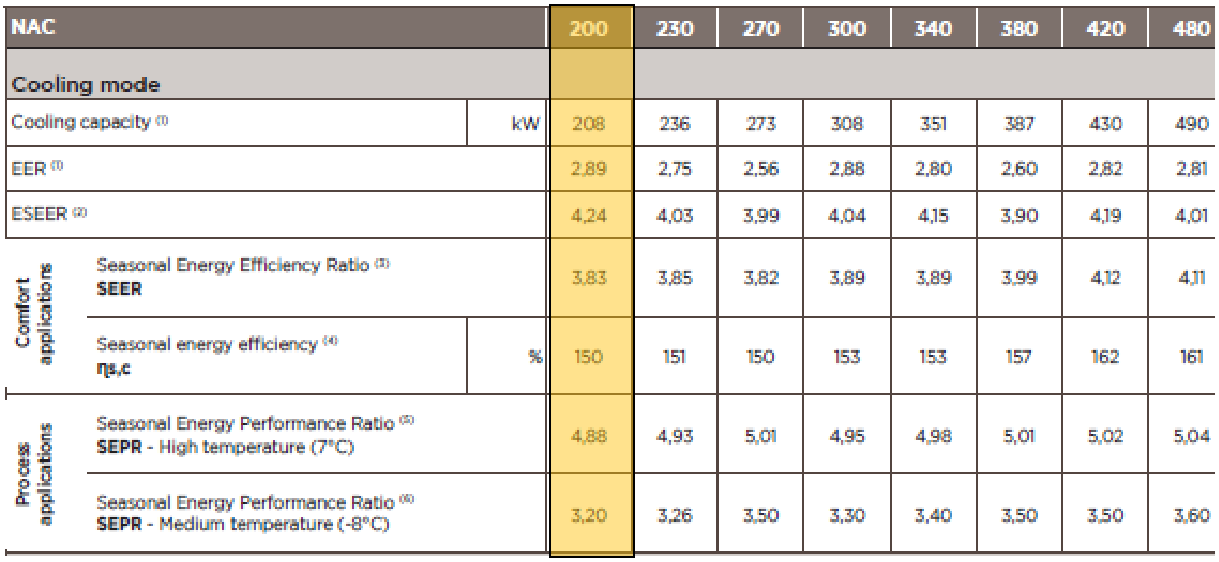


Graph 48. Energy generated by PV types

After placement of PV panels on the roof, PV types are analysed a best option was chosen as predictable. From the graph, it is seen that the monocrystalline is the best one. If the cost are wanted to reduce, the polycrystalline can be chosen because of the closer amount of generated energy; but, this project consider monocrystalline.

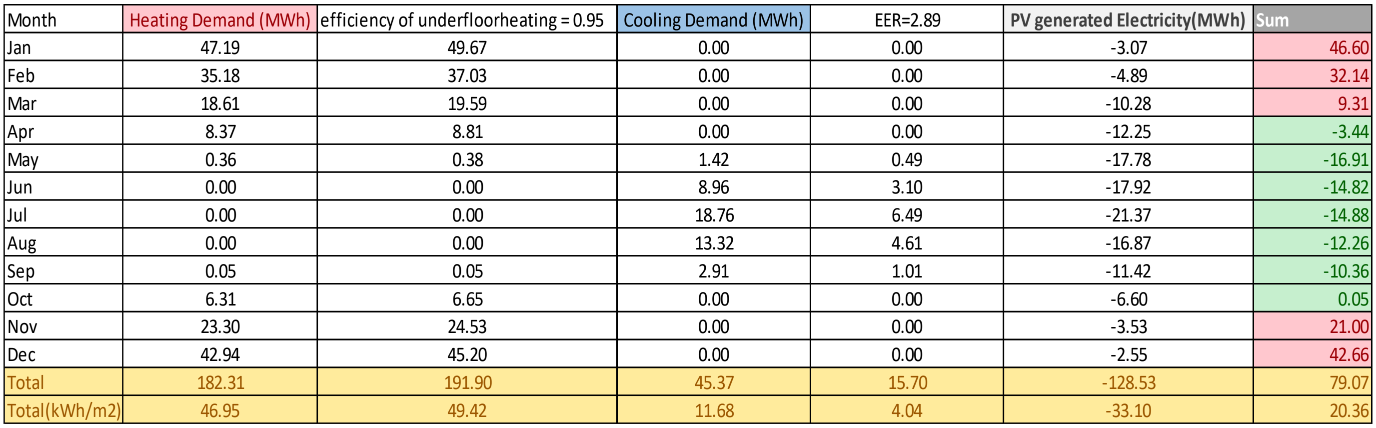
As the heat pump, NEOSYS NAC 200 has been chosen in the project according to design. The maximum cooling plant load is 126.97 kW for 21 July 16.30 and energy efficiency ratio is 2.89. Also, underfloor heating efficiency is 0.95 (*Annex B*).

Table 25. Cooling mode of NEOSYS NAC 200 (source: Lennox)



NAC			200	230	270	300	340	380	420	480
Cooling mode										
Cooling capacity (1)		kW	208	236	273	308	351	387	430	490
EER (1)			2,89	2,75	2,56	2,88	2,80	2,60	2,82	2,81
ESEER (2)			4,24	4,03	3,99	4,04	4,15	3,90	4,19	4,01
Comfort applications	Seasonal Energy Efficiency Ratio (3) **SEER**		3,83	3,85	3,82	3,89	3,89	3,99	4,12	4,11
	Seasonal energy efficiency (4) **ηs,c**	%	150	151	150	153	153	157	162	161
Process applications	Seasonal Energy Performance Ratio (5) **SEPR** - High temperature (7°C)		4,88	4,93	5,01	4,95	4,98	5,01	5,02	5,04
	Seasonal Energy Performance Ratio (6) **SEPR** - Medium temperature (-8°C)		3,20	3,26	3,50	3,30	3,40	3,50	3,50	3,60

Table 26. Efficiency of PV generated energy on heating and cooling



Month	Heating Demand (MWh)	efficiency of underfloorheating = 0.95	Cooling Demand (MWh)	EER=2.89	PV generated Electricity(MWh)	Sum
Jan	47.19	49.67	0.00	0.00	-3.07	46.60
Feb	35.18	37.03	0.00	0.00	-4.89	32.14
Mar	18.61	19.59	0.00	0.00	-10.28	9.31
Apr	8.37	8.81	0.00	0.00	-12.25	-3.44
May	0.36	0.38	1.42	0.49	-17.78	-16.91
Jun	0.00	0.00	8.96	3.10	-17.92	-14.82
Jul	0.00	0.00	18.76	6.49	-21.37	-14.88
Aug	0.00	0.00	13.32	4.61	-16.87	-12.26
Sep	0.05	0.05	2.91	1.01	-11.42	-10.36
Oct	6.31	6.65	0.00	0.00	-6.60	0.05
Nov	23.30	24.53	0.00	0.00	-3.53	21.00
Dec	42.94	45.20	0.00	0.00	-2.55	42.66
Total	182.31	191.90	45.37	15.70	-128.53	79.07
Total(kWh/m2)	46.95	49.42	11.68	4.04	-33.10	20.36

Table 26 shows that the PV generated electricity meets energy needs in April, May, June, July August, September and October. Other months has high heating demand due to the winter season, is hard to meet requirements. The highest electricity generated by PV panels were observed in July when the soar energy diffused more; however, the less produced electricity is in December that is not enough for requirements. After PV generated energy, total 79.07 kW are consumed for plants and equipment in the building. This energy need is equal to 20.36 kWh per square meter.

8. Results

- After building envelope improvement and internal gains affected on indoor temperature, total energy demand reduced by 55% of baseline demand.
- The simulations consider 5 offices and 2 housing units in the different locations in the building. Housings are used from 6 p.m. to 8 a.m. when the main building HVAC system is off.
- Office thermal zones by considering adaptive comfort range of category III are 96% to 97% comfortable which is a pretty good result. The main problem would be in cold months that temperature reaches around 16°C.
- Housing thermal zones have harsher situation in cold days because housings are used from 6 p.m. to 8 a.m. when the main building HVAC system is off.
- Comfort value for these zones are 78% that needs improvement. In what follows, there is simulation result of other scenario by considering HVAC works in winter all day long.
- Focusing on January which is the coldest month of the year in Milan, it is seen that cold hours relate to early in the morning around 8 a.m. when HVAC system of the main building has just started working and there is no problem for other hours of the day.
- Since housing 1 and 2 temperatures are in 78% acceptability, the new scenarios were developed. It was due to the fact that the main building HVAC system is off. New scenarios accepted by considering HVAC works in winter all day long.
- Considering HVAC works in winter all day in housing 1, the temperature in the houses increases and the acceptability rate was achieved 99.6% for house 1 and 98.7% for house 2.
- HVAC heating and cooling energy demands are shown together for two scenarios including on-mode weekdays and on-mode all days for office and housing. Total energy demand for both scenarios together which is 58.63kWh/m2 and 70.37kWh/m2 for the first and second scenarios respectively.
- Total 23 different roof parts has PV and 2000 PV panels with 1142 m2. Final energy need is equal to 20.36 kWh per square meter.

9. Conclusion and Future Works

The study investigates to make unused buildings available for a long time with the prefabricated units after refurbishment to optimize energy performance as the building improves in many respects. The case study has been analysed to see how much these methods contribute to improving energy performance. Firstly, the building envelope was improved without any heating, cooling system and ventilation. The new wall, slab and roof design enhances energy demand by 50% in comparison with baseline of building. Then, different glazing systems were analysed, and total improvement reached to 52%. Then, the internal gains were loaded to building since the new functions requires equipment and machinery and the people occupy the building. This leads to increase indoor temperature and decrease heating demand, so the total energy demand was reduced by 55%.

The significant point of this study is combination of refurbishment of building and reuse of inside with prefabricated units which can be used for office and accommodation. When the energy performance is to ensure comfort conditions, with new function of building, although the energy consumption was increase because of machinery and equipment, the building use makes more usable. 5 different office boxes and 2 different housing boxes were analysed with occupant and equipment schedules to ensure comfort conditions. While the office results were in around 96-97% acceptability, housing scenarios were 78-79% acceptability in comfort category III and should be improved by different scenarios owing to the fact that heating plant didn’t work when the housing units were occupied. In the scenario which systems run all day, 98-99% acceptability of housing comfort.

Finally, if the PV panel is designed to meet this energy requirement, the contribution of prefabricated units is examined. Considering that the use of prefabricated units and offices increases the equipment and service operation, in case of high energy requirement, PV panels are designed and discussed how much service and equipment can be supplied. PV panels couldn’t meet the energy need but, in summer it was observed as quiet enough. PV generated energy, total 79.07 kW are consumed for plants and equipment in the building. This energy need is equal to 20.36 kWh per square meter.

As a result, all project data is imported to REVIT to control in future. When the plans will be changed, the electrical and mechanical systems can be seen in the project. Also, when one of these building systems can ben changed, the

This study includes preliminary stages and the aim is to discuss how the reuse methods of prefabricated units' effect on the energy refurbished buildings. When the systems are assumed, the sizes, factors and other calculations are considered by standards.

In the project, the heating demand is high because whole the building is heated. The project may be improved by the different heating system which integrated to slab of prefabricated boxes directly. In this case, all building isn't heated, and energy need will be decreased. This can be also helped to reduce construction cost of heating system.

PV panels are monochromatic, and it is used for only generation of electricity. The using of The building systems can be designed

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Annex A

Recommended criteria for the thermal environment

ISO/TR 17772-2:2018

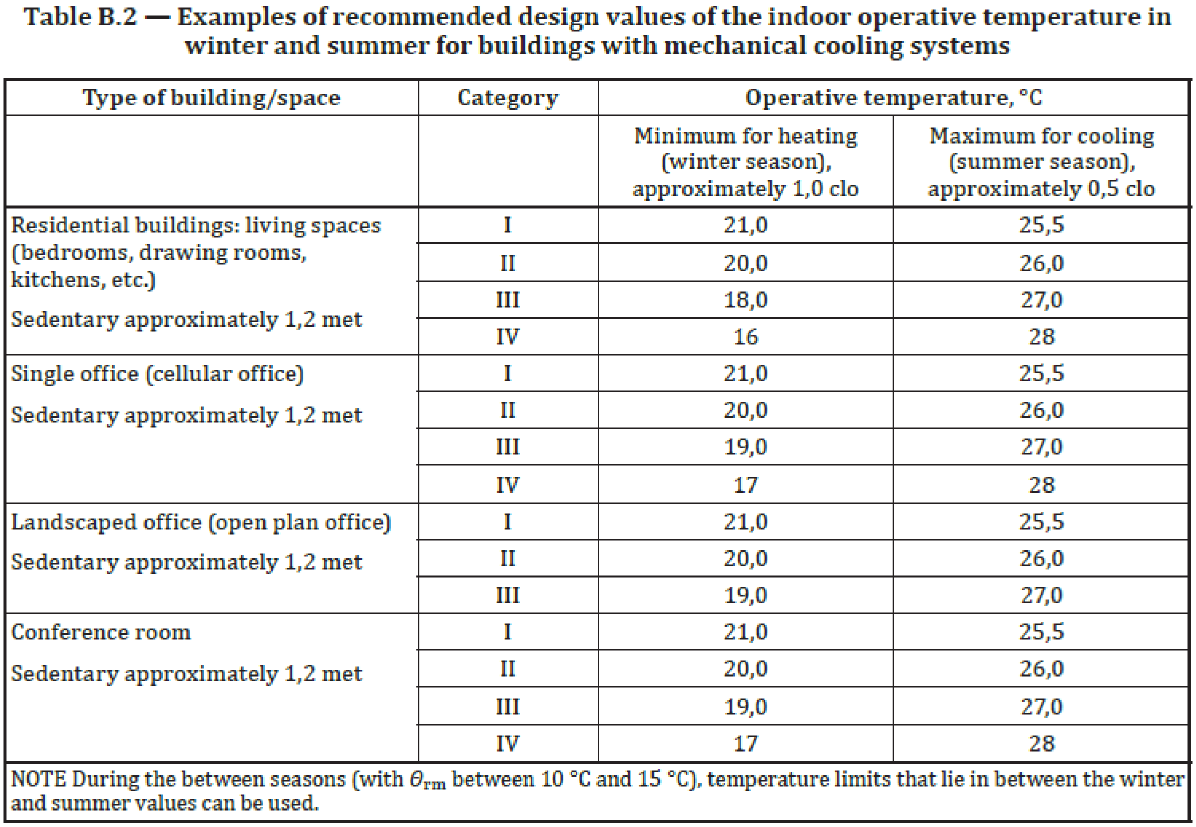
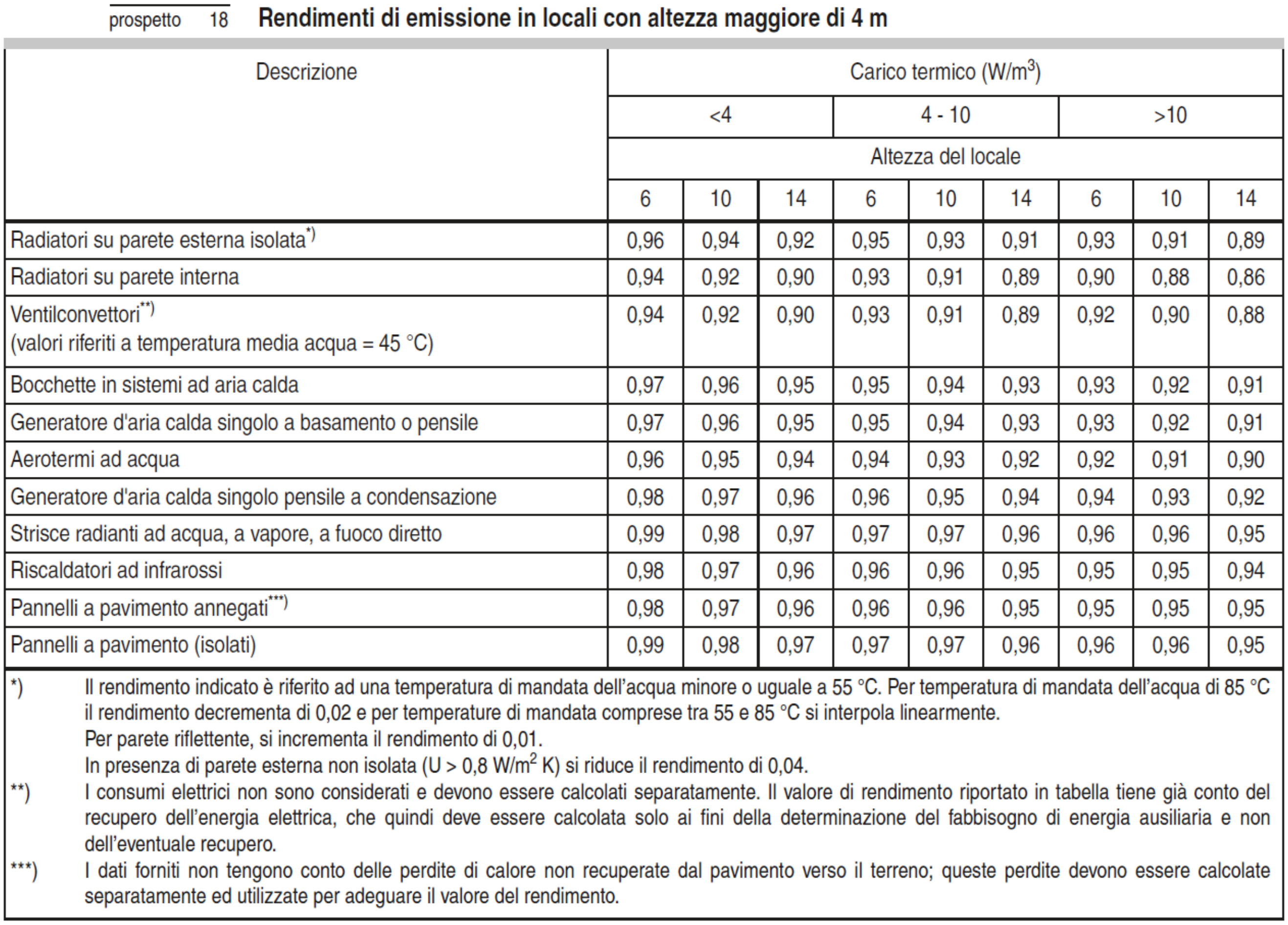


Table B.2 — Examples of recommended design values of the indoor operative temperature in winter and summer for buildings with mechanical cooling systems

Type of building/space	Category	Operative temperature, °C	
		Minimum for heating (winter season), approximately 1,0 clo	Maximum for cooling (summer season), approximately 0,5 clo
Residential buildings: living spaces (bedrooms, drawing rooms, kitchens, etc.) Sedentary approximately 1,2 met	I	21,0	25,5
	II	20,0	26,0
	III	18,0	27,0
	IV	16	28
Single office (cellular office) Sedentary approximately 1,2 met	I	21,0	25,5
	II	20,0	26,0
	III	19,0	27,0
	IV	17	28
Landscaped office (open plan office) Sedentary approximately 1,2 met	I	21,0	25,5
	II	20,0	26,0
	III	19,0	27,0
Conference room Sedentary approximately 1,2 met	I	21,0	25,5
	II	20,0	26,0
	III	19,0	27,0
	IV	17	28
NOTE During the between seasons (with θ_{rm} between 10 °C and 15 °C), temperature limits that lie in between the winter and summer values can be used.			

Annex B

UNI TS 11300-2 for heating efficiency



prospetto 18 **Rendimenti di emissione in locali con altezza maggiore di 4 m**

Descrizione	Carico termico (W/m³)								
	<4			4 - 10			>10		
	Altezza del locale								
	6	10	14	6	10	14	6	10	14
Radiatori su parete esterna isolata*)	0,96	0,94	0,92	0,95	0,93	0,91	0,93	0,91	0,89
Radiatori su parete interna	0,94	0,92	0,90	0,93	0,91	0,89	0,90	0,88	0,86
Ventilconvettori**) (valori riferiti a temperatura media acqua = 45 °C)	0,94	0,92	0,90	0,93	0,91	0,89	0,92	0,90	0,88
Bocchette in sistemi ad aria calda	0,97	0,96	0,95	0,95	0,94	0,93	0,93	0,92	0,91
Generatore d'aria calda singolo a basamento o pensile	0,97	0,96	0,95	0,95	0,94	0,93	0,93	0,92	0,91
Aerotermi ad acqua	0,96	0,95	0,94	0,94	0,93	0,92	0,92	0,91	0,90
Generatore d'aria calda singolo pensile a condensazione	0,98	0,97	0,96	0,96	0,95	0,94	0,94	0,93	0,92
Strisce radianti ad acqua, a vapore, a fuoco diretto	0,99	0,98	0,97	0,97	0,97	0,96	0,96	0,96	0,95
Riscaldatori ad infrarossi	0,98	0,97	0,96	0,96	0,96	0,95	0,95	0,95	0,94
Pannelli a pavimento annegati***)	0,98	0,97	0,96	0,96	0,96	0,95	0,95	0,95	0,95
Pannelli a pavimento (isolati)	0,99	0,98	0,97	0,97	0,97	0,96	0,96	0,96	0,95

*) Il rendimento indicato è riferito ad una temperatura di mandata dell'acqua minore o uguale a 55 °C. Per temperatura di mandata dell'acqua di 85 °C il rendimento decrementa di 0,02 e per temperature di mandata comprese tra 55 e 85 °C si interpola linearmente.
Per parete riflettente, si incrementa il rendimento di 0,01.
In presenza di parete esterna non isolata (U > 0,8 W/m² K) si riduce il rendimento di 0,04.

**) I consumi elettrici non sono considerati e devono essere calcolati separatamente. Il valore di rendimento riportato in tabella tiene già conto del recupero dell'energia elettrica, che quindi deve essere calcolata solo ai fini della determinazione del fabbisogno di energia ausiliaria e non dell'eventuale recupero.

***) I dati forniti non tengono conto delle perdite di calore non recuperate dal pavimento verso il terreno; queste perdite devono essere calcolate separatamente ed utilizzate per adeguare il valore del rendimento.