Net-zero energy refurbishment with circular building materials at the TU Delft

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INTRODUCTION

PREFACE

This thesis is the final assignment of the specialisation Building Technology within the master Architecture, Urbanism and Building Sciences at Delft University of Technology. The topic of this thesis is an energy neutral refurbishment with use of circular building materials. In other words, a refurbishment that results in a highly insulated, little consuming building that maximises the reuse potential of the building's materials.

For long, I have known that upgrading the Built Environment in terms of energy consumption and architecture is my ideal job and I am thankful that I have gotten the opportunity to specialise in this field. For that, I want to thank my mentors Andy van den Dobbelsteen and Thaleia Konstantinou. Their guidance and support kept me on track and ensured that the thesis did not take any longer than it already did.

Iris Snijders Blok

Delft, November 2017

INTRODUCTION

ABSTRACT

The objective of this research is to decrease the energy and material consumption of TU Delft's building stock, by providing the university with a refurbishment method. Refurbishments can have a large impact on the energy and material consumption of the Built Environment, as it focuses on the majority of the Built Environment. By designing net-zero buildings that make use of circular building materials, the impact is decreased and worldwide problems regarding energy and material scarcity are addressed.

This thesis answers the following question: *What technical (re)design solutions should be used in the refurbishment of a TU Delft building to achieve net-zero energy whilst taking circular use of building materials into consideration?* The main topics that derive from and are discussed in this thesis are: method development, refurbishment, net-zero buildings and circular use of materials. The answer to the research question is given by the developed method and the first building proposal. Using this method allows the TU Delft to one by one redesign its buildings to net-zero and circular buildings.

INTRODUCTION

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2. INTRODUCTION

BACKGROUND

There are worldwide climate problems including global warming and depletion of natural resources. The Built Environment is a large contributor to these problems, because it consumes large amounts of energy and materials. Minimising the energy and material consumption of this sector would have a significant impact on worldwide climate issues (De Grauw, 2015; UNEP-SBCI, 2017).

Constructing new and highly insulated buildings will contribute a decrease in consumption, but it will have a larger impact if the current building stock is adapted. There are far more existing buildings, so refurbishment is the best strategy (Greco et al., 2016). In order to bring the building stock to the desired level, it is necessary to execute deep renovations (e.g. savings up to 60% of the original consumption). This is the best solution, both from an ecological and economical perspective (BPIE, 2013; Konstantinou, 2014).

However, decreasing the energy consumption is not the only solution. Using materials in a circular way, according to principles of the Circular Economy, increases the reusability and decreases depletion (BAMB, 2016).

Delft University of Technology (TU Delft) has one of the largest campuses in the Netherlands and owns over sixty buildings (Den Heijer, 2011; FMRE, 2013b). Most of the buildings are in need of refurbishment. One of the aims of the university is to decrease the energy consumption (Berghorst, 2017; FMRE, 2013a).

PROBLEM STATEMENT

The problem definition of this graduation project is threefold:

1. TU Delft owns many buildings, of which most are not up to date and TU Delft wants to bring the energy consumption down. Despite the ambition to renovate, this is occurring too little.
2. New net-zero energy buildings are constructed more and more, but the number of net-zero energy renovations is still limited although the necessity to renovate the current building stock is present.
3. Circular Economy in the Built Environment is relatively new and not many people know how to design with it yet. However, (re)using building materials in a circular way can have a large environmental effect on the carbon footprint.

OBJECTIVE

The objective of this graduation project is to design a method by which a building portfolio can be refurbished and to give an example of the method by making a refurbishment proposal. This method will be developed for the TU Delft, but with minor changes it can also be used by other building portfolio owners.

RESEARCH QUESTIONS

The research question of this graduation projects is:

What technical (re)design solutions should be used in the refurbishment of a TU Delft building to achieve net-zero energy whilst taking circular use of building materials into consideration?

The main topics that derive from this research question are: method development, refurbishment, net-zero buildings and circular use of materials. The sub-questions to this research question are:

1) Which building of TU Delft is able to meet the set criteria best and should therefore be chosen for a renovation proposal?
2) Building analysis
    a) What data can be collected of the building?
    b) What are main reasons for refurbishment?
    c) Which materials, in what quantity and what quality are present in the building?
3) What net-zero energy principles exist and can be implemented in the renovation of this particular building?
4) What options regarding circular use of building materials exist?
5) How should the design be adapted to be net-zero energy and using circular building materials?

METHODOLOGY

The methodology of this thesis is comparable to one of the end results of this thesis, the refurbishment method. Figure 1 shows the proposed research methodology, chapter layout and timeline.

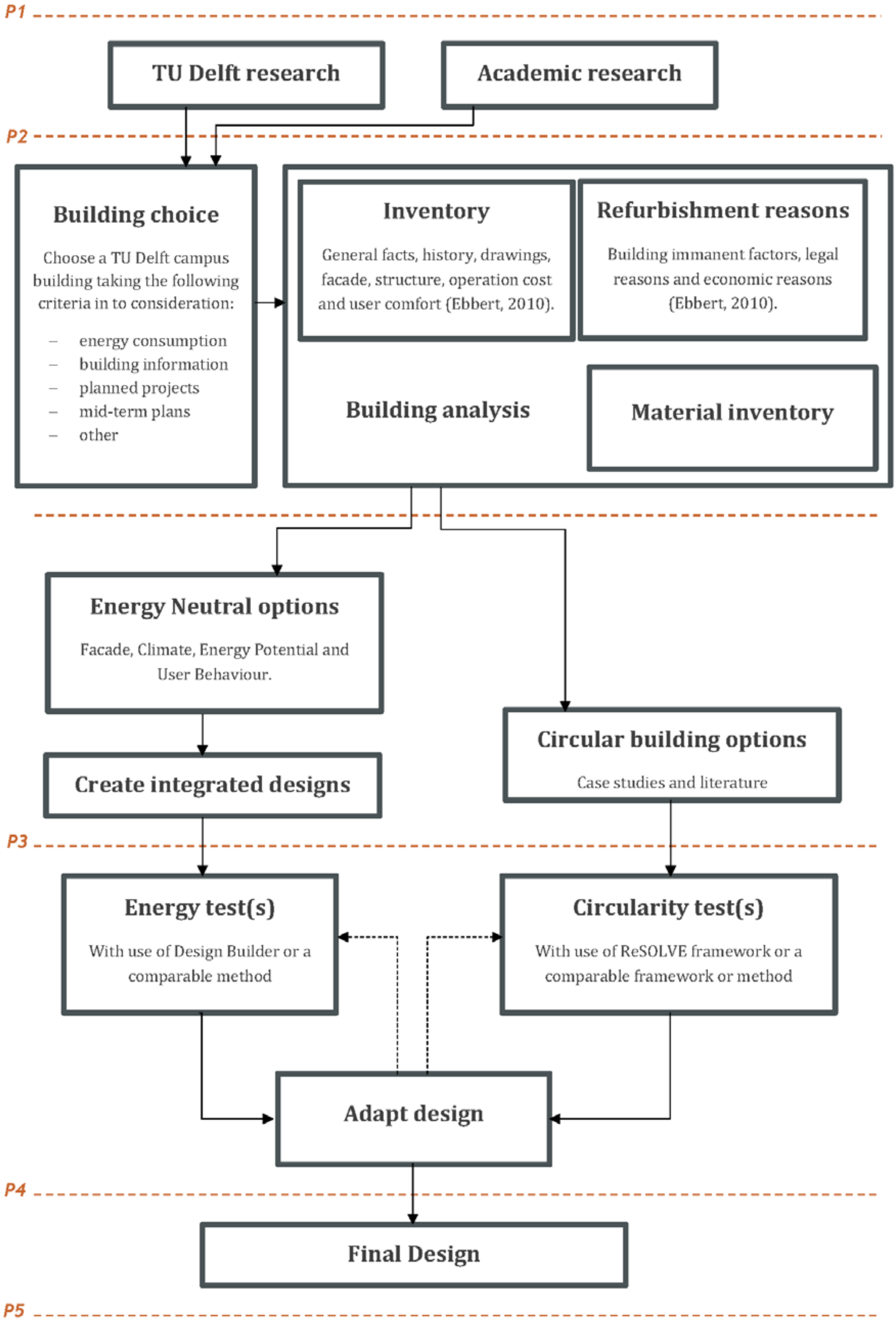


Figure 1: Research methodology

3. RESEARCH ON REFURBISHMENT, NET-ZERO AND THE CIRCULAR ECONOMY

3.1. CURRENT ENERGY DEMAND OF THE BUILDING SECTOR

By now, the majority of earths citizens realise that there are several environmental issues. We have a number of environmental problems that endanger our lives. Depletion of natural resources (e.g. fossil fuel mining) and devastation of natural conditions (e.g. deforestation) are two of them (De Grauw, 2015). These are major global issues, because we cannot restore the natural conditions and we are running out of materials. Unfortunately, the global energy consumption keeps increasing as the world population and living standards do too. A global change should occur.

Fortunately, the importance is being recognised and legislations are becoming stricter. In 2007, EU leaders set climate and energy targets for 2020. And more recently, in 2014, new targets for 2030 have been agreed upon. Table 1 gives an overview of these targets. The package encompasses three key targets and it is expected that all will be achieved by 2020 (Directorate-General for Climate Action, 2017).

Table 1: Climate and energy targets set by the EU in 2007 and 2014 (Directorate-General for Climate Action, 2017)

2007	***2014***	
20%	40%	cut in greenhouse gas emissions (from 1990 levels)
20%	27%	of EU energy from renewables
20%	27%	improvement in energy efficiency

The building sector is a large contributor to earths problems, as it consumes 40% of global resources, 40% of global energy and 25% of global water (UNEP-SBCI, 2017). When it comes to final energy consumption in the EU transport is the biggest sector, followed by households and industry (Eurostat, 2017a).

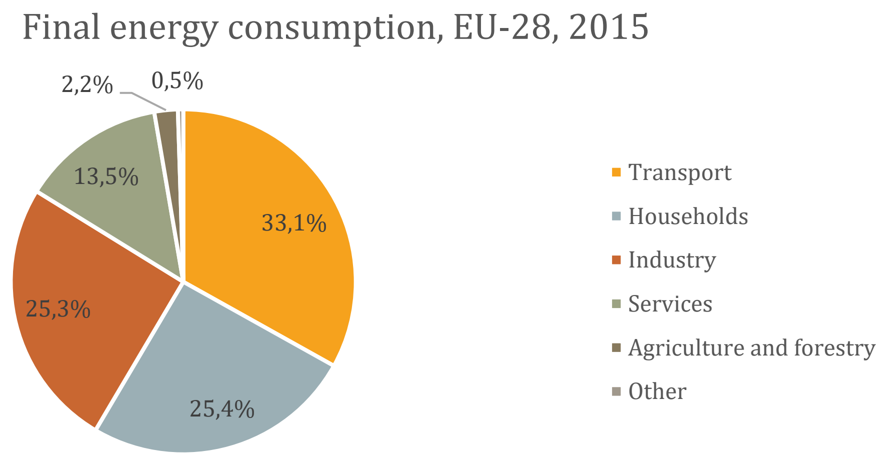


Figure 2: Final energy consumption, EU-28, 2015 (% of total, based on tonnes of oil equivalent) (Eurostat, 2017a)

Of the 25,4% that is consumed by households, almost two-thirds is used for space heating (Figure 2). Space and water heating combined account for more than 75-80% of the final energy consumption. This indicates that savings in the fields of heating can have a large impact om the energy consumption. In The Netherlands, the most used fuel for this is natural gas (Eurostat, 2017b). Figure 3 shows a comparison for households in the EU-28 and in The Netherlands. This excludes other building types, like offices. It also excludes energy for the making of buildings.

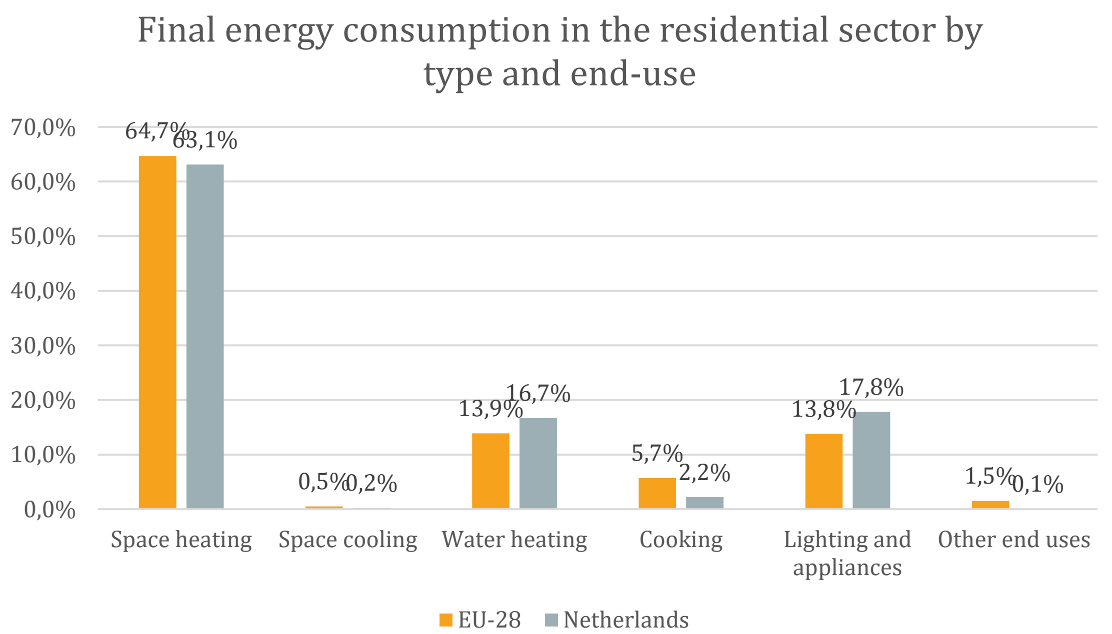


Figure 3: Final energy consumption in the residential sector by type of end-use, EU-28, 2015 (Eurostat, 2017b)

The building sector is a large contributor to worldwide problems, because it uses large amounts of energy and materials. Besides using energy for operating the buildings, e.g. the above-mentioned household consumption, energy and materials are also used for constructing and deconstructing buildings. The embodied energy of materials and products is relevant. The energy use of buildings consists of three types (Yanovshtchinsky, Huijbers, & Dobbelsteen, 2012):

- building-based energy: energy used for heating, cooling, lighting, ventilating and all other processes that are needed to climatize the building.
- usage-based energy: energy used by the occupants for appliances and lighting in the building
- material-related energy: energy used during production, transport and construction of materials

CONSTRUCTION AND DEMOLITION WASTE

So, the Built Environment consumes large amounts of energy. Besides energy consumption, the building sector also produces large amounts of (structural) waste. In 2012, The Netherlands produced 80 Mt of waste, including soils. Figure 4 shows that over 40% of all waste in The Netherlands was construction and demolition waste (CDW). This makes it the biggest contributor. Of that amount, 93% is recovered, of which 95% is recycled (Deloitte, 2015). These are optimistic numbers, but the definition of recycling is deceiving. It encompasses recycling but also energy recovery.

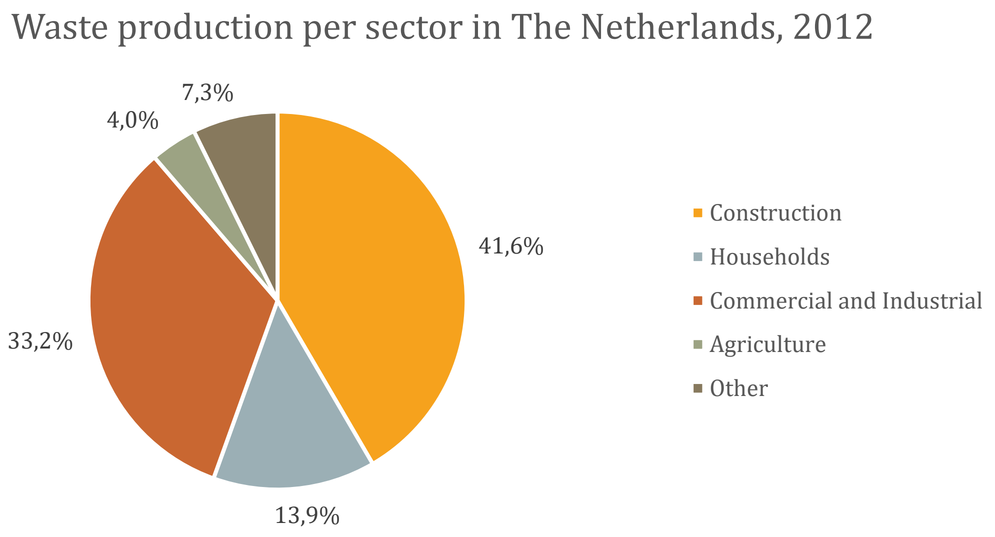
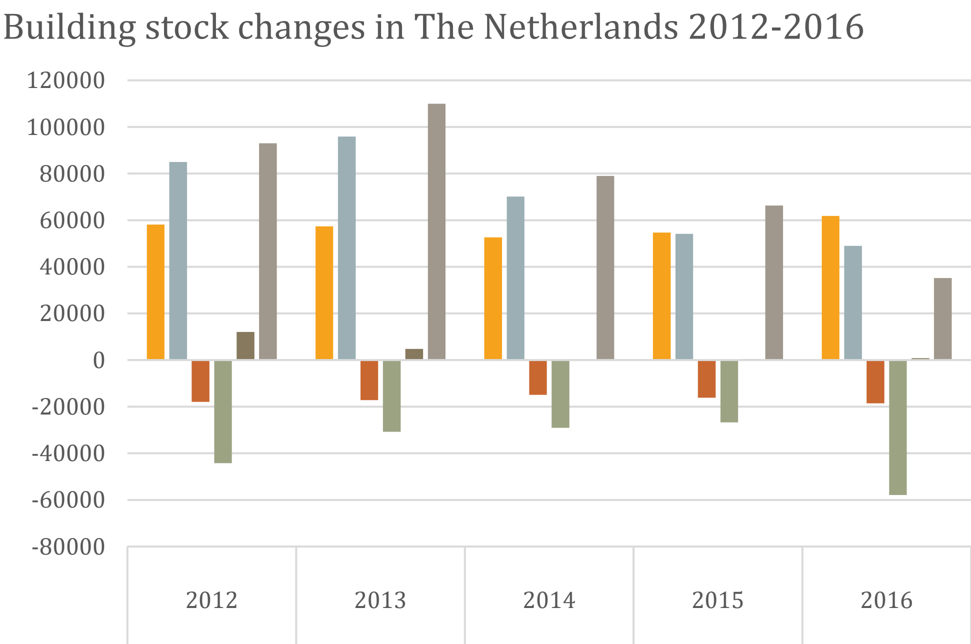


Figure 4: Waste production per sector in The Netherlands in the year 2012, adapted from (BAMB, 2016)

However, the waste industry in The Netherlands performs very well in comparison to other European countries. This is because the percentage of recycled waste is relatively high. However, the amount of CDW is expected to keep increasing over the next years (Deloitte, 2015). As material scarcity and depletion are important, it is best to 1) decrease the amount of CDW and 2) improve the reusability of waste.

We now have an idea how much energy and waste is used and generated in the building industry. Different regulations, including European and national, attempt to improve the current building stock. This is attempted by stimulating energy efficient measures and generation of renewable energy. Also, the regulations for energy efficiency of new build become stricter over time. As a result, more energy efficient buildings are built and renovations occur. But, the rate at which they occur is not yet sufficient. Additionally, most renovations concern so called shallow renovations, i.e. renovations with minor interventions that lead to small energy benefits (Greco et al., 2016).

Replacing the current stock with new buildings seems to be a logical option for lowering the energy consumption. New buildings have to meet stricter criteria and are more suited to new living standards. They can be more architecturally appealing, suit new life standards and make use of the newest techniques. However, the current renewal rate of the existing building stock is low. Around 55.000 buildings are built each year, accounting only for 0,7% of the existing stock. On top of that, only 0,2% is demolished on an annual basis (CBS, 2017b). This is shown in Figure 5.



	2012	2013	2014	2015	2016
New construction	58117	57352	52602	54659	61798
Other addition	84963	95899	70171	54125	48977
Demolition	-17924	-17209	-14905	-16194	-18548
Other withdrawal	-44244	-30804	-29086	-26748	-57871
Correction	12081	4746	242	448	831
Balance	92993	109984	79024	66290	35187

Figure 5: Building stock changes in The Netherlands 2012-2016 (CBS, 2017c)

At this rate, it will be impossible to achieve energy targets by only making new buildings. Stimulated demolition would make room for new energy efficient buildings and reduce energy consumption, but in the demolition rate of the Netherlands, that is not feasible. Moreover, stimulated demolition is simply a waste of (embodied) energy.

A focus on refurbishing the other 99,1% of the building stock therefore seems most logical. Fortunately, the necessity of refurbishment is widely recognised, but it seems that the rate at which buildings are refurbished is too low. “Both the quality and the scale of refurbishment need to improve” (Greco et al., 2016, p. 335). To do so, investments in building energy savings need to increase. But, saving energy is hardly ever the main motive, financial and social incentives are. Making investments is a barrier in the rented sector, as not the owners but the renters mainly benefit from the refurbishment (Konstantinou, 2014). The rental sector includes 43% of the Dutch housing stock and an ever larger percentage of the office stock (CBS, 2017a).

Refurbishments will not only have a larger impact than new build, but the embodied energy of existing buildings will also be preserved. Almost everything that is demolished and or brought into the CDW cycle suffers from loss of value and energy. To recycle glass, for instance, the glass has to be brought to melting temperature. Often only the components that can be reused without much work do not suffer losses. So, for now recycling of materials of existing buildings isn’t that appealing.

CIRCULAR ECONOMY

A newly revived approach to this matter is the Circular Economy. This is a conceptual system that has been around for a long time, but has become well-known in recent years. It resembles principles like Cradle to Cradle, Industrial Ecology, biomimicry, performance-based economy (De Grauw, 2015; Ellen MacArthur Foundation, 2014). Because Circular Economy has only recently gained interest, the knowledge is not yet widespread. At the moment, the Ellen MacArthur Foundation is one of the biggest organisations promoting the Circular Economy.

The Circular Economy is based on a model in which we no longer use the world and its assets in a linear system, because by now we (should) realise that depletion is real. Instead, all assets on earth are used in a circular system that is based on 1) thinking in loops and 2) thinking in performances. Materials should not be designed and used for one-time use, but as a continuous system. That results in a closed system in which there is no material scarcity and everything has value (De Grauw, 2015; Ellen MacArthur Foundation, 2013; Rau & Oberhuber, 2016).

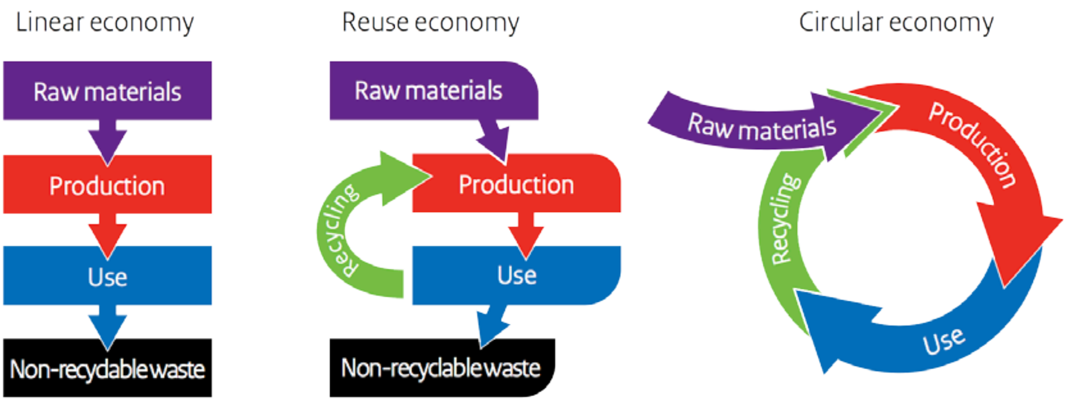


Figure 6: From a linear to a circular economy (Minsterie van Infrastructuur en Milieu, 2017)

Table 2 show a comparison between the linear and circular economy. At the moment, most building are built for the linear economy.

Table 2: Comparison of linear and circular economy (Minsterie van Infrastructuur en Milieu, 2017)

	Linear	**Circular**
Step plan	Take-make-dispose	Reduce-reuse-recycle
Focus	Eco-Efficiency	Eco-Effectivity
System boundaries	Short term, from purchase to sales	Long term, multiple life cycles
Reuse	Downcycling	Upcycling, cascading and high-grade recycling.

Tools for that are for instance material passports and demolition plans. More on this will be explained in chapter 3.9.

3.2. REQUIREMENTS FOR BUILDINGS

Any building, whether it has been built a week or a decade ago, needs to meet certain requirements. But the requirements of a building from the 60s will be different from a recent development, as requirements alter over time. In building practice, most have become stricter. For instance, regarding comfort and fire safety. Additionally, a new range of requirements has been added over time.

(Re)designing a building is a complicated task, because one has to think of a large number of requirements. The building has to be safe (e.g. structural, fire and toxic), encompasses thermal comfort, architectural quality, costs and environmentally friendliness. In general, a building or adaptation must be feasible to make it succeed. According to Douglas (2002, p. 48) feasibility consists of three variables:

1. Viability: (economic feasibility, i.e. potential value versus projected costs)
2. Practicality: (physical feasibility, i.e. is it physically possible in the building and at the site)
3. Utility: (functional feasibility, i.e. fulfilment of spatial and environmental needs of the occupants)

Together they indicate the level of feasibility and by that, the quality of a building. For most projects, economic feasibility is the most important factor. But all variables must be of sufficient quality (Douglas, 2002).

Although these three variables cover the range of requirements a building has to fulfil, it does not provide starting points for a refurbishment. A more detailed list is made by Ebbert (2010) and presented in Figure 7. Although the focus of this list is on office façade refurbishment, it covers a wide range of requirements and can also be used for other building types or phases.

The framework itself is very helpful for determining problems and opportunities in a building. It consists of five categories: Architecture & Function, Building Construction, Technical Installations, Economics and Life Cycle Performance. In essence, this division covers the same topics as feasibility, but underlines the importance of Life Cycle Analysis, adaptability and energy.

Environmental requirements have become more important over time. Regulations for thermal insulation, for instance, have become stricter. Environmental requirements do not only encompass operational energy that is easily translatable to monetary values, but also thermal comfort of occupants, energy storage, renewable generation, usage of low-impact materials and minimising construction waste (Konstantinou, 2014). To maximise the environmental potential of a building (or product), the New Stepped Strategy (NSS) can be used. This framework will be discussed in chapter 3.8.

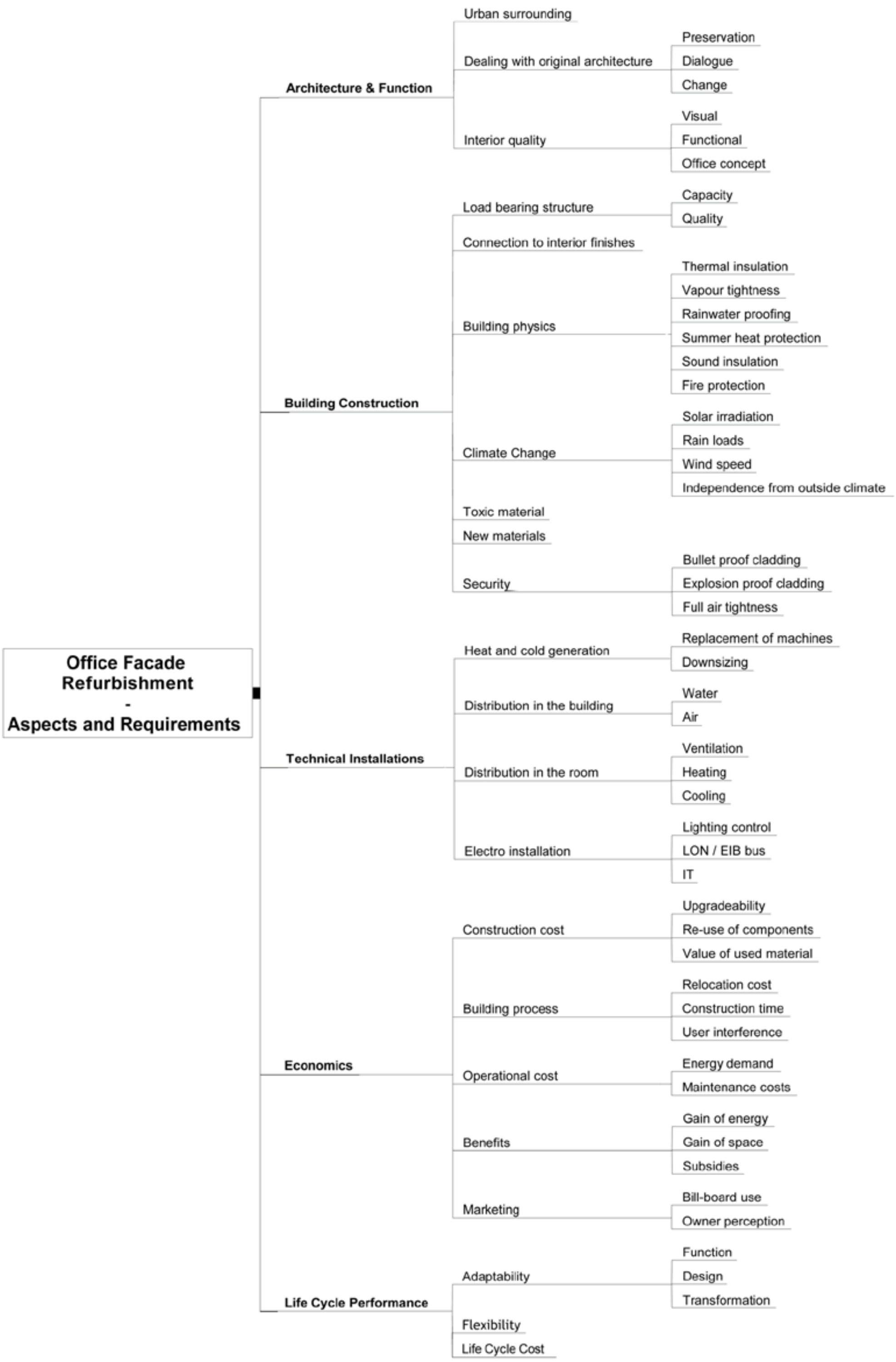


Figure 7: Aspects and requirements in an office façade refurbishment (Ebbert, 2010, fig. 4.1)

One should bear in mind that the list of Ebbert (2010) sums up current requirements. That means it is likely to change over time. One can argue that adaptability of buildings is therefore the most important requirement. Because, as we know regulations change over time, it is best to make a building that is very adaptable. That way, the chances that a building is able to cope with new and altered requirements is larger. Douglas (2002, p. 7) also provides five criteria for adaptability:

1. Convertibility: (allowing for changes in use)
2. Dismantlability: (capable of being demolished safely and efficiently)
3. Disaggregatability: (materials and components from and dismantled building should be as reusable or reprocessable as possible)
4. Expandability: (allowing for increases in volume)
5. Flexibility: (enabling shifts in space planning)

Over time, not many buildings have been purposely designed to be adaptable. The buildings that are, often only score well on convertibility and expandability. For instance, in many buildings the foundations and structure are over dimensioned, which allows for heavier facades or a roof addition (Douglas, 2002).

DESIGN FOR DISASSEMBLY

The above-mentioned criteria for adaptability are combined in a design field called Design for Disassembly (DfD). This design field is very comparable to that of Circular Economy. The aim of DfD is to design buildings that facilitate adaptability by using building materials, components, systems and techniques that allow for reuse (Hamer Center for Community Design, 2008). How to do so will be explained in chapter 3.9.

In conclusion, the most important requirements in a building are feasibility and flexibility.

3.3. MISMATCH AND CHOICE FOR DEMOLITION

In the previous chapter the various requirements that a building could meet were discussed. We know these requirements vary over time, because demands and circumstances change. This means that the usefulness of buildings will vary over time. Besides changing demands, the quality of the buildings structure and fabric also decreases. This is because of environmental influences (e.g. rain, sun, gases) and user activities (Douglas, 2002; Ebbert, 2010).

Because requirements continuously change, there is a permanent mismatch with the building stock. To prevent a mismatch, measures are often taken to improve the usefulness. This can be maintenance, a change in function, a slight adaptation or larger. "Most buildings, therefore, undergo a variety of cycles during their service life (Douglas, 2002, p. 14)".

There are two options to deal with the constant mismatch between current and demanded building stock: replacement or refurbishment. Replacement means demolition of the existing building and the construction of a new building. The term refurbishment means upgrading the existing building and covers a large range of interventions. What these interventions entail will be explained in the next chapter.

Reconsidering a building starts with addressing the problems and determining their importance. Whether a building can best be demolished or refurbished is of later concern. Ebbert (2010) gives a clear overview of reasons to reconsider an existing building (Figure 8). These are categorised in building immanent factors, legal reasons and economic reasons. A single reason from the list can be sufficient to take actions. However, there is often more than one reason to reconsider.

Reasons to reconsider an existing building

Building immanent factors	Urban design	Desired improvement of the urban quality
		Prevent vacancy as cause for social problems in a neighbourhood
	Architectural design	Outdated apperance
		Exterior impression bad for the reputation of the user / owner
		Decay of a valuable architectural heritage
	Function	Transformation of the building
		Change / Optimising of office concept
	User comfort	Unpleasant indoor conditions - users' complaints
		Hygienic problems
		Sick building syndrome (SBS)
		Building related illness (BRI)
	Technical Installations	High operational energy demand
	Hazardous material	Asbestos
		PCB
		PAK
		MMMF
	Building physics	Lack of insulation
		Wind leaks - draft
		Water leaks
		Fire protection deficiencies
		Planning for climate change
	Building owner / user	Tenant considers relocation
		Owner user initiates renovation
Legal reasons	Fire regulation	Compulsory fire safety improvements
	Safety	Danger of damage to third party
	Energy consumption	Compulsory energy consumption certificate (energy passport) for resale or rental contracts
Economic reasons	Operational cost	High energy demand
		High maintenance cost
	Lettability	Bring an empty building back to the market
		Tenant considers relocation
	Marketing	Users' representation need
	Financial market	Institutional investors are bound to invest

Figure 8: Reasons to reconsider an existing building (Ebbert, 2010, fig. 2.2)

For office buildings, for instance, a long-term vacancy is often the reason for reconsideration. By improving the building, the chances of it being rented out are higher. And the desired outcome of this refurbishment is often a change in function to accommodate other users. Other often mentioned reasons are: outdated appearance, insufficient ceiling height and high operation cost. The latter, having to do with energy consumption, is becoming a more important motivation in recent years (Ebbert, 2013; Konstantinou, 2014).

REFURBISHMENT AND DEMOLITION

When the building's owner has concluded that the reasons for change are of overriding importance, a choice has to be made between refurbishment or replacement. For this, Ebbert (2010) made a list of decisive factors that point out in which cases refurbishment is the better option (Figure 9).

Decisive factors for refurbishment instead of replacement

Building immanent factors	Architectural design	Identification with the building
		Preservation of socio-cultural heritage
	Technical installations	Technical components have not reached the end of life span - due to different replacement intervals
Legal reasons	Building permit	New permit would allow less building volume / height
		Prevention of 'urban sprawl'
	Monumental protection	The building is listed
	Life-Cycle assessment	The EU is aims to impose a life-cycle assessment of building projects - refurbishment would score better thanks to less material consumption
Economic reasons	Construction cost	Refurbishment is cheaper
	Construction process	Local situation prohibits demolition
	Operational cost	Interior has been refurbished before and is bound to stay in place (different renovation intervals)
		Wish to keep IT-systems in operation
	Relocation cost	Rent for temporary space
		Off-time
		Reduced productivity during relocation
	Marketing	Sustainability as sales argument
		Users' representation need
	Financial market	Since 2009 financial crisis, investors are more cautions

Figure 9: Decisive factors for refurbishment instead of replacement (Ebbert, 2010, fig. 2.3)

Architectural design is an important reason for people to choose refurbishment over demolition. The architectural design can either be appreciated, in which case the refurbishment becomes a renovation. It can also be that the design of the building is regarded as invaluable and the motive for refurbishment is upgrading the (façade) appearance. In both cases, adaptation can lead to improvement of the urban quality and have a positive effect on its surroundings (Ebbert, 2010; Power, 2008).

Legal reasons can also be at the basis of eliminating a replacement. The building can have a monumental status, not allowing for changes. Also, the land-use planning might not allow for replacing the current volume with a comparable or larger volume on the plot. Retaining property is then often the best option to maximise lettable floor area (Douglas, 2002; Ebbert, 2010).

Third, the feasibility of the actual building works is important. The plot might not allow for large (de)construction activities or storage of building materials. Refurbishment activities can take up less space than replacement, but more importantly: they often take less time. In the best case, the building has no users and is empty. If not, relocating the users can cost much time and money. However, relocation is sometimes necessary in both refurbishment and replacement. Refurbishment is more flexible and can sometimes take place while the building is in use (Douglas, 2002; Ebbert, 2010; Power, 2008).

Nonetheless, Figure 8 and Figure 9 also lists a few factors that are no longer valid. The financial crisis for instance is of less importance, IT systems are more easily relocated and the life span of technical components is of less importance as components are more easily dismantled and reused by urban mining companies.

Demolition is still often preferred over refurbishment. It is an easy and effective way of reducing energy consumption and damaged building components. Demolition also allows for building a new building with better layout, insulation and installations (Konstantinou, 2014). Additionally, the quality of the building components can be so poor that demolition seems the only option. The building can for instance have non-repairable structural problems. At the moment that is not the case in The Netherlands (Ebbert, 2010). However, it is expected that the demolition rate will go up over the next decades, because the condition of buildings from post-war buildings will then be insufficient (BPIE, 2013). These have been built with poor materials and suffer from deterioration (Ebbert, 2010; Konstantinou, 2014).

Moreover, not all building layouts allow for a feasible (i.e. viable, practical, useful) refurbishment. A refurbishment is a series of compromises and cannot always overcome all problems. Toxic materials, inefficiently wide hallways and inadequate ceiling height are hard to overcome (Douglas, 2002).

Often the most important factor for a feasible project is viability, i.e. economic feasibility (Douglas, 2002). If the costs of a replacement exceed those of a refurbishment, owners tend to choose the last. When calculating the costs, one should look at construction costs, operational costs and material value. Especially a calculation of the energy consumption that can be taken down in comparison to the amount of energy which has to be added is of importance. For instance, adding a thick layer of insulation might save operational energy, but if it took more energy to produce than that it saves and it is impossible to reuse or recycle, it might not be worth it (Douglas, 2002; Power, 2008).

From a logical point of view a refurbishment should be cheaper, because the majority of the building is already in place. Especially the larger expenses, like the foundation, structure and ground works, are already made. Also, a refurbishment process is generally faster than a replacement. But, the building might be complicated of shape and not result in the same energy consumption, adding to the design and construction costs (Douglas, 2002; Ebbert, 2013).

EMBODIED ENERGY

The above-mentioned pros and cons are very practical. However, when we zoom out to global scale, we cannot ignore the fact that the depletion and energy consumption are a serious issue. To improve the world by reducing negative aspects of the building industry, we should make buildings that consume as little as possible energy and materials during operational phases and (re)making. To accomplish that, we should look at the embodied energy, not just the practical pros and cons.

"Renovation, repair and upgrading will remain by far the most significant contributors to progress in energy efficiency and environmental protection for the foreseeable future (Power, 2008, p. 4496)". "It reduces both energy consumption and generation of waste. It minimizes the need for using up fresh material resources and energy required in producing and transporting them (Douglas, 2002, pp. 37–38)".

Demolition is a waste of energy and should be avoided, because buildings store energy in the materials they are built with. Buildings can be seen as warehouses with materials, to which you sometimes add and sometimes subtract components. As the life cycle of components in a building vary, taking them out all at once (demolition) is a waste of capital. Continuously adapting a building is a better approach (Crawford, 2011; Douglas, 2002; Ebbert, 2013; Konstantinou, 2014; Power, 2008).

A recent study by Weiler, Harter & Eicker (2016) underlines this. The study researched the energetic difference between refurbishing and replacing a multi-family dwelling. By making Life Cycle Analyses of four types of dwellings, they were able to compare the embodied energy and emissions. The four types were (Weiler et al., 2016, pp. 321–322):

- Multi family house constructed in 1975 as an existing building with no refurbishment
- Multi family house constructed in 1975 with medium refurbishment; building corresponds roughly to a standard between KfW70 and KfW100
- Multi family house constructed in 1975 with advanced refurbishment; building corresponds roughly to a passive house standard
- Multi family house, newly constructed in 2016 with KfW70 standard

The construction, operational phase and demolition were considered. It was concluded that the highest building refurbishment standard led to the best life cycle energy lowest embodied energy and emission performance. A less ambitious refurbishment or new build performed worse.

In conclusion, it is best to refurbish buildings, but in some projects the defects are not to overcome. In that case demolition is allowed.

3.4.TYPES OF BUILDING ADAPTATION

Over time many lists of possible building adaptations have been made. This thesis mainly discusses refurbishment but it is relevant to know how it differs from other adaptations. This chapter offers a definition of refurbishment as well as its correlation to other adaptions. In general, refurbishment means enhancing the quality of something. “In the context of a building, it primarily involves extensive maintenance and repairs as well as some improvement to bring it up to modern standards (Douglas, 2002, p. 2)”. There is a wide variety in types of building adaptation. Depending on the type, different architectural results and energy savings can be achieved.

Douglas (2002) defines four intervention categories: maintenance, consolidation, stabilization and reconstruction. Figure 10 shows there is a link between the level of intervention and the level of obsolescence. The more obsolescent the building is, the higher the level of intervention that is required. In this definition, refurbishment is categorised in the category consolidation, whereas definitions of other authors describe activities in category 3 and 4.

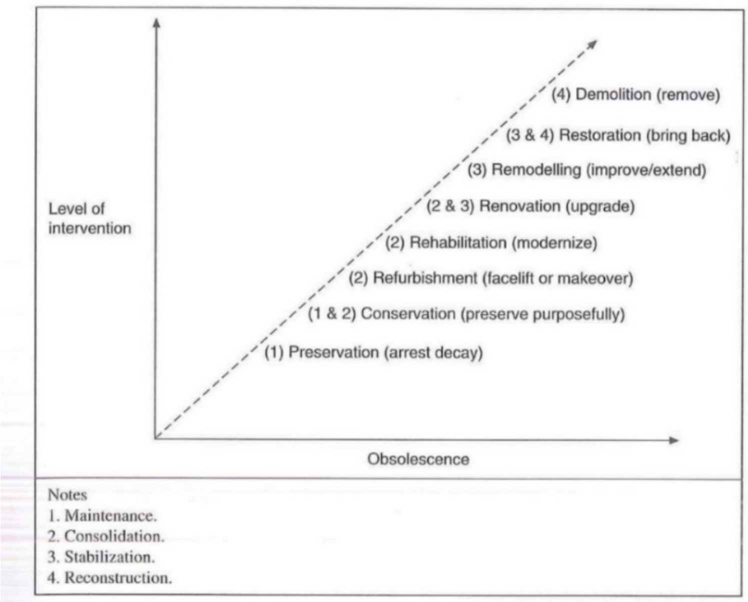


Figure 1.1 Range of interventions

Figure 10: Range of interventions (Douglas, 2002, fig. 1.1)

The definitions that will be used in this report are shown in Figure 11. It combines knowledge of different authors and sorts the interventions by size. This is dependent of how much of the existing condition (structure, appearance, architectural concept) is changed.

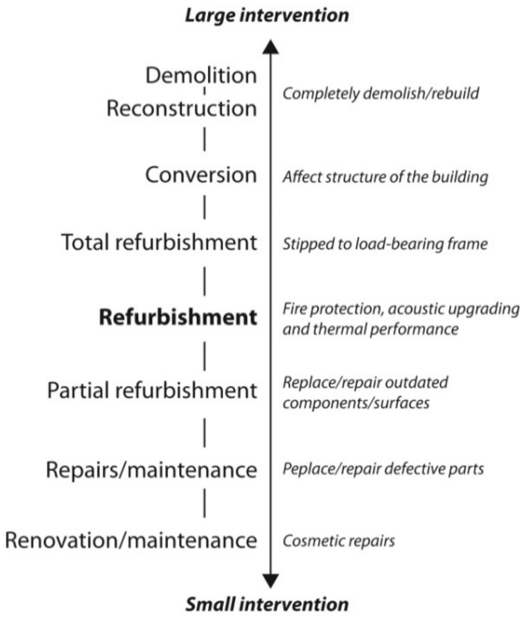


Figure 11: Different intervention levels (Loussos, 2013, fig. 2.1) based on (Giebeler, Krause, Fisch, Musso, & Lenz, 2009; Konstantinou, 2014)

Figure 11 is quite explanatory and only needs some clarifications (Giebeler et al., 2009; Konstantinou, 2014; Loussos, 2013):

- Demolition – Reconstruction: this covers the before mentioned intervention 'Replacement'. A building is demolished (or deconstructed) in order to build something new or rebuild a similar building.
- Total refurbishment: this covers stripping a building to its carcase and completely upgrading it to modern requirements.
- Refurbishment: this covers improving a building or autonomous part without going as far as stripping to carcase. "Any demolition work necessary is mostly limited to surfaces or preparatory work for upgrading fire protection, noise control or thermal performances (Giebeler et al., 2009, p. 13)".
- Partial refurbishment: this covers refurbishing only one component or part of the building (e.g. a staircase, roof or fire protection). In partial refurbishment, it is common that the building is still in use during the works.

Deconstruction is not part of this intervention list, but is discussed in this thesis. It is significant to note that it is of substantial difference to demolition. Douglas (2002) defines deconstruction as planned demolition of vacant properties or blocks to cure urban problems. However, this is in fact the same as demolition, only with a positive connotation. In this report deconstruction stands for carefully taking apart a building in order to preserve materials and its embodied energy best as possible. In a demolition, the aim is to take down the building as effectively as possible and considering the materials to be waste. The driving factor in demolition is time and the driving factor in deconstruction is value.

3.5.TYPES OF MATERIAL CYCLES

In all of the above-mentioned levels of adaptation, from maintenance to demolition, waste is generated. This is called Construction & Demolition Waste (CDW) and makes up over 40% of all waste in The Netherlands (Deloitte, 2015). To decrease the amount of waste that is produced and improve the reusability, many guidelines have been developed over the years.

These guidelines, or waste hierarchy's, have their origin in different fields (e.g. waste management, Circular Economy and Life Cycle Analysis). For instance, the Waste Framework Directive defined a hierarchy, the Ellen MacArthur Foundation published the 'butterfly diagram' and Winkler (2010) set up a LEED-based toolkit. These organisations use comparable terminology for material cycles (Table 3). For instance, reduce, maintain and prevention have the same meaning: prevent the waste from being generated.

Table 3: Comparison between different waste approaches

Toolkit (Winkler, 2010)	**Butterfly Diagram** (Ellen MacArthur Foundation, 2013)	**Waste Hierarchy** (Deloitte, 2015)	**Lansink's Ladder - The Waste Hierarchy** (Deloitte, 2015)
Reduce	Maintain	Prevention	Prevention
Reuse	Reuse/redistribute	Preparing for re-use	Re-use
Recycle	Refurbish/remanufacture	Recycling	Recycling
Return	Recycle	Recovery, e.g. energy recovery	Recovery
Reprocess	Energy recovery	Disposal, e.g. landfill	Energy recovery
	Landfill		Incineration
			Landfilling

The system diagram presented by the Ellen MacArthur Foundation, an organisation promoting Circular Economy, describes not only the technical cycle, but also the biological attribute of the waste (Figure 12). This is because of the development in waste management. "Most waste products of former times were of biological nature. This was about to change with the rise of the industrial revolution. The composition of solid municipal waste changed dramatically during the 19th and 20th centuries (Hebel, Wisniewska, & Heisel, 2014, p. 13)".

The system diagram (Figure 12), also called the butterfly diagram, best explains the 'value circles' that the Circular Economy strives for. The butterfly diagram consists of biological circles (left) and technical circles (right).

The system is based on three principles:

1. minimize what enters the system (depletion)
2. maximize looping

3. minimize what leaves the system (landfill and incineration)

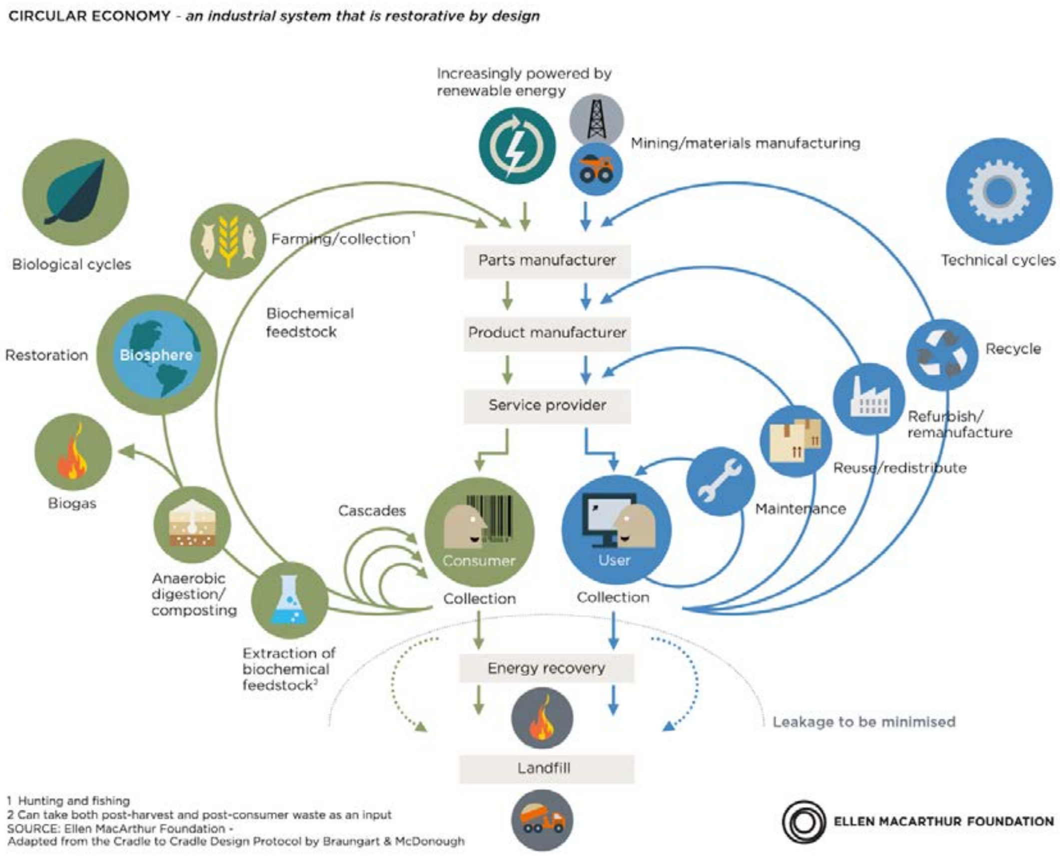


Figure 12: Circular Economy System Diagram (Ellen MacArthur Foundation)

In reality, recycling often comes down to downcycling (i.e. cascading). This is a reduction in quality of a material, as it gets more contaminated with other materials over time. For most materials, the original purity can no longer be achieved. These cycles can be seen in the butterfly diagram. Products and materials are better to be preserved, because then the least amount of energy and quality are lost. This is the smallest circle in the diagram. Redistribute, in its turn, is presented as a larger circle. This is because redistribution consumes more energy (for deconstruction, transport and assembly). The larger the circles in this diagram, the more energy is needed.

Processes that can occur in such a loop are: dismantling, sorting, crushing, compacting, pelletising, drying, shredding, conditioning, repackaging, separating, blending or mixing (European Parliament, 2010, p. 33).

EMBODIED ENERGY

Embodied energy is the total quantity of energy that is required to produce, supply, and install a material (initial embodied energy). Additionally, the amount of energy that is required to maintain the material can also be added (recurring embodied energy). This happens in a Life-Cycle Analysis, where both the initial and recurring embodied energy are taken into account (Rauf & Crawford, 2015) Embodied energy is often expressed in both energy (MJ per kg) and Greenhouse Gases (kg CO2 per kg material).

Figure 13: Lansink's ladder - The Waste Hierarchy (Recycling.nl, 2017)

A few terms in the butterfly diagram and waste hierarchy proposed by Lansink in Figure 13 need clarification (European Parliament, 2010).

Table 4: Definitions in waste management

Recycling		reprocessing waste materials into products, materials or substances whether for the original or other purposes
Recovery		includes incineration and backfilling
	Energy recovery	thermal treatment (combustion) of waste to generate energy
	Incineration	thermal treatment (combustion) of waste to generate energy
	Backfilling	a recovery operation in which waste is used to fill excavated areas or used for landscaping and substitutes non-waste materials
Disposal		includes landfilling, incineration with low energy recovery and injection into land
	Landfilling	burial of waste underground

The categories recovery and disposal can best be avoided, because they include operations that are a pure waste of energy.

COMPOSITION OF CDW

Construction & Demolition Waste includes waste that is released during the build or adaptation of buildings, roads and waterworks. The majority of CDW consists of concrete and stony waste (Deloitte, 2015). It includes all the below mentioned types:

- Asbestos and waste which contains asbestos
- Dredging
- Aerated concrete
- Roof waste
- Mixed CDW and mixed fractions
- Separately collected glass
- Gypsum
- Fiber optic cables
- Wood
- Other mono streams
- Paper- or plastic insulated cables and remnants
- Materials containing stone
- Grit
- Tar-containing asphalt
- Contaminated soil
- Packaging of paint, adhesive, sealant and resin
- Sieve sand

The recycling percentage of The Netherlands is high compared to other European countries. Especially the experience with treatment of stony materials is well developed, because of a lack of space in the country. CDW is often used for road construction. However, most concrete and masonry fractions that are used for road construction are down-cycled and only a small percentage is reused (BAMB, 2016).

Over the past years, the amount of Construction & Demolition Waste (CDW) in The Netherlands has grown to 80 Mt in 2012. Almost 70% of this amount is soils and dredging spoils (Table 5). These two categories include for instance the displacement of sand or dredging activities. The most common waste types are dredging spoils, mineral waste, soils and wood wastes (BAMB, 2016; Deloitte, 2015).

Table 5: CDW waste per type in tonnes (Deloitte, 2015, p. 22)

CDW waste type	2012
Glass wastes	48,543
Plastic wastes	34,091
Wood wastes	1,321,587
Waste containing PCB	76
Mixed and undifferentiated materials	11,870
Soils	6,494,428
Metal wastes, ferrous	701,882

Metal wastes, non-ferrous	163,898
Metal wastes, mixed ferrous and non-ferrous	74,758
Mineral waste from construction and demolition	21,150,419
Dredging spoils	49,150,419
Other Mineral wastes (W122+W123+W125)	380,619
Total	**80,237,326**

Table 6**Fout! Verwijzingsbron niet gevonden.** shows the growth of CDW streams in The Netherlands between 2006 and 2012. These numbers exclude soils and dredging spoils. It is expected that the amount of CDW waste will increase to 31 Mt in 2021 (Deloitte, 2015). Most of the recycled content consists of concrete aggregates, which is mainly used for roads.

Table 6: CDW generation and recovery official statistics in tonnes (Deloitte, 2015, p. 20)

Year	2006	2007	2008	2009	2010	2011	2012	2013
Generated (Kt)	24,457	24,147	25,303	25,176	24,528	24,410	25,706	NA
Recycling (Kt)	21,627	22,772	23,864	23,052	23,034	24,249	24,249	NA
Energy (Kt)	362	435	607	805	923	964	944	NA
Recovery (Kt)	1,174	28	13	1	12	2	3	NA
Incineration (Kt)	115	35	27	43	64	25	16	NA
Landfill (Kt)	1,169	820	745	659	455	367	477	NA
Disposal and unknown (Kt)	11	57	47	59	22	18	16	NA
Other removal (Kt)	0,029	0,003	0,003	0,002	0.002	0.002	0.002	NA

The waste hierarchy, as discussed in previous sections is used by the Dutch government to improve the quality of waste as much as possible. Looking at the figures, this seems to be working: the amount of waste in the categories Recovery, Incineration and Landfill has decreased, while the percentage of recycled waste has increased. However, the total amount of generated waste has increased.

For years, waste has been put in to landfills as it was a simple and economical solution. In the 1980s and 1990s, the view on waste finally changed and recycling became a point of attention. People started to understand that waste did not only contain valueless material, but could be used a source for new materials and be economically feasible (Hebel et al., 2014).

To maximise those gains, products should be designed in such a way that they can be part of continuous material cycles. Downcycling should be avoided as much as possible and waste leaving the cycles even more so. In recent years, the understanding that the current products do not recycle well has gained terrain. They are not designed to be reused or recycled (Hebel et al., 2014). “Dedicated design for repurposing, reuse and remanufacturing will significantly lower the amount of C&D waste (BAMB, 2016, p. 71)”. By changing the design process, both the amount of generated waste as the recyclability of waste can be improved. To accomplish this, all disciplines in the building industry (e.g. waste management, urban design, construction, architecture, engineering) must design circular products and processes. Through this, the built environment can slowly be transformed.

URBAN MINING / DECONSTRUCTION

A great deal needs to be done to transform the existing stock into buildings that are;

- easily deconstructed;
- only contain recyclable materials;
- and consume as less as possible.

The current new build rate in The Netherlands of 55.000 a year is not going to be sufficient to decrease the energy consumption of the Built Environment (CBS, 2017b). Therefore, it is best to focus on refurbishments. However, a new method of recovering materials and components has become feasible in recent years. This method is called ‘urban mining’ and is best explained as the process of recovering materials from our surroundings.

The materials can be windows of a to be demolished building, rare metals in a landfill or in mobile phones. Since the 1980s, landfills have been mined for economically feasible products. By now that has shifted to mining products and buildings, because landfills have been emptied over the years, material costs have become higher and scarcity has increased. Additionally, products like mobile phones are mined for their metals (Hebel et al., 2014; Kohler, König, Kreissig, & Lützkendorf, 2010).

A building can be demolished, but it can also be deconstructed. That way, the reclaimed components are not down-cycled as much as in a demolition and more money can be made on the products. It takes more labour to have the same result, but has proven to be a feasible case. “The strategic objective of every deconstruction is to ensure the highest possible level of subsequent reuse for all components, the minimisation of losses during deconstruction, transport and reinstallation and to control the risks of the whole demolition process […](Kohler et al., 2010, p. 29)”.

In the Netherlands, a rising number of companies has emerged in mining end-of-life buildings. These companies claim to recycle the buildings up to 97%. The level of deconstruction varies from stripping to handing back a clean building site.

Although it is a big improvement in comparison to demolition, it also bears the risk that perfectly fine buildings get demolished because the business case is simply feasible. Whereas demolition of a building used to only cost money, it can be profitable. A building that has been vacant for five years, but has ten-year-old windows might be demolished.

Nonetheless, the refurbishment rate in The Netherlands has to increase to accomplish energy targets. The low-hanging fruit has already been picked in order to achieve the 2020 targets. When this refurbishment rate goes up, more building components will be replaced and can be mined. This will slowly lead to a circular and adaptable building stock. Also, the end-of-life of certain components of post-war buildings is approaching, which will give a bulk of to be recycled materials.

RECYCLING PLANS

Urban mining takes careful preparation and covers a large spectrum of activities. The better the plan, the higher the quality of the salvaged materials and revenues. Therefore, it is best to understand how this process can best be executed.

The most important part of a demolition plan is the sequence of deconstruction, because executing it in the wrong order can lead to unpractical working conditions and a decreased value (BAMB, 2016; Kohler et al., 2010; Winkler, 2010). Taking off the roof coverings after deconstructing the load bearing frame is for instance not practical. Figure 14 provides insight in the order at which components can be taken out. The order is based on 1) practicality and 2) the hierarchy of material cycles. For example, reuse comes before recovery.

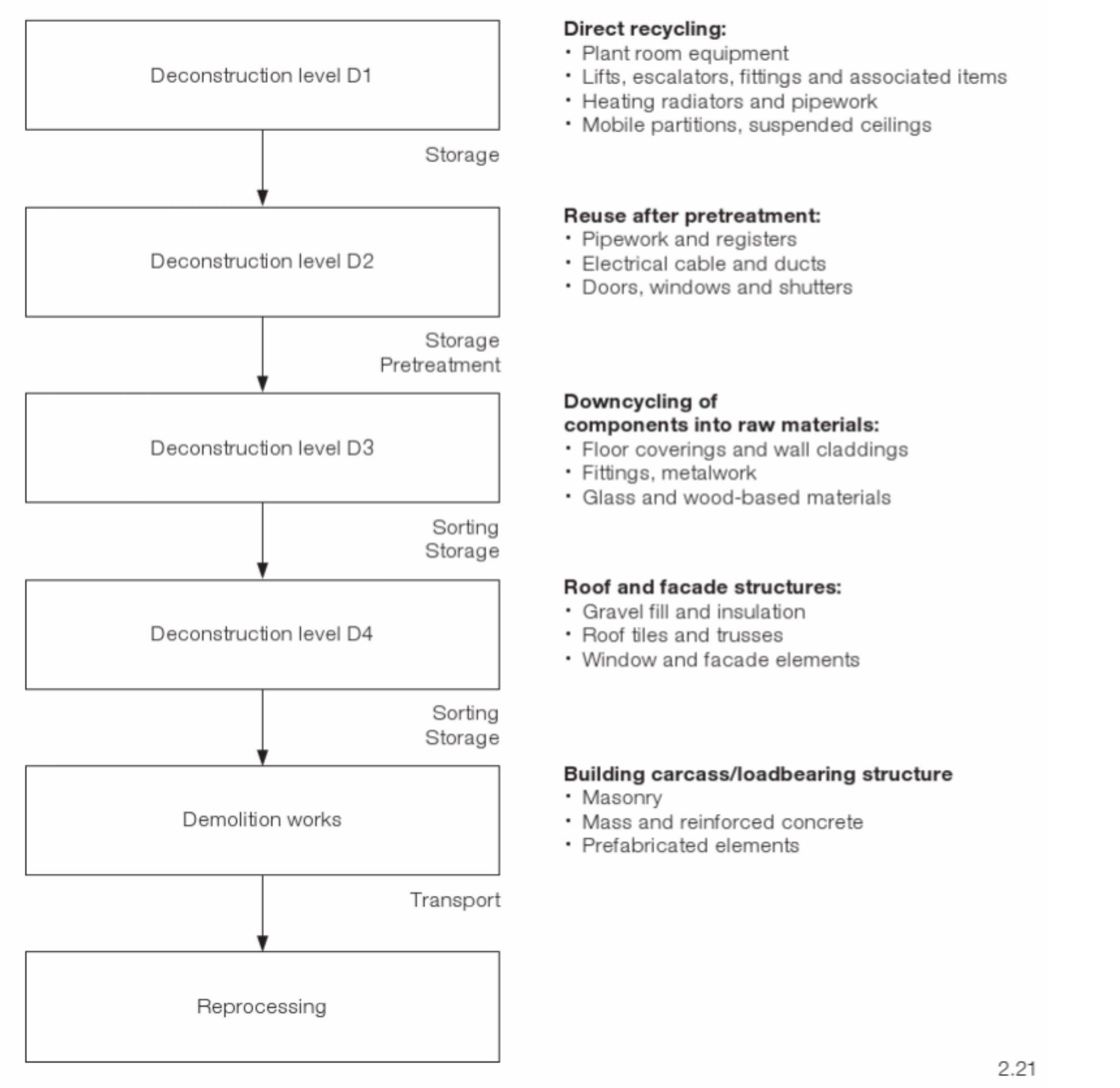


Figure 14: Building deconstruction levels (Kohler et al., 2010, fig. 2.21)

It is best to start with individual, free standing components like radiators, cable gutters, suspended ceilings and even stairs. These items can be reused for the same function, possibly even on site. Then, one can work with the items which are reusable after pre-treatment like electrical wiring, doors and water taps. Windows also belong to this category, but are often difficult to reuse as the insulation values do not meet current requirements. In deconstruction level 3 the building is stripped from architectural finishes like wall claddings, carpet and metalwork. These components are often down-cycled or processed in to raw low-grade materials. The elements in 'Deconstruction level 4' are bulk and specialist products. These include reusable materials like gravel and roof tiles, but also insulation batts. After this stage, the building is almost stripped to carcase. The load-bearing structure of the building often tends to be hard to take apart (e.g. like in-situ concrete). Prefabricated concrete panels are easier, but are often mounted with in-situ concrete. Steel structures are often one-of a kind. This does not improve the reusability. Concrete can often be crushed and mixed into new concrete (Kohler et al., 2010).

In order to get to the above-mentioned demolition sequence, a feasible plan must be made. This plan includes the profitability, monitoring, procedures and marketability. An integrated demolition plan can highly increase the quality of recycled products. In order to get to an integrated plan, it is necessary to get all actors (e.g. architect, demolition contractor, recycler) on board (Hebel et al., 2014; Winkler, 2010).

There are several approaches for developing a demolition approach. Winkler (2010) has defined an extensive approach worth reading in: 'Winkler, G. (2010). Recycling Construction & Demolition Waste: A LEED-Based Toolkit. McGraw Hill Professional.' The summary of this approach is listed below.

The Recycling Method (Winkler, 2010, p. 16):

1. Identify recycled products
2. Choose a recycling method
3. Select (local) recyclers
4. Estimate the savings
5. Train subcontractors
6. Monitor the program
7. Calculate final values

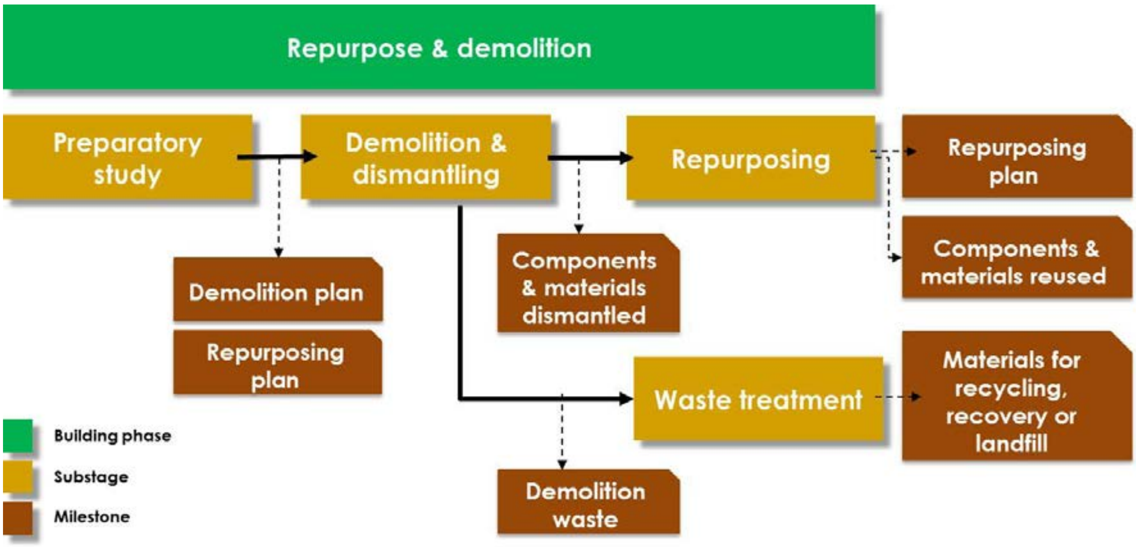


Figure 15: (BAMB, 2016, fig. 22)

The repurpose & demolition plan can be subdivided (BAMB, 2016; Kohler et al., 2010; Winkler, 2010):

- Preparatory study: In this phase, the building's components are identified, quantified and evaluated. Toxic materials and structural risks should also be evaluated. Before entering the next phase, the economic feasibility has to be agreed upon.
  - Demolition plan: sequence of demolition phases, cost and planning.
  - Repurposing plan: desired recycling goals, desired component size, type of separation (at source or single-stream) and repurposing plan per material.
- Demolition and dismantling: dismantling according to a demolition sequence.
- Repurposing: Recycling (e.g. reuse, redistribute) of materials and components in other projects.
- Waste treatment: sorting and recycling of CDW

3.6.BUILDING ANALYSIS

The complex nature of buildings makes it essential to conduct a thorough building analysis. Especially in refurbishments, considering the physical and spatial context of the building is vital and can significantly improve the success of a refurbishment. The analysis should be conducted very systematically to minimise the number of errors. For that, a step-to-step approach is best (Ebbert, 2013; Noy & Douglas, 2005).

A thorough building analysis comprehends many topics, including: motivation, method of construction, architectural significance, morphology, physical condition and adaptation potential. For that, a variety of information is required, including: drawings, user profiles, photographs, material choice, energy bills, operation cost, location, future plans, weaknesses and strengths. This information can be found in various sources and gathering the information can take much time. Therefore a step-to-step approach is advised (Douglas, 2002; Ebbert, 2013).

According to Douglas (2002, pp. 67–70), the following stages should be passed:

- Inception: a rigorous evaluation of the client's requirements
- Reconnaissance: establishing the physical and spatial context
- Feasibility: checks economic, technical and legal implications
- Desk-top survey: property documents, planning applications, geological maps
- On-site survey
- Structural appraisal: inspection of loadbearing elements
- Diagnostic survey
- Evaluation of options
- Proposals

At the end of these phases, the building can finally be best understood (Douglas, 2002). In addition to that, Ebbert (2010) set up an extensive checklist that can be used in several of the above-mentioned phases. The full checklist can be found in Appendix 14.2. Considering a refurbishment proposal for a building at the TU Delft, the following plan has been developed:

1. Inventory of general data with use of the checklist
2. Photographs
3. User interviews to establish strengths, weaknesses and client wishes.
4. Occupancy schedules
5. Energy consumption
6. Architectural building analysis including analytical drawings
7. Calculate current quality of facades
8. Inventory of present materials

3.7. NET-ZERO ENERGY BUILDING

The aim of this thesis project is to design a net-zero energy building. In short, a net-zero energy building is a building that consumes about the same amount of energy as it produces. A net-zero energy building has an energy use of 0 kWh/(m^2a) primary energy per year (Torcellini, Pless, Deru, & Crawley, 2006).

Σ (adding factors) - Σ (subtracting factors) / Δ time = 0 (Conci, 2014, p. 14)

Synonyms for net-zero energy building (NZEB) include: energy neutral building, zero-energy building (ZEB), net zero building. And in Dutch: energieneutraal (Rijksdienst voor Ondernemend Nederland, 2017). A NZEB should not be confused with a nearly-zero energy building (nZEB). These are buildings that are almost net-zero. The EU aims to increase the amount of nZEB buildings and national plans have been drawn up. In Dutch, the term BENG (Bijna EnergieNeutrale Gebouwen) is more common (DGMR, 2015).

Both a new construction and a refurbishment can be designed as a NZEB, although it is more difficult to accomplish this in a refurbishment. The reason for this is that the main parameters (location orientation, and construction) are already fixed (Konstantinou & Knaack, 2013).

Usually, a NZEB is connected to the electricity grid. When the renewable production on site is larger than the consumption, the building exports electricity to the grid. And when the generation is smaller than the consumption, vice versa. The consumed electricity thus consists of both renewable and non-renewable electricity as it comes off the grid (Crawley, Pless, & Torcellini, 2009).

There are different types of net-zero energy buildings. The National Renewable Energy Laboratory of the U.S. Department of Energy has defined a number of definitions and classifications (Table 7 and Figure 16). The main difference between these types is the focus (e.g. energy, cost or emissions).

Table 7: Definitions of NZEB

NET ZERO SITE ENERGY	ALSO NAMED: SITE NZEB
Produces at least as much energy as it consumes. The amount of generated renewable energy is similar or larger than the amount that is taken of the grid and is measured at the building site.	
NET ZERO SOURCE ENERGY	**ALSO NAMED: SOURCE NZEB**
Produces as much energy as it consumes. The amount of generated renewable energy is larger than the amount that is consumed, such that after taking efficiency and transport losses in account, the net energy use of the building is (smaller than) zero. The generated amount is measured at the source (e.g. power plant, windmill) and counts the primary energy that is used to make and transport the energy to the site. Therefore, the amount of renewable energy generated at the site is larger than in a site NZEB. For this, so called site-to-source indicators are used.	
NET ZERO EMISSIONS	
Focuses on compensating for the pollution of emission-producing energy sources (e.g. carbon oxides, nitrogen oxides and sulphur oxides), by producing emission-free renewable energy. In order to achieve this, so called emission multipliers are used. If the imported energy comes from an off-site zero emissions source (see below), compensation is not necessary.	
NET ZERO ENERGY COSTS	**ALSO NAMED: COST NZEB**
The production is based on the amount of money that would be spent on energy from the grid including taxes and other charges. The amount of money that would be earned by selling the on-site produced renewable energy to the grid equals this cost.	
Two additional definitions that are worth explaining:	
NET OFF-SITE ZERO ENERGY USE	*ALSO: AUTARKIC BUILDING*
Produces at least as much energy as it consumes. However, it is not connected to the normal electricity grid because it only consumes renewable energy. It is part of a smart grid, because the normal grid delivers a mixture of non-renewable and renewable electricity.	
OFF THE GRID	
Is not connected to the grid, but stores its energy locally. The production is less efficient than connected buildings as it cannot benefit from mass production and has to compensate for its own peak loads.	

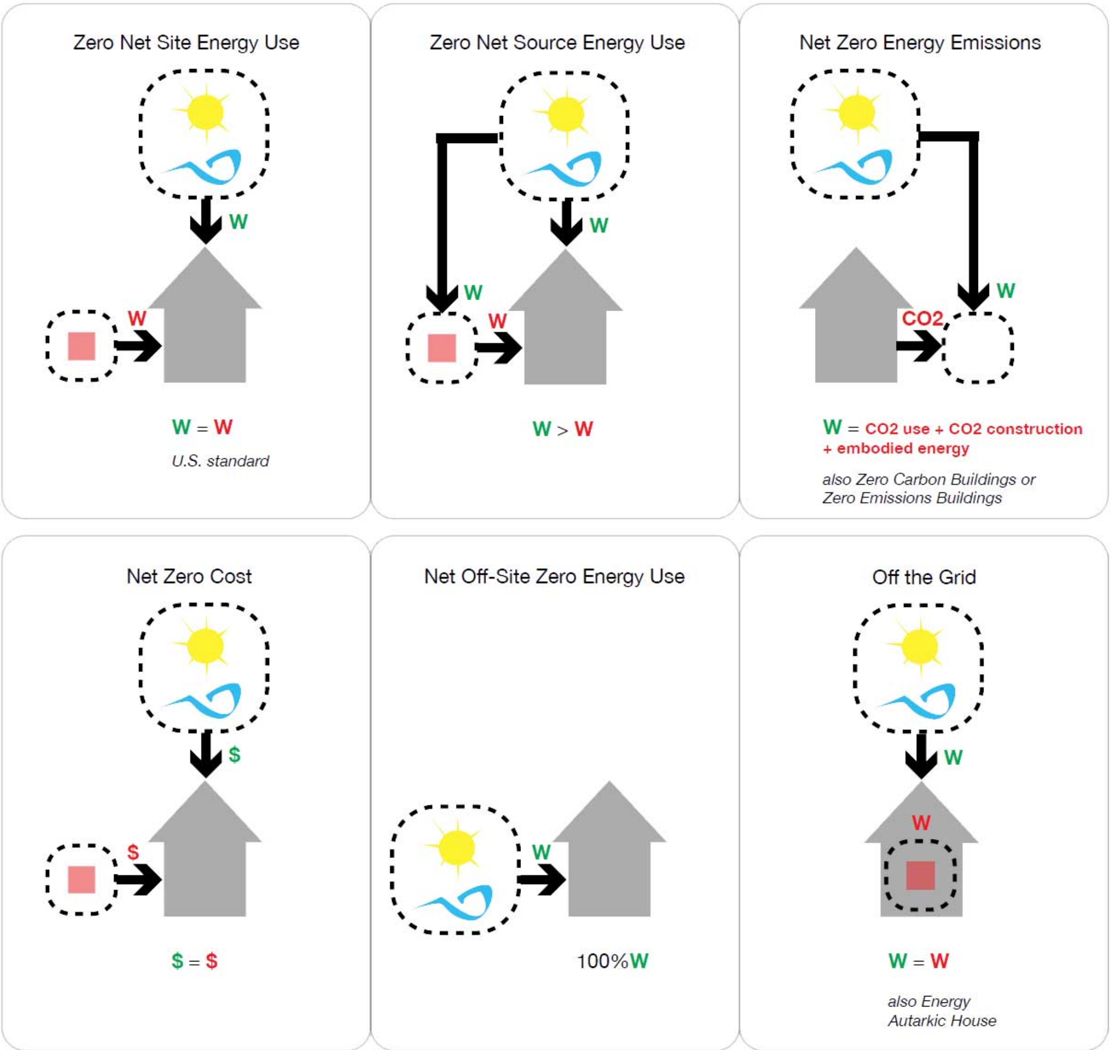


Figure 16: NZEB definitions (Conci, 2014; Torcellini et al., 2006)

The above-mentioned definitions mainly differ from each other in accounting method. The difference is in the amount of energy that should be produced to compensate. The NREL also classifies the source of the generated energy. Generation by photovoltaic panels on the building's roof is surely not the same as investing in a windmill at sea. Table 8 shows the four classifications.

Overall, the first step in designing a NZEB is limiting the energy usage and reusing waste streams. Then, the type of energy source can be designed and classified. In this classification, renewable-energy stands for electricity, warm water and preheated air.

Table 8: NZEB classifications

NZEB:A	ALSO NAMED: OPTION 1
Generate renewable energy within the building footprint	

NZEB:B	ALSO NAMED: OPTION 2
Generate renewable energy within the building footprint and site footprint	

NZEB:C	ALSO NAMED: OPTION 3
Generate as much renewable energy on site as possible (option 1 and 2) and combine that with imported off-site materials or rest streams to generate the additional renewable energy on-site. For example, biomass or ethanol.	

NZEB:D	ALSO NAMED: OPTION 4
Generate as much renewable energy on site as possible (option 1, 2 and 3) and combine that with purchasing (investing in) off-site renewable energy. For example, a wind park at sea. The energy that is bought is brought into the grid and the building uses mixed energy.	

Not all definitions and classification can be combined and be feasible in a NZEB. The main reason for this are fluctuating energy prices and emission multipliers (Pless & Torcellini, 2010). Figure 17 shows possible and feasible combinations.

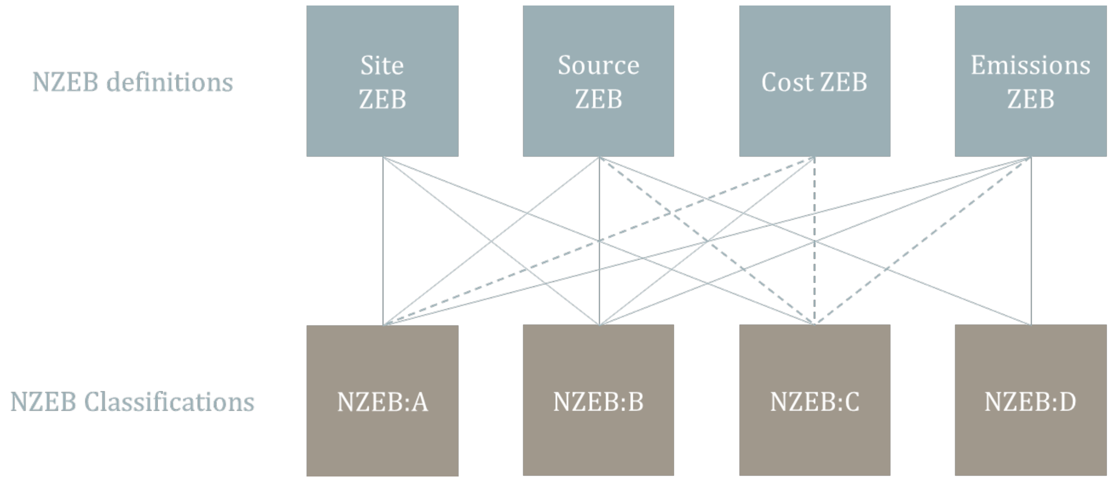


Figure 17: Possibilities to combine the definitions and classifications for NZEB. The dotted lines represent possible but difficult to accomplish combinations.

3.8.THE THREE AND NEW STEPPED STRATEGY

For several decades, the 'Trias Energetica' (Lysen, 1996), or three stepped strategy was used in designing sustainable buildings. This strategy is composed of three steps: 1. Reduce the demand, 2. Use renewable energy, 3. Supply the remaining demand cleanly and efficiently (Van den Dobbelsteen & Tillie, 2011).

This framework did not lead to the required transformation and energy generation in the Built Environment. Therefore, Van den Dobbelsteen (2008) presented the New Stepped Strategy (NSS) as a substitute for the Trias Energetica (Figure 18). The main differences are that fossil energy is no longer considered to be an option for energy generation, and that waste streams (e.g. water, heat, materials) are now considered in the system.

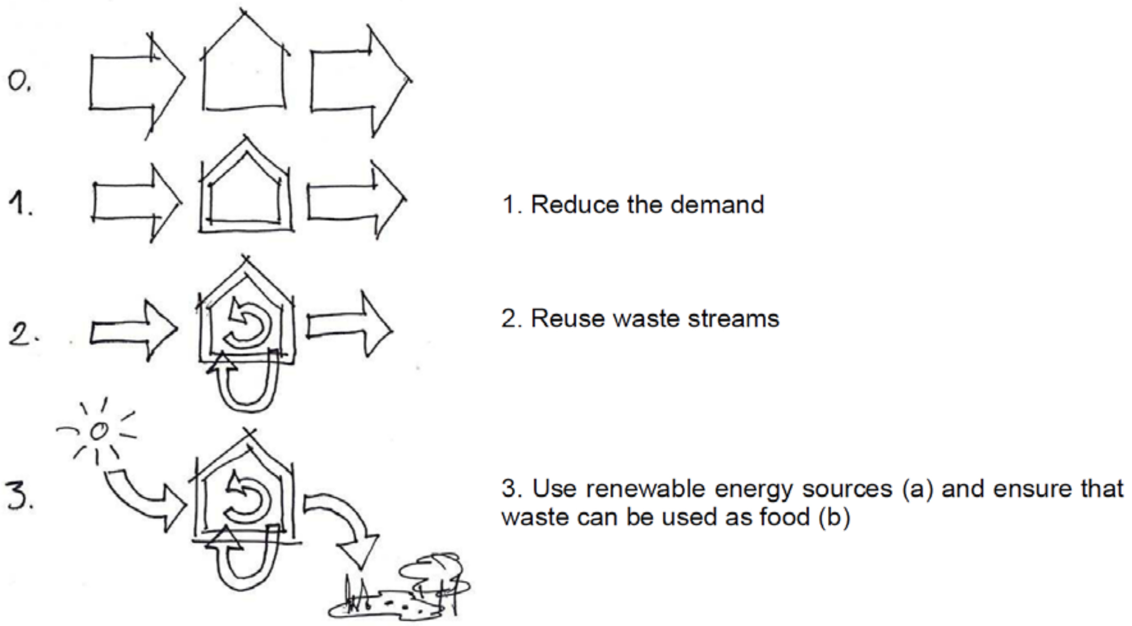


Figure 18: Principle of the New Stepped Strategy (Van den Dobbelsteen, 2008) Step 3 is split in two parts, a and b.

The first step in the NSS is to reduce the demand. This means reducing the energy that a building consumes. Energy consumption can be divided into three categories: building-based, usage-based and material-related energy. In all three types, a reduction can be realised.

The biggest reduction in building-based energy consumption can be made by improving the building skin. A simple step is increasing the thermal resistance of the building skin (both façade and openings). But the higher the thermal resistance (R-value), the more important the infiltration factor becomes (Loussos, 2013).

Usage-based energy involves the behaviour of occupants. For instance, users can accept and adjust to higher and lower room temperatures. Also, the consumption can be changed by adjusting the working hours. Working shorter in winter to save energy for lighting and heating, for instance.

Concerning material-related energy, it is best to preserve materials and material flows. This can be done by leaving as much intact as possible of the existing building, reusing components on site and choosing new materials with care (e.g. low embodied energy, locally produced, reusable) (Crawford, 2011).

Other ways to reduce the consumption are:

- Increase the thermal resistance
- Decrease air infiltration
- Implement heat mitigating principles
- Design compact buildings
- Use passive design principles
- Use passive measures
- Change user behaviour
- Keep existing structures
- Limit material consumption

There are three commonly used energy saving levels for renovations (BPIE, 2013):

- Shallow, i.e. savings up to 30% of the original energy consumption
- Deep, i.e. savings up to 60% of the original energy consumption
- nZEB, i.e. savings over 90% of the original energy consumption

At the moment, shallow renovations are executed most. These superficial energy savings will contribute, but not enough to meet climate targets (BPIE, 2013). In order to bring the building stock to the desired level, it is necessary to execute deep renovations. This is the best solution, both from an ecological and economical perspective (Konstantinou, 2014).

Table 9 gives an overview of for current regulations in The Netherlands (Bouwbesluit) regarding thermal resistance.

Table 9: Design values for building components (DGMR, 2015; Nieman, 2017; SBRCURnet, 2015)

	Bouwbesluit	**Comfort details**	**Passive house standard**
Ground floor	3,5 m^2K/W	4,0 m^2K/W	7,0 m^2K/W
Facade	4,5 m^2K/W	5,0 m^2K/W	9,0 m^2K/W
Roof	6,0 m^2K/W	6,0 m^2K/W	10,0 m^2K/W
Windows	1,4 W/m^2K SHGC 0.6	-	1,1 W/m^2K SHGC 0.5
Air infiltration	0,6 $dm^3/s.m^2$	0,3 - 0,6 $dm^3/s.m^2$	0,2 $dm^3/s.m^2$

A list of examples for all three NSS steps is given in Table 10.

Table 10: Improvement possibilities or the energy performance by actions for certain components (Loussos, 2013, figs. 2-9)

Improving insulation	
Component	**Action**
Walls, floors, ceilings	Insulation on inside or outside or in cavity
Windows	Double or triple glazing with inert gas filling, coating, insulated frames
Doors	Insulated doors
Cold bridges at junctions and balconies	Careful detailing, external and internal insulation
Ventilation	
Component	Action
Cracks and air paths	Seal cracks, open joints, service entries, unused chimneys
Draught stripping	Draught-stripping doors and windows
Natural ventilation	Passive stack ventilation from kitchens and bathrooms
Mechanical ventilation	Efficient heat recovery
Avoid overheating	
Component	**Action**
Reducing internal heat gains	Insulating pipe work and storage cylinders, efficient electrical equipment
Reducing external heat gains	Solar shading
External landscaping	Trees, vegetation
Use of thermal mass	Internal thermal mass to reduce temperature swings, night ventilation
Adequate ventilation	Cross ventilation
Existing components and new sustainable materials	
Component	**Action**
Existing components	Reuse and restoration of components instead of replacement
New materials	Minimal embodied energy and environmental impact
Domestic hot water	
Component	**Action**
Solar water heating	Solar water system
District of block heating system	Linking to block or district heating, CHP
Gas and oil boilers	Efficient boilers
Heat pumps	Electrical heat pumps with high performance
Direct electric heaters	Small electric heaters for small use
Storage cylinders and pipe work	Insulate storage cylinders, short pipe work
Reducing hot water use	Reduced flow taps
Daylighting, efficient lighting and control systems	
Component	**Action**
Optimizing daylight	New windows and skylights in dark spaces
Light surfaces	Light paint
Efficient lamps and luminaries	LED
Switching	Individual switching, dimmer controls, sensors
Efficient appliances and controls	
Component	**Action**
Kitchen and utility equipment	Efficient equipment, gas cooking

The second step of the NSS is to reuse waste streams. Like the material cycles of the Circular Economy, it is essential to make use of waste streams. Not just one building, but a whole network can be connected. In principle, there are three types of waste streams: heat, water and materials. Some examples of these waste streams are:

- Heat of the drainage water from the shower
- Water from sink, toilet or shower.
- Heat from extracted ventilation air
- Cut-offs from construction works

The third step of the NSS consists of two parts: use renewable energy sources and ensure that waste can be used as food. In the previous chapter, the possibilities for generating renewable energy were discussed. According to that classification, the options are: generation within the building footprint, site footprint, off-site and purchasing off-site renewable energy (Pless & Torcellini, 2010).

Renewable energy (RE) is generated in natural processes. These processes are unlimited and can be renewed and repeated. Moreover, they energetically earn themselves back over the course of time. Generation from fossil fuels as well as energy recovery are not renewable. Examples of RE-sources are biomass, soil, sun, water and wind (Broersma, Fremouw, & Van Den Dobbelsteen, 2013; Konstantinou, 2014).

Local generation is preferred in the classification presented in chapter 3.7, but centralised generation also has advantages. A central plant can produce energy with a higher efficiency, produces a steadier output and saves in material consumption (one product instead of single units). It can be adventurous on campus scale, for instance (Parr & Zaretsky, 2011).

The second part of step three is called: ensuring that waste can be used as food. This resembles the Circular Economy, it comes down to: making the materials and components easily available and providing information. This can be done by design for disassembly, standardisation, material passports and BIM.

It is worth mentioning the principles of Biomimicry, as it shares many principles with the NSS (Parr & Zaretsky, 2011, p. 27):

- Diversify and cooperate
- Use waste as a resource
- Gather and use energy efficiently
- Optimize not maximize
- Use materials sparingly
- Clean up, don't pollute
- Do not draw down resources
- Remain in balance with the biosphere
- Run on information
- Use local resources

3.9.CIRCULAR BUILDING MATERIALS

The Circular Economy and the underlying theory has been described in previous chapters. In this chapter, the potential influence of Circular Economy on the Built Environment will be discussed. At the moment, the theory of Circular Economy that is best applicable to the Built Environment are value circles (Figure 19). The main principles of value circles are:

1. minimize what enters the system
2. maximize looping
3. minimize what leaves the system

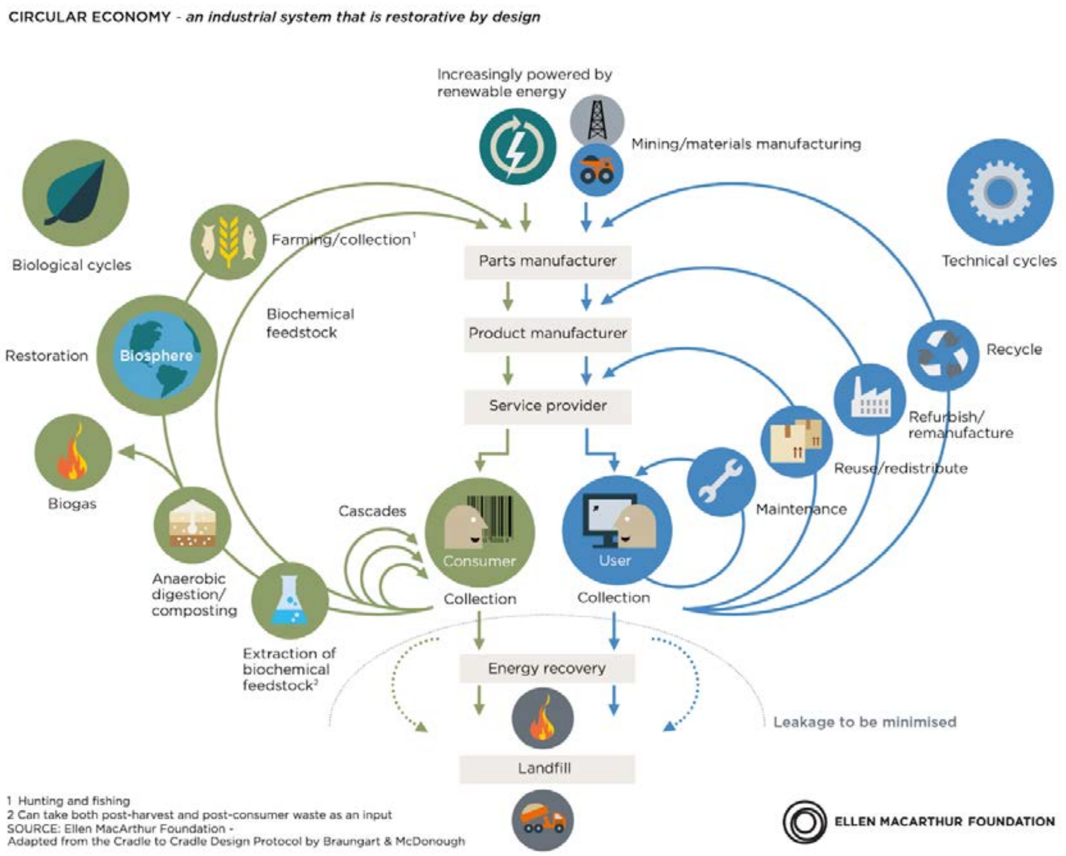


Figure 19: Circular Economy System Diagram (Ellen MacArthur Foundation)

In the Built Environment, this means that we should pursue buildings that (BAMB, 2016; Crawford, 2011; Rau & Oberhuber, 2016; Verhaar, 2014):

- have components for disassembly;
- are adaptable;
- consume as little as possible;
- are built of low impact materials;
- are reusable at the same energy level.

To accomplish this a variety of methods and principles should be used. Table 11 provides an extensive list of strategies.

Table 11: Strategies for improving the environmental performance of the built environment, based on (Crawford, 2011; Loussos, 2013)

Strategy	Aim	Action
Resource efficiency	– Preservation of non-renewable resources – Sustainable consumption of renewable resources – Reduced waste production	– Improving thermal performance building envelope, by designing according to passive design principles (orientation, direct solar gain, artificial lighting, more energy efficient appliances – Upgrade manufacturing equipment to be more efficient, fewer raw materials and less energy and water
Minimize non-renewable resource use	– Preservation of non-renewable resources – Minimized emissions from energy production – Minimize impacts from processing, transportation	– Renewable sources of energy supply – Adapt/replace technologies and practices that rely on the non-renewable resources – Use naturally renewable resources sustainably so it's not depleted – Using local materials – Use of recycled or recyclable materials without compromising the overall performance of the building, by design for recyclability and disassembly
Minimize pollutant releases	– Maximize water, air and soil quality – Preservation ecosystems	– Minimize release of pollutants in every stage of the life cycle, acquiring, processes, manufacturing, disposing, landfill – Cleaner (industrial) production – Eliminating use in materials that result in pollutant releases in any stage of the life cycle.
Design for disassembly	– Preservation of natural resources – Maximized resource value – Reduced waste production	– Use fastening and joining techniques to ease disassembly – Minimizing weight of individual parts – Avoid composite materials, where separation of individual materials is difficult
Minimize (solid) waste production	– Minimize generation of waste associated with the built environment – Minimized landfill – Minimize soil and water contamination – Minimized resource value	– Recovery of waste materials by reuse or recycling – Designing in accordance with standards material dimensions – Waste management plan, controlling production and disposal of waste – Improving efficiency of manufacturing process, maximum raw material use
Design for recyclability	– Preservation of natural resources – Maximized resource value – Reduced waste production	– Make sure the building parts with a short lifetime can be recycled (like finishes) – Design building for easy separation for easy recyclability and reuse – Chose materials according to their recyclability or reusability performance

Design for durability	– Due to resource depletion, preservation of non-renewable resources – Reduce demand for raw materials, energy, water – Reduce waste production	– Long durability, while still maintaining their recyclability and reusability – No over-specification of materials, considering the intended life of the building – Durability depending on function – Good maintenance plan
Design for adaptive use	– Value of resources embodied energy in these elements can be maximized – Reduce demand of natural resources – Reduced demand for raw materials, energy, water – Maximize resource value – Reduce waste production	– Easily accessible service ducts and flexible internal configurations

Most of the above-mentioned strategies can be quantified, including the potential for adaptability and deconstruction. The level of deconstruction can, for instance, be calculated with the BRE Design for Deconstruction methodology. The focus of this methodology lies on the used materials, connection method and potential to be taken apart. Each element gets scores for reuse and recycling potential, accessibility, deconstruction process and connections (BAMB, 2016).

The potential for adaptability of a building can be quantified with use of tolls of BREEAM Netherlands and DGNB. These look at the presence of columns, possible change to interior walls, morphology, load-bearing capacity, building depth and daylight penetration (BAMB, 2016)

MATERIAL CHOICE

Choosing the ideal materials for a building is difficult as there are many variables. “These materials vary in energy use during production, toxic waste or gasses during production and use, recyclability, water use, resource depletion, CO2 emissions and so on” (Verhaar, 2014, p. 7). For instance, a material that scores well on embodied energy and durability can sometimes only be incinerated after use. Or in some cases a product that scores well on all factors has to be transported over long distances. To choose a material and look at the different scores for the above-mentioned aspects, several databases containing Life-Cycle-Analysis results can be used. Examples are: NIBE, CES Edupack, ÖkobauDat and GreenSpec. Unfortunately, there is no database that provides answer to which material can best be used in designing closed value circles (Loussos, 2013; Verhaar, 2014).

3.10. MATERIAL PASSPORTS

A Material Passport is a collection of data on components and materials in a building, enabling circular principles in the Built Environment. This so-called passport is often digital and contains information on, for instance, the material, location, quality, changes, life expectancy and reusability.

NEED FOR MATERIAL PASSPORTS

To close material cycles, the building sector needs to know what buildings, materials and components are stored in buildings. With this knowledge, buildings can be designed for re-use and material value can be recovered. Ideally, this leads to less depletion and material scarcity (BAMB, 2016; Verhaar, 2014).

Not having a Material Passport is a major cause of waste creation. Not having information on the components and materials in a building costs time, value and money. Making an inventory costs time, taking the building apart without knowing how to get it out best costs material value and not having a purpose for the salvaged materials costs money. That while buildings contain a vast amount of stored materials. In fact, buildings should be seen as warehouses. They temporarily store materials, before giving it another life someplace else (BAMB, 2016; Rau & Oberhuber, 2016).

Considering building materials as building parts in a warehouse has an important psychological effect. In life, giving something an identity by providing information on the subject, results in people giving it a higher value. Anonymous things are of lesser value to people. Nowadays, our materials are anonymous. This makes people care less about its origin and future. Labelling materials (and components) by documenting it ensures that the material is put on the map (Rau & Oberhuber, 2016).

A problem in current building practice is that the information on a new buildings design and construction are often not passed on to actors in following phases. Often, the information is scattered or not available. In general, the actors in the design and build phases work well together and share the information. But, after the building is put into use, the information is not handed over to actors responsible for maintenance, remodelling or demolition. These have to make their own inventories and work with what they can observe (BAMB, 2016). More and more, BIM models are made to save such information, but most do not contain the desired amount of information.

Making Material Passports for new and to be refurbished buildings will contribute to circular building materials, but does not have enough impact. This is because per year only 0,7% of the building stock in The Netherlands is added (CBS, 2017b). The effect will be much more influential if inventories are also made for the existing stock. By this, larger quantities of materials will be re-usable (Rau & Oberhuber, 2016).

Ideally, it is desirable that all buildings are designed with components that can be disassembled without loss of value. Architects, product designers, users and deconstruction companies have to work together in this (BAMB, 2016).

DEFINITION

To stimulate the making of Material Passports, an EU based research program called Building as Material Bank (BAMB) has been established in 2015. BAMB its aim is to enable data gathering, display applications for reversible building and stimulate innovation through information sharing.

The definition that BAMB keeps is: “Materials Passports are (digital) sets of data describing defined characteristics of materials and components in products and systems that give them value for present use, recovery and reuse" (EPEA, IBM, & SundaHus, 2016). In recent years, a number of Material Passports has been developed. They differ much and can be categorised in (BAMB, 2016):

- Product passports
- Passports for products in buildings
- Passports for buildings

In 2016, Mulhall et al. (2016) identified 13 product passport initiatives (Figure 20). This overview is already outdated, as several other passports have been launched since. However, it gives an interesting overview of the different initiators and types. Many passports are not public as initiators keep the product to themselves. This is understandable as the development of the passports costs time and money, but does not enable the shift towards circular building materials.

Two recent material passports that have been launched in The Netherlands are Madaster of Rau Architects (https://madaster.com/) and Construction Passport by Architekten Cie. Unfortunately, both are not for public use.

Passport name	*Initiator's name*
C-passport	*Cirmar*
Circularity passports	*EPEA*
Cradle to Cradle Passport	*Sustainable Shipping Initiative*
Declaration of Performance (DoP)	*EC Product Directives*
Environmental Product Declaration (EPD)	*ISO*
Health Product Declaration (HPD)	*Health Product Declaration Consortium*
Material Safety Data Sheet (MSDS) & Safety Data Sheets (SDS)	*The Hazard Communication Standard, OSHA*
Product Passport *	*European Resource Platform*
Raw Materials Passport	*Turntoo & Double Effect*
Recycling Passport	*Agfa-Gevaert & Electrocycling GmbH*
Resource Identity Tag or Tool *	*Groene Zaak/Metabolic/Fairmeter.org*
Technical passport for equipment	*Kazakhstan & Russia*
Workwear Passport	*Dutch Awearness*

* = marketplace status uncertain

Figure 20: Identified Material Passports (BAMB, 2016, fig. 10)

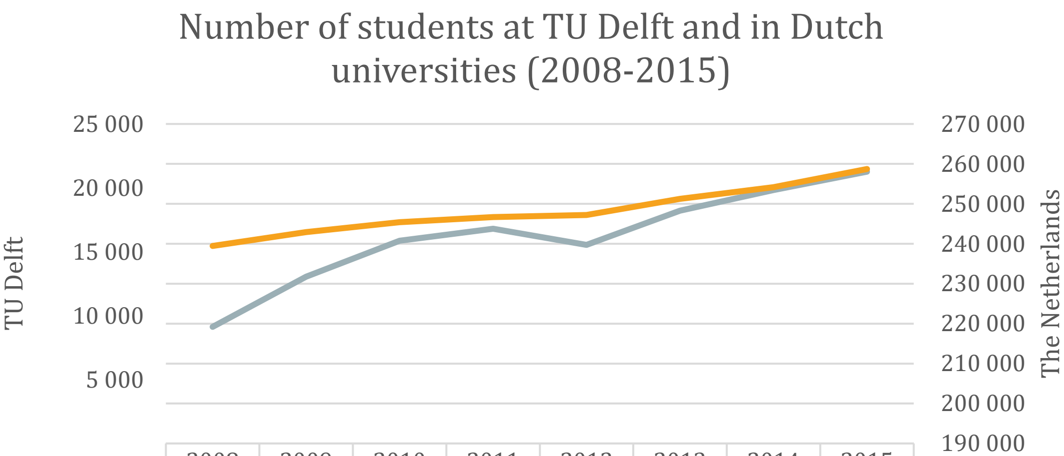
4. RESEARCH ON TU DELFT

4.1.TU DELFT CAMPUS

Delft University of Technology (hereafter TU Delft) is the largest and oldest technical university in The Netherlands. The university was founded in 1842 and nowadays comprises 16 BSc and 31 MSc programmes (TU Delft, 2015a). Ranking in 59th place in the THE World University Rankings, TU Delft is best ranked of 13 Dutch universities (Times Higher Education World University Rankings, 2017).

Figure 21: Photo of TU Delft campus (source: Beeldbank TU Delft)

The university accommodates almost 21.000 students, 2600 PhD candidates, 3000 scientific staff members and over 2000 other staff members. Around 27.000 people use the university premises on a daily basis and it is expected that that number will keep increasing (TU Delft, 2015a, 2015d). Figure 21 shows the growth of the student population in recent years.



	2008	2009	2010	2011	2012	2013	2014	2015
Total	219 19	231 77	240 74	243 78	239 73	248 27	253 45	258 05
TU Delft	15 455	16 544	17 317	17 720	17 873	19 144	20 053	21 475

Figure 22: Number of students at TU Delft and in Dutch universities (2008-2015), based on (VSNU, 2016)

The Delft University of Technology was originally located in the inner city of Delft. After the Second World War the student numbers rose and the university decided to relocate to a larger greenfield site, south of the inner city (Van der Hoeven, 2015). This gave TU Delft the opportunity to develop a new campus. As universities became more and more attractive to students after the Second World War, an enormous development of university campuses arose. Many of the then established campuses are in need of refurbishment now (Ebbert, 2010).

Nowadays the campus comprises 161 hectares (1.610.000 m^2), which makes it the single biggest of The Netherlands and one of the largest campuses in the world (Den Heijer, 2011; TU Delft, 2016a). Figure 23 shows the size of Dutch campuses in 2007. Also, TU Delft spends above average on real estate. In 2012, 16,3% of the income of the TU Delft was spent on real estate, compared to 9-14% by other Dutch universities (Berghorst, 2017).

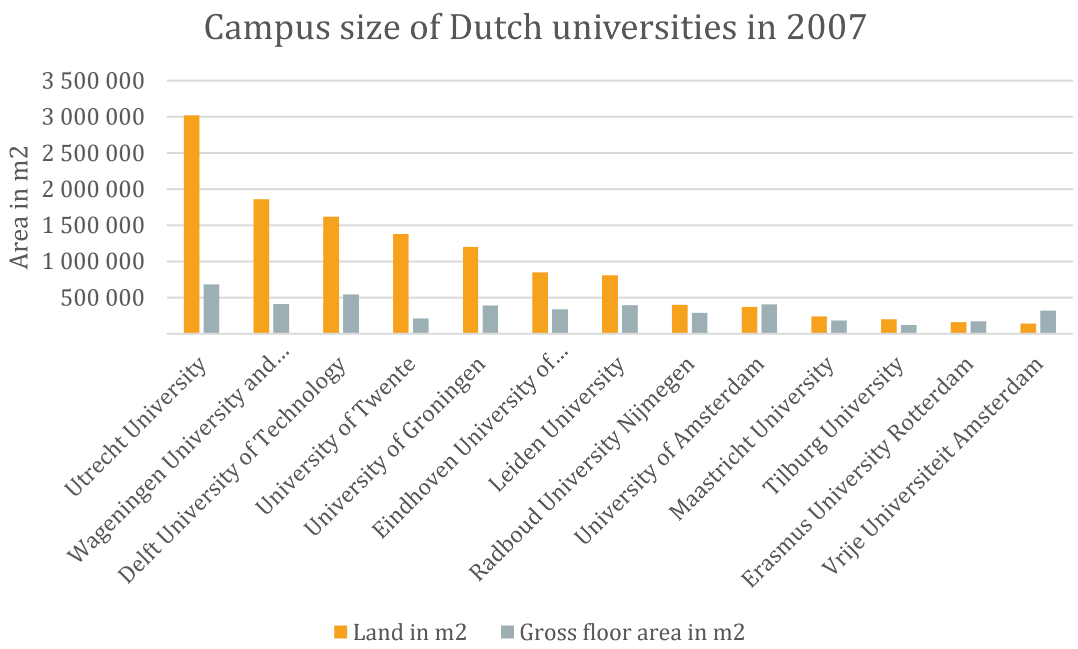


Figure 23: Campus size of Dutch Universities in 2007, based on (Den Heijer, 2011)

From this it can be concluded that TU Delft comes in second place when it comes to gross floor area. Comparing that to recent data and the number of students in 2007 and 2015, Figure 24 shows that:

- the campus size has slightly decreased from 162 to 161 hectares;
- the gross floor area in m^2 has increased by 12%;
- the number of students has increased by 45% (6580 students);
- the number of employees has stayed about the same.

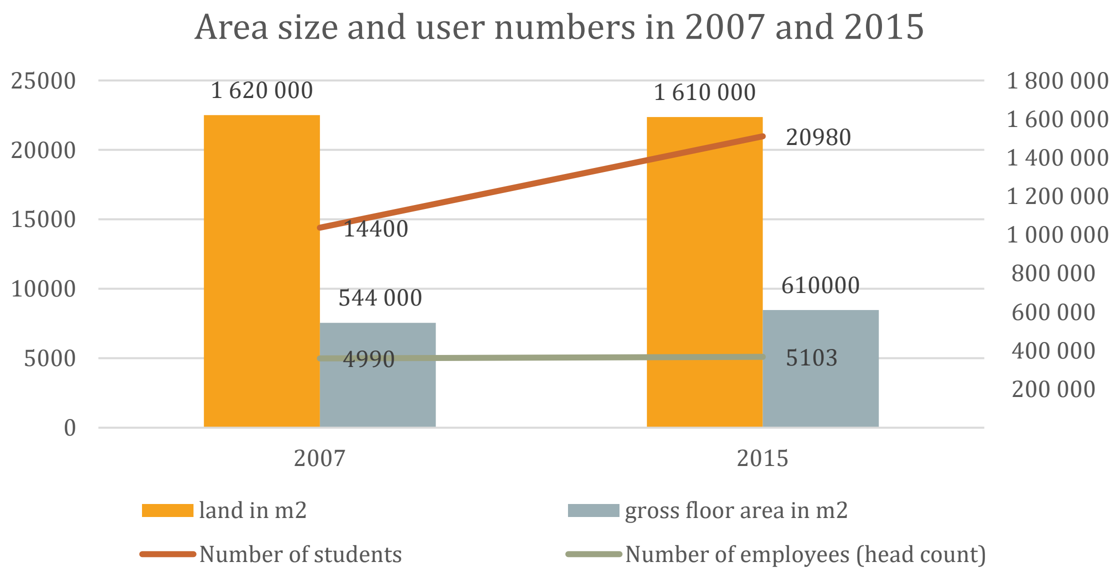


Figure 24: Comparison between land, gross floor area, student and employee numbers in 2007 and 2015, based on (Den Heijer, 2011; TU Delft, 2015a)

Also, Figure 25 shows both hectares of land and gross floor area per student have decreased over time. This is in line with one of the objectives of TU Delft: decrease the footprint per user. More on this will be discussed in chapter 4.6.

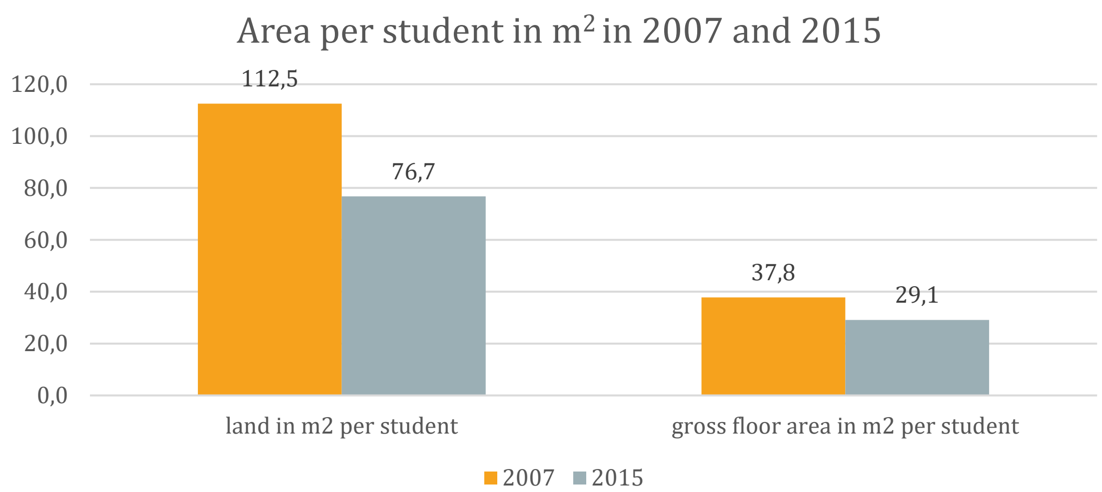


Figure 25:Area per student in m², based on (Den Heijer, 2011; TU Delft, 2015a)

The TU Delft campus is very elongated and most schools (hereafter named faculties) are located along a central axis: The Mekelpark (Figure 26). This 80 metre wide park places the buildings at a considerable distance from each other (Van der Hoeven, 2015). In recent years, the campus has expanded towards the south of Delft. Similar to the developments in the 60s, this was a greenfield and easy to build on.

Simultaneously, TU Delft started selling buildings at the north side of the campus. However, in 2008 the Faculty of Architecture was lost in a fire. “This had significant implications for the further development of the TU Delft campus. The university had planned to abandon the northern part of the (pre-war) campus altogether. Now it was forced to retain a strong foothold there” (Van der Hoeven, 2015, p. 155). The latest Campus Vision (TU Delft, 2016a) describes a very different concept in expanding the campus.

Figure 26: The Mekelpark (source: Beeldbank TU Delft)

Nowadays TU Delft comprises 62 buildings, accounting for 610 000 m^2 of gross floor area. Since 2012, the buildings are maintained by the department Facility Management & Real Estate (FMRE, Dutch: FMVG). This organisation is part of the University Corporate Office. FMRE is subdivided into the departments: Real Estate Development, Projects, Management and Maintenance, Campus Facility Management, and the Support Unit. Like many other universities, TU Delft is owner, developer and user of the properties at their campus (FMRE, 2013b; TU Delft, 2017).

A large part of the building stock has a cultural or monumental value (TU Delft, 2016a). Most characteristic for the campus are the buildings along the Mekelpark, including EWI, the Auditorium, 3ME and the Library Learning Centre. However, a large portion of the buildings is located at the perimeter. Figure 27 shows the functions of all buildings at the TU Delft campus. Besides academic buildings, the campus has buildings for companies, housing, sport & leisure and infrastructure as well.

Figure 27: Buildings at campus and their functions, modified image of (Den Heijer, 2007; KAAN Architecten, 2016)

The building vary greatly in size, as is shown in Figure 28. The largest buildings on campus are:

- 23. Civiele Techniek en Geowetenschapen
- 36. EWI
- 22. TNW – Technische Natuurkunde
- 08. Bouwkunde
- 34. 3ME

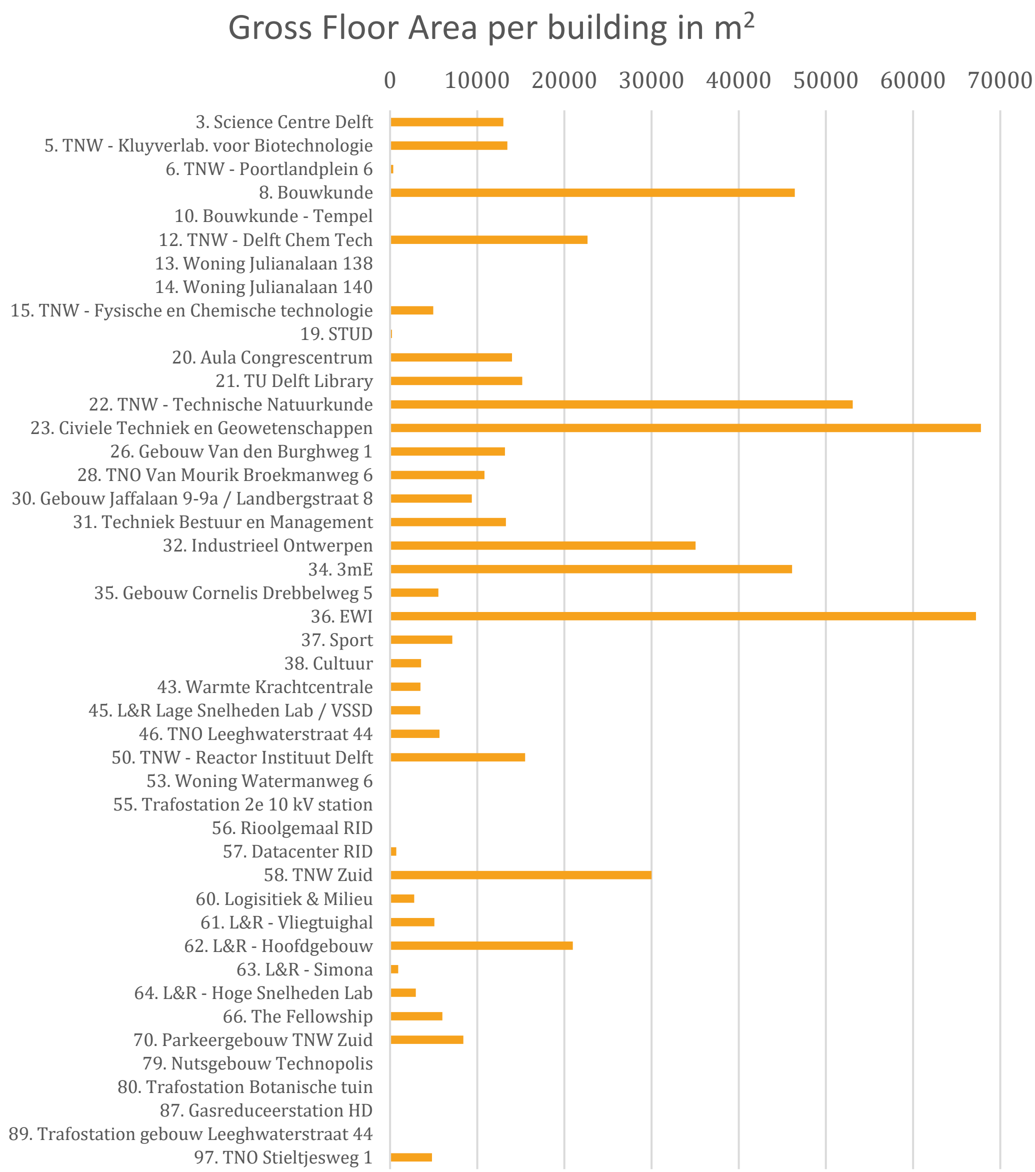


Figure 28: Gross Floor Area per building in m2, based on (KAAN Architecten, 2016)

Figure 29 shows that most buildings were built in the '60s and '70s. In comparison to current standards, these buildings are not very energy-efficient (TU Delft, 2015b), because only a few of them have been renovated. In general, the building stock of Dutch universities is relatively old: 62% of the university buildings originates from before 1980. "The [Dutch] university with the biggest portfolio from the 1960s and 1970s is Delft University of Technology (320,000 m2 GFA)"(Den Heijer, 2007; Ebbert, 2010, p. 66).

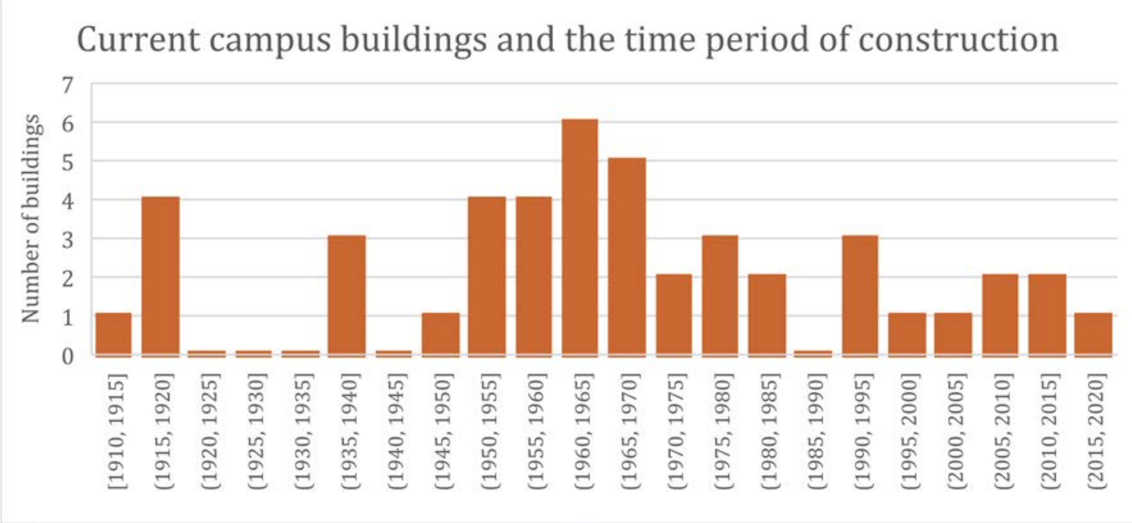


Figure 29: Current campus buildings and the time period of construction, based on (KAAN Architecten, 2016)

Furthermore, Figure 30 shows 60% of the current gross floor area has been labelled 'Poor' or 'Very Poor' according to NEN2767 (Berghorst, 2017). Again, this indicates the absence of sufficient maintenance in the past. The necessity of refurbishment is underlined by several documents of TU Delft and FMRE: i.e. Campusvision 2013, Vastgoedstrategie and Campus Vision 2016 (FMRE, 2013a, 2013b; TU Delft, 2016a).

> *"The campus consists of many buildings that have a cultural-historical value but are technically outdated. TU Delft's accommodation is an operating asset that must provide excellent technical and functional support for the primary processes of education and research. Technically and functionally outdated property does not 'perform' sufficiently in that respect, constitutes a business continuity risk and costs a lot to operate each year. [..] TU Delft wants to improve the quality of the existing buildings by tackling the state of repair and clearing the maintenance backlog for some buildings and improving maintenance standards to meet the current comfort and climate criteria" (FMRE, 2013a, p. 28).*

FMRE (2013b) states that it wants to bring all essential buildings to condition level 'Good' (NEN2767), the level comparable to new estates.

> *"The historic buildings, some of which are listed, are in need of renovating or redevelopment. All buildings, public spaces, laboratories, lecture halls and workspaces will be upgraded according to the state of the art"(TU Delft, 2016a).*

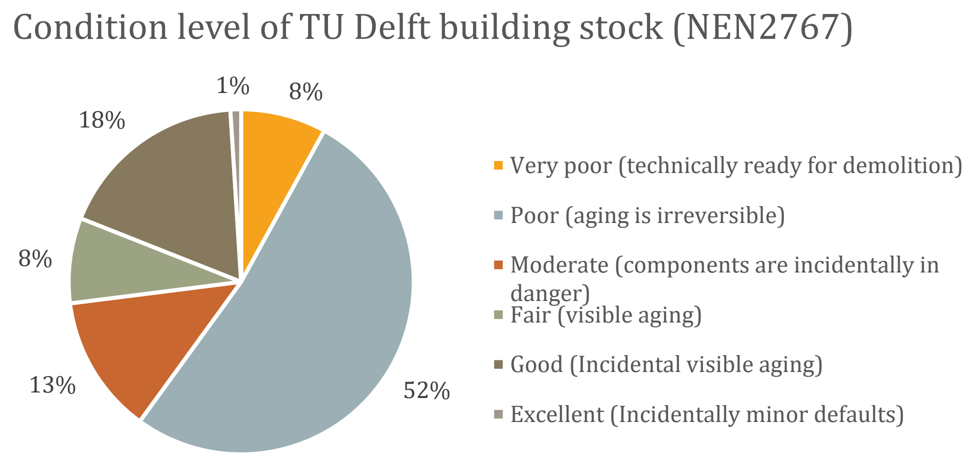


Figure 30: Condition level of TU Delft building stock in 2017, based on (Berghorst, 2017)

4.2. ENERGY CONSUMPTION AND PROJECTS

The building stock of TU Delft is in need for refurbishment and consumes too much energy (FMRE, 2013a). Therefore, a long-term energy agreement was signed in 2008 by the higher education in The Netherlands, amongst which the TU Delft. This agreement (MJA3) strives to reduce energy consumption of universities by 2% annually and involves active energy reduction, monitoring and quadrennial Energy Efficiency Plans (Den Heijer & Teeuw, 2011; FMRE, 2013a).

In addition to the MJA3 agreement, TU Delft signed the "E-deal Delft energieneutraal 2050" (in English: E-Deal Delft Energy Neutral 2050) with a number of companies and institutions in 2013. By this, TU Delft declared to take responsibility for reducing its CO2 emissions (FMRE, 2013a). Furthermore, the Energy department of FMRE published its energy use on a website (energymonitor.tudelft.nl) to stimulate people to come up with ideas on energy reduction and help analyse the data (TU Delft, 2016b).

However, TU Delft (2016a) also mentioned another motive to participate in these agreements: practice what you preach. "In time, students will be decision-makers themselves or policy makers on sustainable development. Changing the mindset of all user groups – students, employees, visitors – by implementing sustainable solutions or by setting a good (visible) example with innovative technology is an extra objective for the higher education, apart from the CO2 reduction and energy efficiency targets for 2030" (Den Heijer, 2011, p. 83).

Reducing energy consumption and CO2 emissions requires objectives. These have been determined by the Executive Board in 2014 (TU Delft, 2015c, 2017):

2020: 40% primary energy saving (in comparison to 2005)

2020: 25% sustainable energy generation

2020: 50% reduction in CO2 emissions (in comparison to 2005)

2040: no more gas-fired heating on campus (from 2035 onwards)

2040: fully energy neutral campus as far as energy provision is concerned

Here two deadlines are stated: 2020 and 2040. The 2020 deadline is approaching and several measures have been taken to reach this target. In 2040 the campus has to be energy neutral and free of gas-fired heating. TU Delft wants to accomplish this by reducing energy consumption, generating sustainable energy and reducing CO2 emissions.

The main goal, however, is CO2 reduction. TU Delft strives to achieve this through technical, organizational and behavioural measures (FMRE, 2013a). FMRE is the executing party of the energy objectives and will work in cooperation with the Green Office, a new department that is devoted to sustainability within TU Delft. For instance, the Green Office works on "the introduction of sustainability and innovation to all levels of real estate strategy and decision-making processes" (TU Delft, 2016b, p. 1).

COMBINED HEAT AND POWER PLANT

Buildings of TU Delft can receive three types of non-sustainable energy for building use: grey electricity, gas and heat. The latter comes from the combined heat and power plant (CHP), which is an underground heat distribution network and accounts for approximately 25% of the energy demand for heat. Electricity is a by-product of this plant and accounts for 25% of the electricity demand (FMRE Energy, 2013). Figure 31 shows the underground network on campus.

In 2012 the CHP was made more efficient with the replacement of two gas engines, which led to a higher electricity yield. In 2015 a larger sustainability project has begun: the heating network transition. This project involves the transition from a high temperature network (130-80°C) to medium temperature (70-40°C). This will be combined with a so-called smart thermal grid, allowing the heat to be cascaded and the grid to be connected to sustainable energy sources in the future (TU Delft, 2017; Villares, 2016).

However, the combined heat and power plant does not generate sustainable energy. It cannot operate forever, as one of the set energy objectives is to stop operating it in 2040.

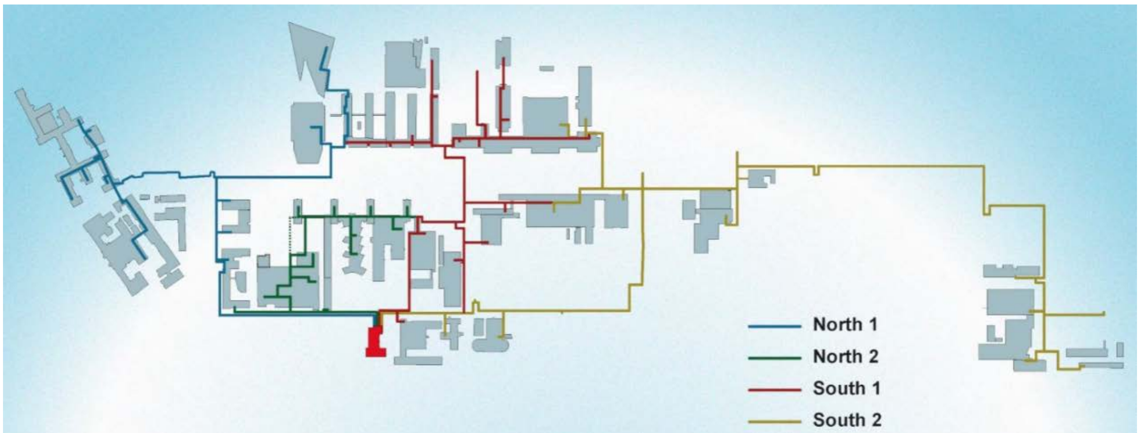


Figure 31: Map of CHP network on campus (TU Delft, 2017)

Figure 32 shows that TU Delft plans to switch from fossil fuels to renewable energy. First, the aim is to reduce the primary energy consumption from 205.000 to 115.000 MWh/year. The percentage of electricity usage is aimed to decrease from 65% to 53%. Reducing the footprint and disposing highly consuming buildings will accomplish this.

Once there is less to generate, it will be easier to replace the fossil fuel options with renewable alternatives. In 2012, there were three sources of energy: natural gas fired in the Combined Heat and Power Plant (CHP), natural gas fired in buildings, and grey electricity. In 2020, two new energy sources should be added: geothermal energy and solar energy (PV). More on these projects will be explained in chapter 4.4.

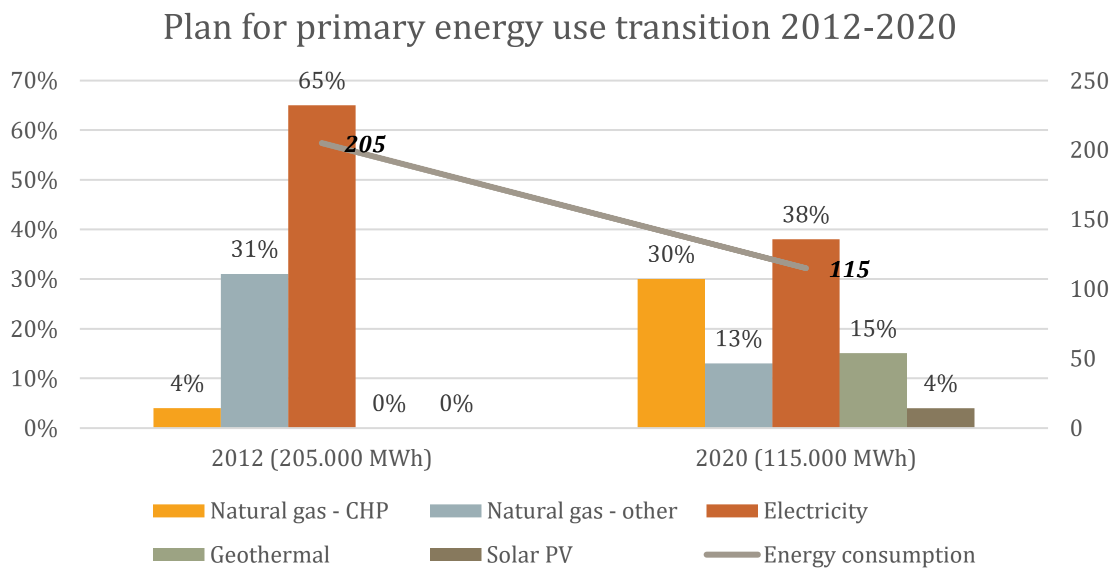


Figure 32: Plan for primary energy use transition 2012- 2020, based on (TU Delft, 2012, p. 61)

Of the 62 buildings at the campus, energy consumption data is collected from 31 buildings. 25 of these buildings are relevant for this research. The monitoring of the energy consumption is done by FMRE Energy. The information provides numbers on the total consumption of a building only, not for individual wings or floors. Besides that, not all data is correct. This influences the general statistics, but also the building choice. Nonetheless, it provides interesting information. Figure 33 gives an overview of the primary energy consumption of these buildings.

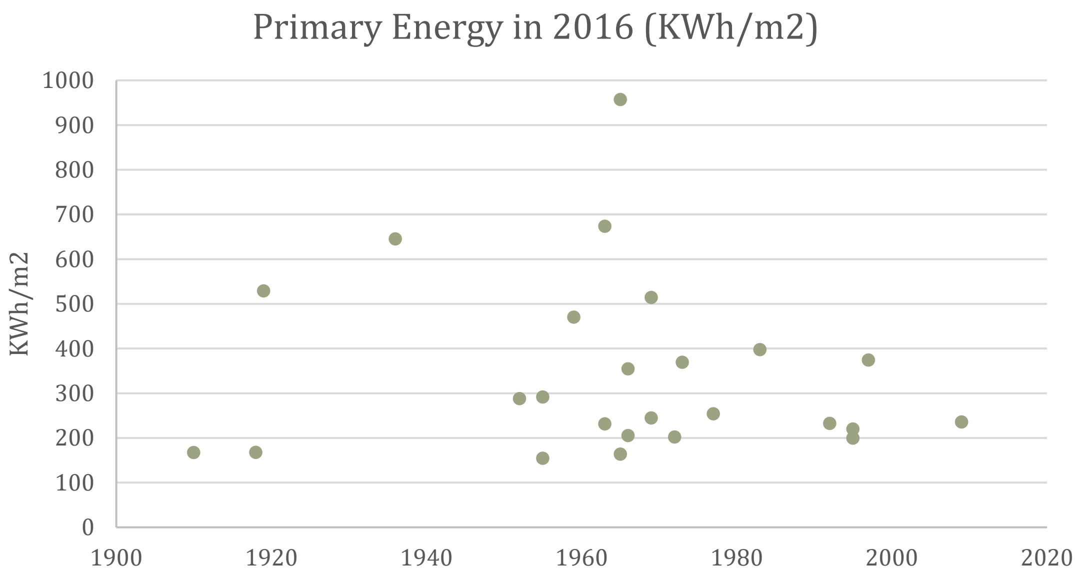


Figure 33: Primary energy use in 2016 (FMRE Energy, 2013)

Although one would expect, no trend can be seen in Figure 33. A correlation between building age and primary energy consumption for buildings at the TU Delft is not found.

Figure 34 and Figure 35 give an overview of the energy consumption in 2011 and 2016.

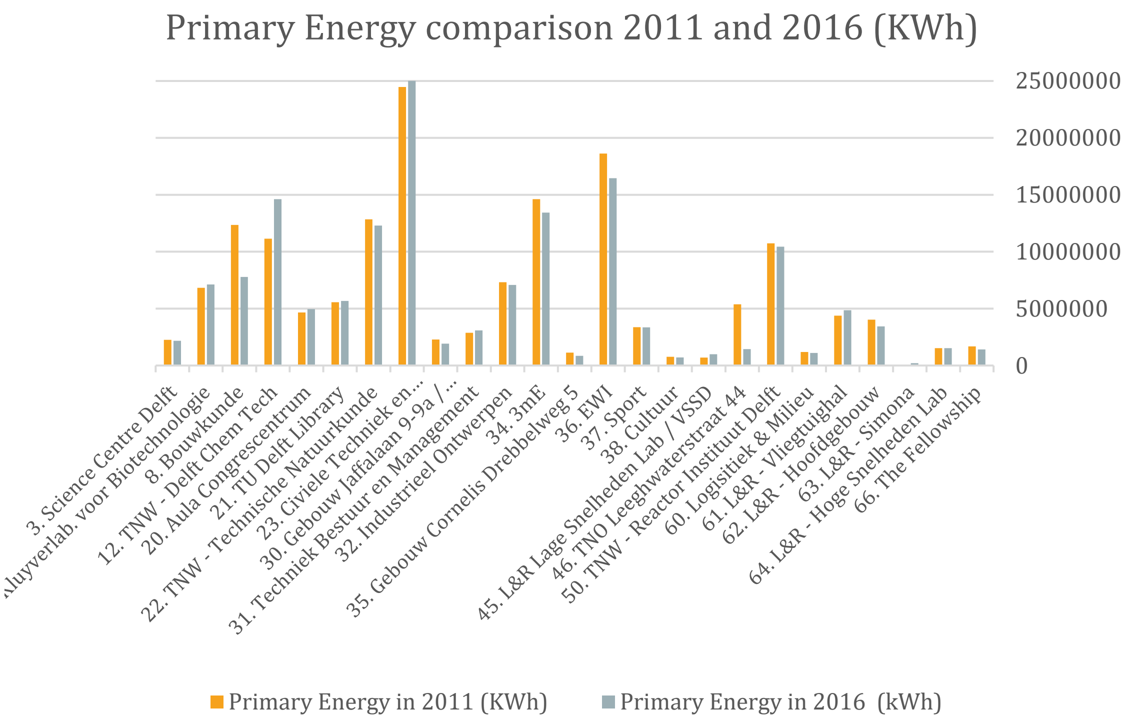


Figure 34: Primary Energy comparison 2011 and 2016 (KWh) (FMRE Energy, 2013)

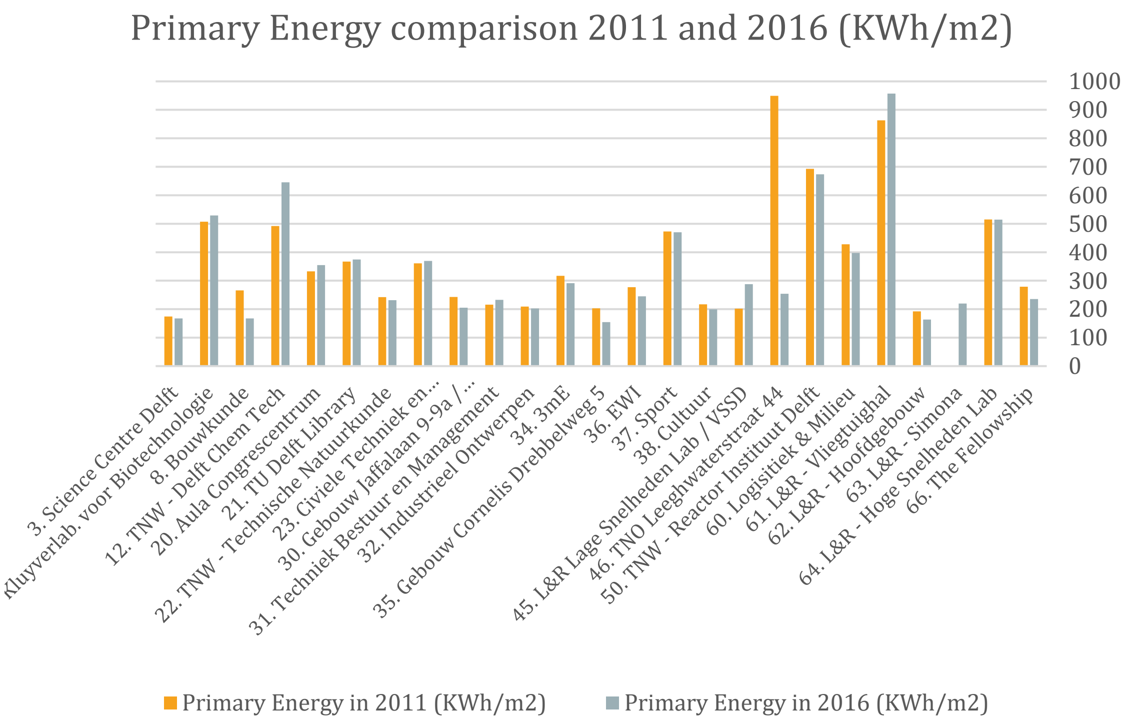


Figure 35: Primary Energy comparison 2011 and 2016 (KWh/m2) (FMRE Energy, 2013)

For most buildings the primary energy consumption has changed more than 5%. On average, the consumption of these 25 buildings has decreased by 5%. Some buildings are worth taking a closer look at:

- Buildings 23 and 36 are the largest and the most consuming buildings on campus.
- The refurbishment of building 08. Bouwkunde seems to have had an effect of the energy consumption. It decreased by 31% from 266 to 168 KWh/m2.
- Building 46. TNO Leeghwaterstraat 44 consumed almost 950 KWh/m2 in 2011, which dropped to 250 KWh/m2 in 2016. However, in the past five years not much has changed in this building. These results could not be explained by FMRE Energy and are considered to be false by FMRE.
- Per square meter, building 61. L&R – Vliegtuighal consumed most, in 2016. This building basically consists of one large badly insulated hall equipped with hundreds of energy consuming devices and machines. Most of the energy consumed is grey electricity, as can be seen in Figure 36.

Figure 36 shows the subdivision of primary energy in electricity, natural gas and heat. Almost all campus buildings are heated with gas or heat from the CHP network. Therefore, one can assume these two represent the amount of energy needed for heating. Of the twenty-five buildings, five are not connected to the heat distribution network. Four buildings consume both heat and natural gas for heating. On average, electricity accounts for 55% of the total consumption.

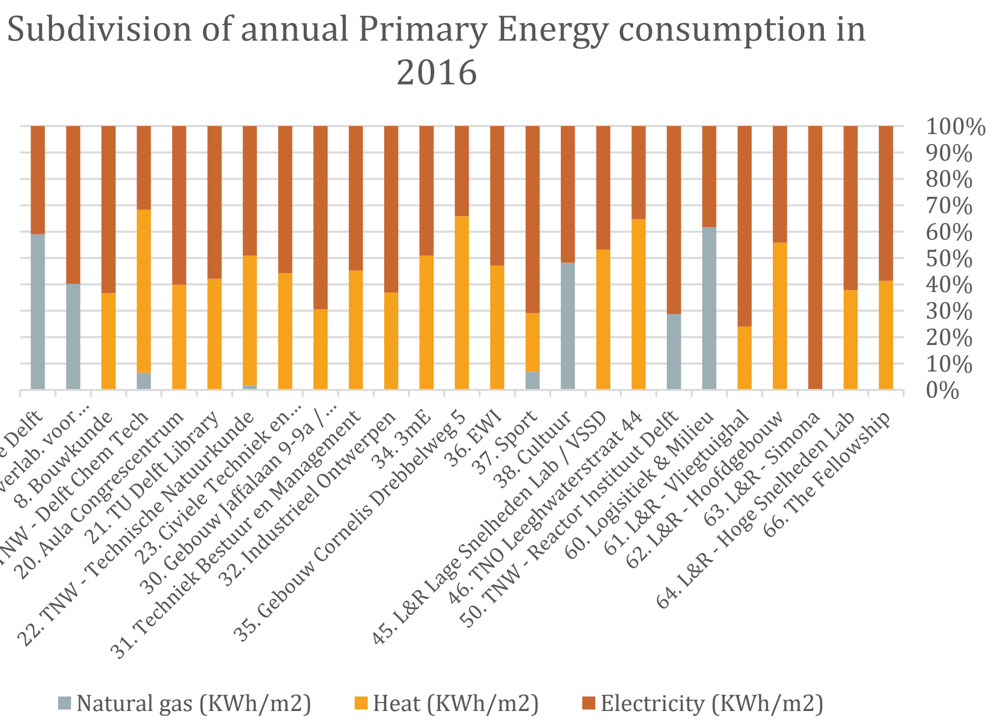


Figure 36: Subdivision of annual Primary Energy consumption in 2016 (FMRE Energy, 2013)

4.3.REDUCE ENERGY CONSUMPTION

Technical, organizational and behavioural measures are at the basis of reducing the energy consumption. Regarding the building stock, these can be achieved by less consumption per building or by decreasing the number of buildings. Below a list with these two categories is presented. Recent projects are added as examples (FMRE, 2013a, 2013b, TU Delft, 2015c, 2017).

ENERGY CONSUMPTION REDUCTION

- Renovate — 08. BK-City
- Better (new) buildings — 58. TNW-Zuid, 30. Pulse
- Decrease area per user — 58. TNW-Zuid
- Behavioural changes (opening hours, temperature) — All buildings
- Improve efficiency building installations — LED-lighting, new computers
- Improve efficiency of local energy generation — Heating network transition

LESS BUILDINGS

- Demolish — 96. Stevin IV
- Sell — 05. Kluyverlab
- Rent out — 26. Van der Burghweg

4.4. GENERATE RENEWABLE ENERGY

The second part of creating a sustainable campus is generating renewable energy**;** Energy that is practically endless and does not have environmental effects. The goal of the TU Delft is to generate 25% of its consumed energy in sustainable ways by 2020, and 100% by 2040. Below, a list is presented with projects FMRE has planned to execute or has already executed in recent years (FMRE Energy, 2013; TU Delft, 2015c, 2016b, 2017; Villares, 2016).

EXECUTED

- Photovoltaic panels on roofs (2016)
  - About 1 million KWh/year (1,7% of the total electricity demand)
- Thermal Energy Storage Technopolis
  - Heat and cold storage in the southern part of campus, exploited by TU Delft (Suenso B.V.). Several systems are currently in use (Exact, Yes!Delft, Applikon, 3M, TNW-Zuid and Holland PTC).
- Green energy deal Eneco (2016)
  - TU Delft wants to only consume electricity that has been sustainably generated at the Dutch coast. However, the electricity still comes from a mix of energy sources with fossil fuel power plants providing the baseline.

PLANNED

- Geothermal well (GO/NO GO 2017)
  - 2 km deep geothermal well, which provides heat at 70°C

4.5.REDUCE CO2 EMISSIONS

The listed measures contribute to lower energy consumption, higher energy generation and above all: lower CO2 emissions. Three targets for 2020 have been set: 40% primary energy saving, 25% sustainable energy generation and 50% reduction in CO2 emissions.

TU Delft has already reached these targets in 2016; four years before the deadline. The most important contributor to reaching all three targets is the Green energy deal with Eneco. This deal accounts for primary energy saving, sustainable energy generation and a reduction in CO2 emissions.

However, the Green energy deal with Eneco is not a good example of a project for a sustainable campus nor an example of sustainable energy generation. The energy is not locally generated (Figure 37). However, it is approved by the organisation of the MJA3 deal.

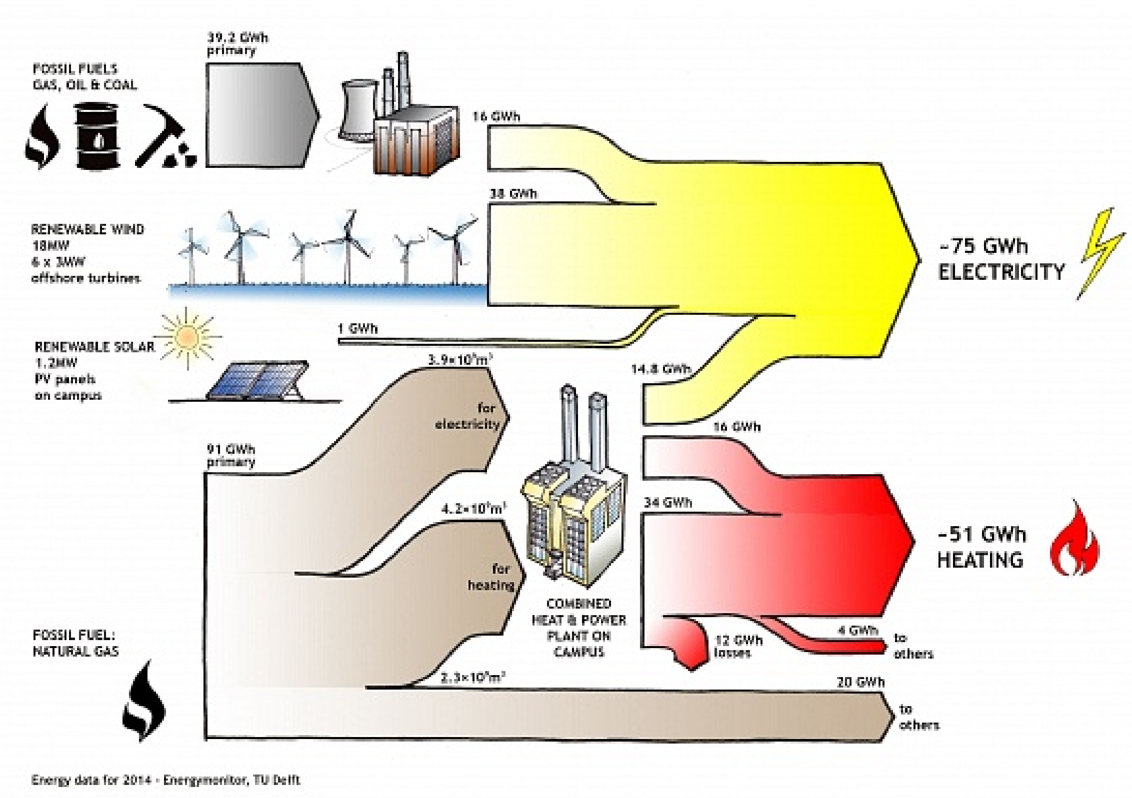


Figure 37: Energy data for 2014 (Villares, 2016)

4.6. CAMPUS DEVELOPMENT AND PROBLEMS

In 2013 the TU Delft formulated a new vision for the campus, divided in four themes: Education, Research, Valorisation and Living Campus (FMRE, 2013b). The themes Education and Research speak for itself, but the latter two might need some clarification. Valorisation involves the utilisation of (new) scientific knowledge and skills in practice. In recent years TU Delft decided to focus more on valorisation, the southern part of campus is destined for that. Living Campus refers to a livelier and more appealing campus. This plan comes with mixed use: student housing on campus, recreation and place for food & beverages are examples of this plan.

CAMPUS PROBLEMS

The campus of TU Delft has some spatial problems. The frayed urban environment at the backsides of buildings along the Mekelpark, is one of them. The original idea of the Mekelweg, named 'Het Schaatsmodel', placed buildings along the central axis. This axis is now a green and spacious park. However, a downside exists: the space left behind the buildings is very frayed and often neglected. Examples of these are Leeghwaterstraat and Schoenmakerstraat (Máčel, Schutten, & Wegner, 1994; Van Schadewijk, 2011).

Adding to this, the campus does not have a centre, mainly because of its size. This makes centralising activities difficult and explains why TU Delft does not have an easily recognisable campus image (Berghorst, 2017). TU Delft's most recent solution is to make a series of centres at the campus, amongst which one at the backside of CiTG. This is an attempt to improve the frayed urban space.

Nonetheless, the most influential issue is a mismatch between current and desired building stock. On the one hand, there is a shortage of chemistry labs and large lecture rooms, and on the other hand a surplus of office space and ancillary spaces exists. Mainly because of digitalisation, traditional small offices are less in need. Unfortunately, the majority of the current offices stock consists of this type (FMRE, 2013a).

According to FMRE less than 25% of usable floor space is now used for educational purposes and research, whilst the majority of usable floor space consists of functional spaces, corridors and storage (Berghorst, 2017). TU Delft has 30% hidden access spaces (FMRE, 2013a). This leads to unnecessary maintenance and costs.

CAMPUS VISION AND POSSIBLE SOLUTIONS

Reduction of m^2 footprint is one of the goals. TU Delft wants to reduce its floor space to bring maintenance costs down. A number of ways to achieve that exist. The easiest way is disposal of property, which can be executed by selling, renting out or demolition.

TU Delft wants to dispose all property that is no longer functional and/or has substantial maintenance costs. As a result, seven buildings that had fallen in disuse have been demolished between 2010 and 2016 (FMRE, 2013a, 2013b; Van der Hoeven, 2015):

- 17. IWeb pavilion

- 23. Stevin IV education
- 44. Rotterdamseweg 145 mixed
- 47. Cornelis Drebbelweg 3a residential
- 54. Watermanweg 8 residential
- 65. Kluyverweg 4-6 education
- 67. Botenloods Proteus unknown

Because of national politics and funding, TU Delft decided to reorganise in 2010. This involved evaluating all buildings. Based on that, TU Delft expected 44.000 m^2 to become vacant. Years later, it turned out to be a wrong prediction, as the student number kept increasing and a shortage in space still exists.

Den Heijer (2013) describes another method for reducing the footprint. "Interviews with decision makers about campuses in the past five years illustrated a change in strategy: from creating territory to creating shared space."(2013, p. 12). Faculties will no longer be given their own buildings, but will be sharing facilities. This way occupancy rates will go up and maintenance costs can go down (FMRE, 2013a). This can be achieved by optimal utilisation of floor area by renovation or by the construction of new buildings.

The new faculty building for Applied Sciences (58. TNW-Zuid) is a good example of this (Figure 38). This state-of-the-art complex replaces three big campus buildings. With 30.000 m^2 it is very compact, has many laboratories and high energy efficiency. In sum, very beneficial to reduce the footprint. The plans for the vacant buildings included a partial renovation of building '22. TNW' and a dispose of properties 05, 06, 12 and 15.

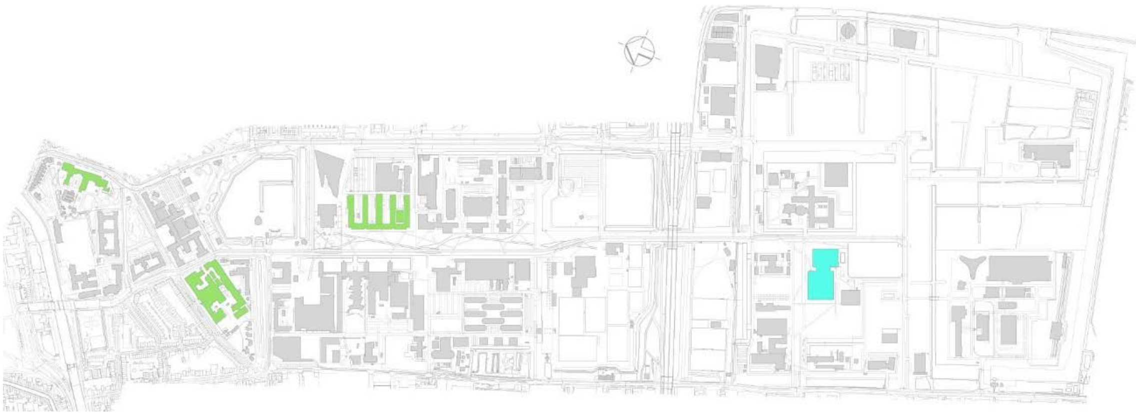


Figure 38: Reallocation of Applied Sciences from three buildings to TNW-Zuid, based on (KAAN Architecten, 2016)

However, the majority of these buildings are still occupied. This is due to two major reasons: long-term laboratory research and temporary housing. Building 12. TNW Delft Chem Tech still houses three research groups that conduct long-term laboratory research and cannot move to building 58 yet (M&C Webredactie TU Delft, 2017). In building 22. Applied Physics temporary accommodation for QuTech has been realised, because of the institutes rapid growth (TU Delft, 2017). This rapid growth has continued within the walls of the building. A suitable location to move to no longer seems to exist. From this, it follows that building 22 cannot be renovated in the current situation.

PLANS OF FMRE

At TU Delft building plans often change. One of the reasons for this is that the property strategy of FMRE has a six-month cycle. As discussed, in 2013, FMRE planned to bring all essential buildings to condition level 'Good'. In addition, they wanted to reduce the footprint by selling or demolishing outdated, non-functional, expensive buildings (FMRE, 2013a, 2013b). In the following paragraphs, the change of plans regarding the themes vacancy, renovation and new buildings will be discussed.

After the reorganisation in 2010, FMRE reasoned that 11 buildings (44.000 m^2 usable floor area) would become vacant within a few years as a result of cost reduction (Figure 39). With this in mind, the organisation started exploring options for adaptive reuse, like student housing. But when the new Campus Vision was published in 2013 only one of those buildings had become vacant. The objective for footprint reduction had increased from 44.000 to 70.000 m^2 gross floor area as well. The majority, 55.000 m^2, would be disposed on short term (2013-2016) and another 15.000 m^2 between 2016-2022 (FMRE, 2013b; TU Delft, 2010, 2014). As discussed, seven building have been demolished.

Figure 39: Expected vacancy for 2011 and 2012, modified by author (Bosnjak, 2013; TU Delft, 2010)

According to the Real estate strategy of FMRE (2013b), all essential buildings would be brought to condition level 'Good'. Plans were made for the biggest three buildings at the campus: 22. TNW, 23. CiTG and 36. EWI. CiTG and EWI would be relocated, so renovation could take place. EWI would however, get a life extension until 2022. The majority of TNW would in time move to a new building. After that the building would be renovated and partially demolished.

In reality the plans for the three biggest buildings have drastically changed (Berghorst, 2017; TU Delft, 2016a) since publication of the Real Estate Strategy in 2013:

- 22. TNW is still in use;

- 23. CiTG is getting a life extension;
- 36. EWI is being relocated, but the plans for renovation have been cancelled;
- all three are more likely to be demolished than to be renovated.

On top of that, the new statement from TU Delft is:

"The overall campus development, in which demolition of older buildings and the establishment of new, energy efficient buildings is prioritised over renovations, will play an important role for campus energy saving in the coming decade" (TU Delft, 2016b).

In an interview with one of the campus policy makers this change was explained. It turns out that there has been research on the renovation, but that the plans for the particular buildings were functionally and financially not feasible. The main reason given by FMRE is the large percentage of non-functional space (e.g. wide hallways, unused built-in closets and basements) that cannot be used efficiently but still needs maintenance, heating and cleaning (Communication-FMVG, 2017). Renovations leading to energy efficient buildings are for the most part cancelled because of this.

The faculty of Architecture has been the only one renovated and majorly upgraded from 2012 to 2015. This change in policy has a big effect on the plans for new buildings. It now seems more buildings will be replaced by state-of-the-art properties as has been the case for building 58. TNW-Zuid.

A new multifunctional building is being built (30. Pulse). It will be the first energy-neutral building on campus and also the first building that does not belong to one single faculty. Pulse is a good example of how TU Delft goals can be achieved by replacing old with new buildings. However, demolition of property is also a waste of embodied energy. In the opinion of Den Heijer (2011) old buildings should be reconsidered before replacing them with new ones, as it can save a lot of costs.

4.7. SUMMARY

TU Delft is a large technical university in the Netherlands and has over 21.000 students. The university moved to the current campus site in the '60s. FMRE is the organisation responsible for all services on campus and the university is the owner, developer and user of the properties.

The estate comprises 62 buildings, of which most were built in the '60s and '70s. The condition level of the majority of the building stock is poor and TU Delft has expressed the ambition to upgrade the existing buildings by renovation to condition level 'Good'.

The outdated building stock consumes a lot of energy. TU Delft has signed two long-term energy agreements and strives to reduce energy consumption and CO2 emissions. For 2020, the TU Delft has three goals: 40% primary energy saving, 25% sustainable energy generation and 50% reduction in CO2 emissions compared to the current situation. To achieve this, FMRE has devised a plan with a range of projects and solutions. The biggest contributor is the 'Green energy deal Eneco'. Thanks to this deal the targets for 2020 have been achieved in 2016.

Main themes in campus development are Education, Research, Valorisation and Living Campus. The biggest theme however, is a mismatch between current and desired building stock. TU Delft has too few laboratories and large lecture rooms, whilst 30% is hidden access space. This results in unnecessary costs.

Concluding, a reduction of m^2 footprint and a change in the use of space is desired. Several ways of achieving this exist, e.g.: dispose of property, renovation, creating shared space and new building construction. Since 2010, seven buildings were demolished, one building has undergone deep renovation, and two new buildings were built or are being built. A few years ago, it seemed most buildings would be renovated. However, there has been a recent shift in mind-set. Building new and energy efficient buildings is prioritised over renovating the outdated property. The full result of this change is not yet clear, but the major renovations of the three largest buildings at the campus have been postponed or cancelled.

5. BUILDING CHOICE

This chapter will go into the process of choosing a building to refurbish. One of the motives for this thesis is to provide TU Delft with a step-to-step approach for upgrading its building stock. Therefore, much time and attention has been spent on the process of selecting a building.

Nowadays, TU Delft owns 62 buildings, accounting for 610 000 m^2 of gross floor area (GFA). A list of all buildings is presented in Appendix 14.1. Figure 40 gives an overview of all buildings located within the area considered to be the campus. The buildings that are currently owned by TU Delft are highlighted.

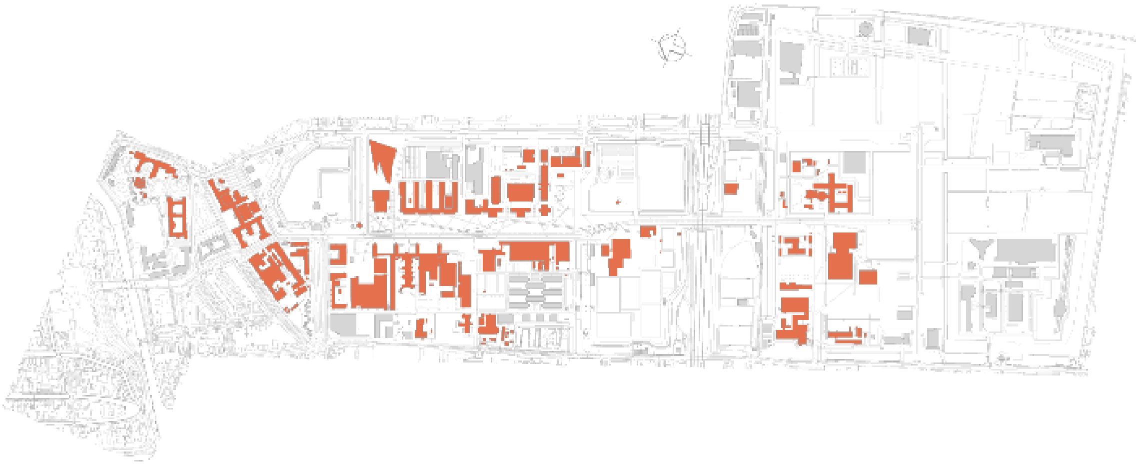


Figure 40: Buildings owned by TU Delft at the campus in 2017

To come up with a list of requirements to choose a building, the analysis of the previous chapter was used and several employees of FMRE have been interviewed. The latter led to a long list of recommendations. Some examples are given below.

- "The Aula has major cold bridges"
- "3ME has nog been built very rigid"
- "Has not been renovated in years"
- "The building has potential"
- "High energy consumption"
- "Users complain about the air quality"
- "Very uncomfortable offices"
- "Just added to the building stock. Maybe you can have an impact"

The arguments were analysed. Combined with the research on TU Delft described in chapter 4, a list of six criteria was set up. The criteria, explanation and used sources are listed below.

Which building:

1. **Is of reasonable size (2.500-25.000 m²)?**
    a. Most buildings under 2500 m^2 at campus are public infrastructure (parking, water management and energy stations). These buildings will not be taken into consideration for this thesis, as this is not the scope of this research.
    b. 25000 m^2 has been chosen to eliminate large complexes. For the larger faculties and complexes, there is not enough specific information on building age, user behaviour and energy consumption.
        i. *Source:* FMRE. (2016a). Gebouwenlijst.
2. **Consumes above average regarding heating and primary energy consumption?**
    a. All heat that comes from the CHP is used for heating buildings.
    b. The assumption is made that natural gas is used for heating a building.
    c. There are hardly any electrical heaters at the TU Delft. Therefore, the amount of required for heating a building is the sum of energy from heat and natural gas.

    The data on energy consumption was taken from the Energymonitor of TU Delft. To convert the data from this website to useful data, the following formulas and key numbers were used.

    Natural gas = total consumption natural gas in m3 * calorific value / 3600

    Heat = (total consumption natural gas for WKK in m3 * calorific value / 3600) / energy efficiency * 100

    Calorific value (LHV) = 31,65 Nm3 ae

    Energy efficiency of WKK = 72,7 % (2015)
        i. *Source:* FMRE Energy. (2013). TU Delft Energy Monitor
3. **Has not undergone or will not undergo major renovations before or in 2025?**
    a. Major developments include demolition, refurbishment and dispose of property.
    b. The time frame corresponds to that of FMRE in February 2017
        i. *Source:* Zeepkistsessie Vastgoedstrategie, Interview Bart Verhaar and Communication-FMVG. (2017). FMVG Nieuws maart 2017.
4. **Is in need of refurbishment before or in 2025?**
    a. The need is based on a 25-year lifespan after the last renovation or new build, instead of the proposed 50 years in the source document.
        i. *Source:* FMRE. (2016b). Planning assets.
5. **Can sufficient information be found on (façade, installations and user comfort)?**
    a. Starting a design challenge without drawings, knowledge on installations or comfort problems is problematic.
        i. *Source:* Information of FMRE-Technische Informatie Dienst
6. **Is in use by TU Delft?**
    a. The building should be in use for academic purposes, research or sport & leisure.
        b. It will not be in TU Delft's best interest to invest in a building that is not in use by the university.
            i. Source: KAAN Architecten (2016) TU Delft Campusatlas.

Figure 41 shows the resulting dataset. The full document can be found in Appendix 14.1. If there is no data available, the cells are filled with 'no data'. If one of the criteria in a row is equal to 'white cell', the building is crossed off. All criteria have to be either coloured green or yellow. And the criteria are given equal weight.

Criteria	1. Gross Floor Area 2.500-25.000 m2	2. Energy Consumption			3. Recent developments		4. Is in need of renovation between 2017-2025	5. Can sufficient information be found on	6. In use by TU Delft	Outcome
Building name	**GFA in m2**	**Primary Energy in 2016 (KWh/m2)**	**Heating (KWh/m2)**	*Heating as % of Primary Energy*	**Executed (since 2010)**	**Plans (until 2025)**	**year+ 25 years**		**Usage**	**Qualify for all criteria**
3. Science Centre Delft	12996	167	96	*58%*	Partially renovated		Maybe			
5. TNW - Kluyverlab. voor Biotechnologie	13460	525	209	*40%*		Dispose of property	Yes			
6. TNW - Poortlandplein 6	365	no data	no data	*no data*			no data			
8. Bouwkunde	46421	168	61	*36%*	Renovated					
12. TNW - Delft Chem Tech	22650	645	157	*71%*		Dispose of property	Yes			
13. Woning Julianalaan 138	100	no data	no data	*no data*			no data	Not enough		
14. Woning Julianalaan 140	100	no data	no data	*no data*			no data	Not enough		
15. TNW - Fysische en Chemische technologie	1958	no data	no data	*no data*		Dispose of property	Yes			
19. STUD	222	no data	no data	*no data*		Renovation	no data		No	
20. Aula Congrescentrum	13987	355	141	*40%*			Yes			20. Aula Congrescentrum
21. TU Delft Library	15158	374	158	*42%*			Yes			21. TU Delft Library
22. TNW - Technische Natuurkunde	53083	232	119	*51%*		Demolition	Yes			
23. Civiele Techniek en Geowetenschappen	67779	365	156	*42%*		Demolition	Yes			
25. Terrein Green Village	11800	no data	no data	*no data*	New	New		Not enough		
26. Gebouw Van der Burghweg 1	13183	no data	no data	*no data*	Partially renovated		no data	Not enough		
28. TNO Van Mourik Broekmanweg 6	10827	no data	no data	*no data*		Renovation	no data			
30. Gebouw Jaffalaan 9-9a / Landbergstraat 8	9577	205	62	*30%*						
31. Techniek Bestuur en Management	13293	233	106	*45%*			Yes			
32. Industrieel Ontwerpen	35046	202	74	*37%*			Yes			
33. Pulse	4700	no data	no data	*no data*		New		Not enough		
34. 3mE	46122	291	150	*51%*						
35. Gebouw Cornelis Drebbelweg 5	5547	154	106	*69%*	Partially renovated					
36. EWI	67220	245	116	*47%*		Demolition	Yes			
37. Sport	7130	470	134	*29%*		Renovation	Yes			
38. Cultuur	3564	199	94	*47%*			no data			
43. Warmte Krachtcentrale	3486	no data	no data	*no data*			Yes			43. Warmte Krachtcentrale
45. L&R Lage Snelheden Lab / VSSD	3458	288	155	*54%*			Yes			45. L&R Lage Snelheden Lab / VSSD
46. TNO Leeghwaterstraat 44	5675	254	169	*67%*			Yes		No	
50. TNW - Reactor Instituut Delft	15500	673	186	*28%*						
53. Woning Watermanweg 6	100	no data	no data	*no data*			no data	Not enough		
55. Trafostation 2e 10 kV station	100	no data	no data	*no data*			no data			
56. Rioolgemaal RID	100	no data	no data	*no data*			no data			
57. Datacenter RID	706	no data	no data	*no data*	New		no data			
58. TNW Zuid	30000	no data	no data	*no data*	New					
60. Logisitiek & Milieu	2763	398	240	*60%*			no data			60. Logisitiek & Milieu
61. L&R - Vliegtuighal	5077	957	225	*23%*			no data			61. L&R - Vliegtuighal
62. L&R - Hoofdgebouw	20972	164	92	*56%*			Yes			
63. L&R - Simona	941	220	0	*6%*			no data			
64. L&R - Hoge Snelheden Lab	2962	514	193	*37%*			no data			64. L&R - Hoge Snelheden Lab
66. The Fellowship	6000	236	97	*41%*	Partially renovated					
70. Parkeergebouw TNW Zuid	8400	no data	no data	*no data*	New		no data			
76. Woning Hammenboerderij	0	no data	no data	*no data*				Not enough	No	
79. Nutsgebouw Technopolis	100	no data	no data	*no data*			no data			
80. Trafostation Botanische tuin	100	no data	no data	*no data*			no data	Not enough		
87. Gasreduceerstation HD	100	no data	no data	*no data*			no data	Not enough		
89. Trafostation gebouw Leeghwaterstraat 44	100	no data	no data	*no data*			no data	Not enough		
97. TNO Stieltjesweg 1	0	no data	no data	*no data*			no data	Not enough	No	
161. Yes! Delft Labs	5528	no data	no data	*no data*	New		no data		No	
181. Yes! Delft	0	no data	no data	*no data*			no data		No	
193. Applikon Biotechnology B.V	0	no data	no data	*no data*	New		no data		No	

Figure 41: Dataset of buildings corresponding to criteria

After testing the requirements seven buildings remain. Figure 42 shows remaining buildings on the campus map and Figure 43 shows a summary of the criteria for these seven buildings.

Figure 42: Location of buildings that made the first selection

Criteria	1. Gross Floor Area 2.500-25.000 m2	2. Energy Consumption			3. Recent developments		4. Is in need of renovation between 2017-2025	5. Can sufficient information be found on	6. In use by TU Delft	Outcome
Building name	**GFA in m2**	**Primary Energy in 2016 (KWh/m2)**	**Heating (KWh/m2)**	*Heating as % of Primary Energy*	**Executed (since 2010)**	**Plans (until 2025)**	**year+ 25 years**		**Usage**	**Qualify for all criteria**
20. Aula Congrescentrum	13987	355	141	*40%*			Yes			20. Aula Congrescentrum
21. TU Delft Library	15158	374	158	*42%*			Yes			21. TU Delft Library
43. Warmte Krachtcentrale	3486	no data	no data	*no data*			Yes			43. Warmte Krachtcentrale
45. L&R Lage Snelheden Lab / VSSD	3458	288	155	*54%*			Yes			45. L&R Lage Snelheden Lab / VSSD
60. Logisitiek & Milieu	2763	398	240	*60%*			no data			60. Logisitiek & Milieu
61. L&R - Vliegtuighal	5077	957	225	*23%*			no data			61. L&R - Vliegtuighal
64. L&R - Hoge Snelheden Lab	2962	514	193	*37%*			no data			64. L&R - Hoge Snelheden Lab

Figure 43: Dataset of buildings that made the first selection

The next step in the selection process was based on varying criteria, including interviews, TU Delft research, and personal preference.

20. Aula Congrescentrum
It has large cold bridges in the façade. It is a monument and therefore difficult to refurbish. The possibilities for changing the façades are very limited. Refurbishing it will have a great impact on the appearance of the campus.

21. TU Delft Library
The energy consumption is high, but misleading because the building is open many more hours than others. This building is open 365 days a year and from 08:00-24:00. Besides that, it is one of the newest buildings on the campus, being built in 1997.

43. Warmte krachtcentrale (CHP)
There is no data available on its energy consumption. Only 10-15 people use the building on a daily basis, so the impact of refurbishment is not very big. However, the office quality is very poor.

45. L&R - Lage Snelheden Lab/VSSD (Low Speed lab)
The building has not been renovated in forty years. In recent years, two adjacent buildings were demolished and a new building is planned. The building is very aesthetically appealing.

60. Logistiek & Milieu
Logistiek & Milieu has the same safety restrictions as the Reactor Institute. Therefore, accessibility and access to information will be difficult.

61. Vliegtuighal
The Vliegtuighal is part of the complex of Aerospace Engineering. It is a large machine hall and the majority of energy consumed is process energy.

64. L&R - Hoge Snelheden Lab (High Speed Lab)
The building has not been renovated since it was build. The building is very aesthetically appealing.

Based on this information, two buildings are most promising:

- 45. L&R Lage Snelheden Lab/VSSD
- 64. L&R Hoge Snelheden Lab.

These buildings coincidentally both belong to the faculty of Aerospace Engineering and are both in use for wind tunnel research. To ease the process of deciding, site visits were made to acquire key data. Table 12 shows the data on these two buildings.

Table 12: Comparison of building 45 and 64

		
Building Inventory	**45. L&R Lage Snelheden Lab/ VSSD (Low Speed Lab)**	**64. L&R Hoge Snelheden Lab (High Speed Lab)**
Address	Leeghwaterstraat 42	Kluyverweg 2
Users	Aerospace, InHolland, VSSD, OWee Bestuur and other student organisations	Aerospace
Form of use	Windtunnels research and offices	Windtunnels research and offices
Year of construction	1952	1967
Refurbishment	None Addition in 1976	None Addition in period 2000-2015
No. of floors above ground	5	2
No. of floors below ground	0	1
Floor height (estimated)	2500-6000 mm	2500-6000 mm
GFA	3458 m^2	2962 m^2
Persons in the building	50-100	100-150
Number of user groups	>5	1
Users' complaints	Outdated appearance Unpleasant indoor conditions Lack of insulation High energy demand High maintenance cost Transformation of building	Outdated appearance Unpleasant indoor conditions Lack of insulation High energy demand High maintenance cost Asbestos Change of office concept Hygienic problems Sick building syndrome (SBS)
Construction principle	Concrete and brick walls heavy construction	Steel skeleton with concrete infill

Final energy heating	155 KWh/m2	288 KWh/m2
Final primary energy	193 KWh/m2	514 KWh/m2

The buildings are very comparable. The main differences are the construction principle, shape, and number of user groups. The High Speed Lab is a simple building with a straightforward construction, only one user group and simple layout. The Low Speed Lab, on the other hand, has a complicated concrete construction, large internal wind tunnel and many user groups.

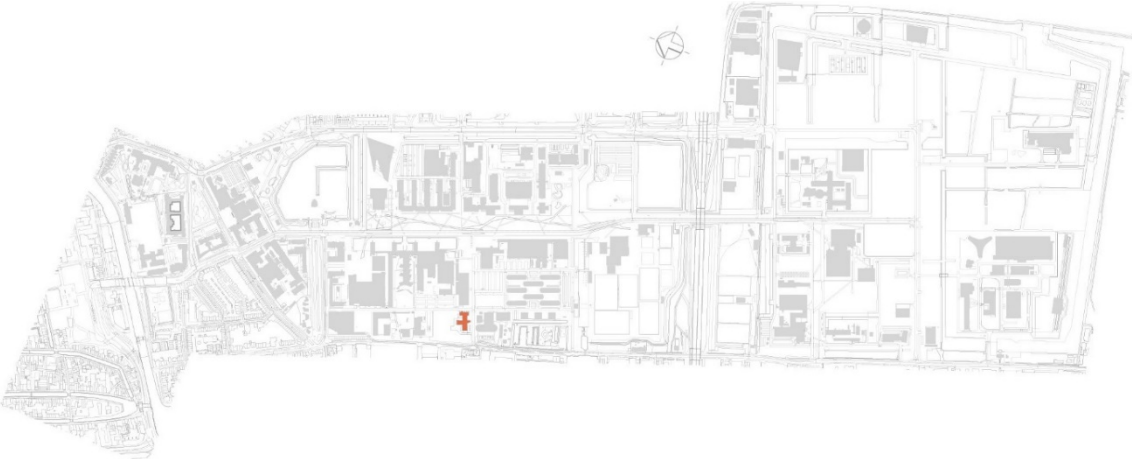


Figure 44: Location of the chosen building at the campus of TU Delft

Both buildings meet the set criteria. Therefore, the decision was made based on personal preference. Choosing a more difficult building seems to be the best option. It is a challenge more suitable for a graduation project and, if this difficult building can be made energy neutral, many more at TU Delft can. In conclusion, this thesis focuses on a refurbishment proposal for the Low Speed Lab (building 45).

6. BUILDING ANALYSIS

This chapter elaborates on the building analysis of the chosen building. The structure of this research is based on literature discussed in chapter 3.6 Building Analysis.

6.1.GENERAL DATA

Building number 45 at the campus is located at the Leeghwaterstraat, a road parallel to the Mekelpark. Since the construction in 1952, the building is housing a wind tunnel research lab of Aerospace Engineering, one of the faculties of TU Delft. This lab is called the Low Speed Lab (LSL) and is a low speed low velocity wind tunnel. In fact, the building was built around this three-storey high wind tunnel. To date, it is one of the best wind tunnels in its field.

Over the years the amount and type of users have changed. At the moment nine user groups are located in the building, of which the wind tunnel research group is still the largest.

Recently, the urban surroundings of this building have changed, because two adjacent buildings were deconstructed: containers for student housing and Rotterdamseweg 145, a former lab for aero- and hydrodynamics. These changes combined with plans of FMRE to improve the Leeghwaterstraat and build a new parking garage next to the LSL, make a refurbishment desirable.

With use of a datasheet developed by Ebbert (2010), a building inventory was conducted. Over time more and more information has become clear and has been added to the sheet. A summary of this data is given in Figure 45. The full datasheet can be found in Appendix: datasheets.

Name of building	45. L&R - Low Speed Laboratory/VSSD		
Address	Leeghwaterstraat 42, Delft		
Date of inventory	14-3-2017		
Contacts	**Company**	**Contact person**	**Phone**
Client	FMRE		
Building user			
Facility Management	FMRE	Thijn Forrer, asset manager	n.a.
Architect	Multiple	n.a.	
HVAC planner			
Structural engineer			
Fire Protection Engineer			
Facade expert			
Building history	**Year**	**Architect**	**Action / Comment**
Construction	1952	Ir. A. vd Steur	Rijksgebouwendienst
Refurbishment 1	1977	Drexhage, Sterkenburg, Bodon & Venstra (DSBV)	
Refurbishment 2			
Refurbishment 3			
General facts			**Comment**
Form of use (if multiple, relation in %)		research facility, office, educational and laboratory	
Orientation of the main entrance		east	
Building shape		open city block	
Urban setting		solitaire	
Number of floors above ground		five	
number of floors below ground		zero	

Figure 45: Example of filled in building inventory sheet

6.2. PHOTOGRAPHS

Taking pictures is an important step of the building analysis, because it saves time solving many questions that arise in other phases. Take many photographs and with much variation in:

- Position
- Time and season
- In- and outdoors
- Level of detail

Do not only make well balanced pictures for a report, but also capture the details and less appealing parts. For instance: lighting, mould, wall finishing, ventilation pipes, glare and people at work. All types of photographs will be useful at some point.

6.3.USER INTERVIEWS

The next step was getting information from the different users, like their wishes, their complaints and how they experienced the climate of the building. This was done by interviewing them. Again, a template of Ebbert (2010) was used. This template lists 'reasons to reconsider an existing building'. It is meant as a guide for building owners, but can be used for building users too. In total, five interviews were conducted. One with one of the owners and four with user groups. The student organisations at the first floor have not been interviewed, because these are small organisations and are expected to move within a couple of years.

Interviews with (in chronological order):

1. L&R; Henk-Jan Siemer
2. FMRE; Thijn Forrer
3. VSSD; Nanny Marks
4. OWee Bestuur: Jorik van Koppen
5. Hogeschool Inholland; Antoine Gerritse

FMRE and the LSL-group both agreed that the wind tunnel will be used for a long time, simply because it is a good wind tunnel. However, the building has been overlooked, one could even say neglected, for years. The current condition level is Moderate. Since the main part of this building, the wind tunnel, will be used for many years to come, the building should be brought to a better condition level. However, FMRE wants to maintain the condition it is in until 2026. By then, new plans will be made. For now, the only planned interventions are painting the facades and updating the roof coverings.

The difference in flexibility of user groups is very interesting. The wind tunnel research group and Inholland are both bound to this location. The wind tunnel research group because of an immovable wind tunnel, Inholland because of a recent financial investment. On the other hand, the VSSD, OWee Bestuur and the other student organisations do not need an office in this building. They could just as easily move to another building at the campus.

Interesting results of these interviews will be discussed in an architectural building analysis in chapter 6.6. A summary of the 'reasons to reconsider' is given in Table 13. It shows that:

- Users have many arguments in favour of a refurbishment.
- The low speed research group can address most arguments.
- The asset manager in not yet informed or not acknowledging the arguments of the building users.
- The arguments mentioned most are (by three interviewees):
  - Decay of valuable architectural heritage
  - Change / optimising of office concept
  - Unpleasant indoor conditions – users' complaints
  - Lack of insulation
  - Users' representation need

- There is no argument that all users agree on.
- The climate differs greatly between the ground and top floors.

Table 13: Summary of reason to reconsider an existing building, taken from Ebbert (2010)

Summary: Reasons to reconsider an existing building			U	O	U	U	U	∑
Building immanent factors	Urban design	Desired improvement of the urban quality						
		Prevent vacancy as a cause for social problems in a neighbourhood						
	Architectural design	Outdated appearance	X			X		2
		Exterior impression bad for social problems in a neighbourhood						
		Decay of valuable architectural heritage	X		X	X		3
	Function	Transformation of the building						
		Change / optimising of office concept			X	X	X	3
	User comfort	Unpleasant indoor conditions – users' complaints	X		X		X	3
		Hygienic problems						
		Sick building syndrome (SBS)						
		Building related illness (BRI)						
	Technical installations	High operational energy demand	X					1
	Hazardous material	Asbestos	X				X	2
		PCB	X					1
		PAK	X					1
		MMMF	X					1
	Building physics	Lack of insulation	X			X	X	3
		Wind leaks – draft				X	X	2
		Water leaks	X					1
		Fire protection deficiencies	X					1
		Planning for climate change						
	Building owner/user	Tenant considers relocation			X			1
		Owner user initiates renovation	X					1
Legal reasons	Fire regulation	Compulsory fire safety improvements						
	Safety	Danger of damage to third party						
	Energy consumption	Compulsory energy consumption certificate (energy passport) for resale or rental contracts						
Economic reasons	Operational cost	High energy demand	X			X		2
		High maintenance cost						
	Lettability	Bring an empty building back to the market						
		Tenant considers relocation						
	Marketing	Users' representation need	X	X			X	3
	Financial market	Institutional investors are bound to invest						

6.4. OCCUPANCY SCHEDULES

One of the questions in the interview is about working hours and occupancy schedules. The reason to ask this question, was to get insight in the behaviour of the different users. For the energy consumption, it is interesting to know if they work regular office hours, if they have peak intensity in certain months and how many users are present at a certain time. As the student organisations were not part of the interviews, this question was asked separately.

The occupancy schedules provide is interesting information for the next phase: design solutions for energy reduction. If the users can adjust their consumption to the energy generation of the building, this will decrease the peaks. Figure 46 and Figure 47 show the occupancy schedules for the users of the LSL.

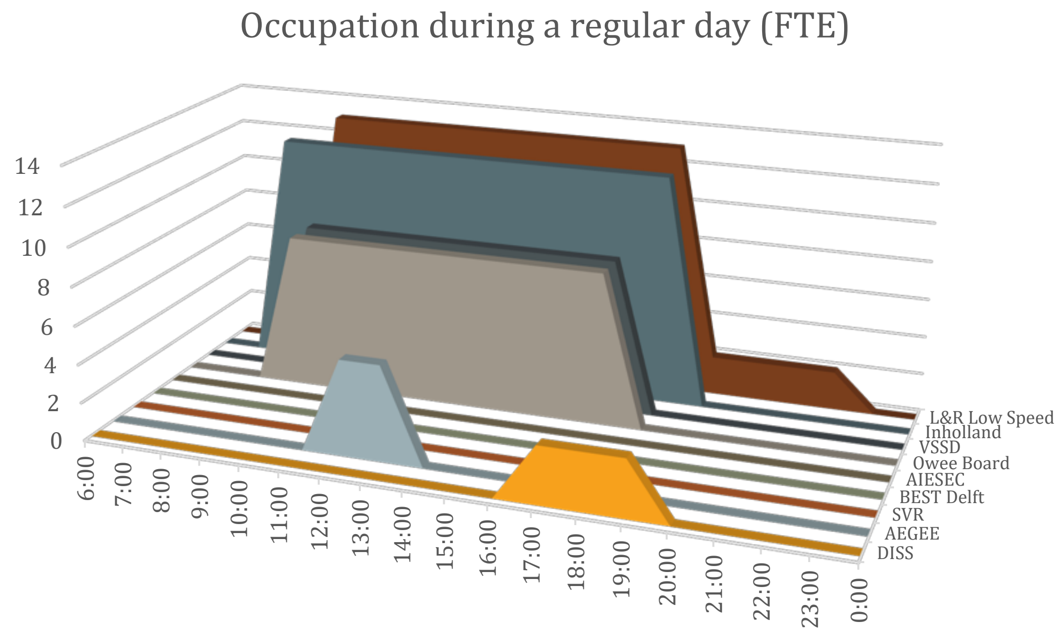


Figure 46: Occupation during a regular day (FTE)

Except for the student organisations, the users have regular work hours from 9:00 to 17:00. Inholland usually starts an hour earlier than the wind tunnel research group. And it often happens that experiments in the wind tunnel take longer than expected or are planned in the evening, so there are often people there until 23:00.

AEGEE comes together almost every lunch to have a meeting. On the contrary, DISS usually meets a few times a week in the evening. Information of the other three student organisations (AIESEC, BEST Delft and SVR) has not been shared.

The biggest differences can be seen in Figure 47. Most student organisations have a lower occupation during summer, while other work all year round. The OWee Bestuur is the most irregular user: this group does not work all year round and stops after the introduction week in August.

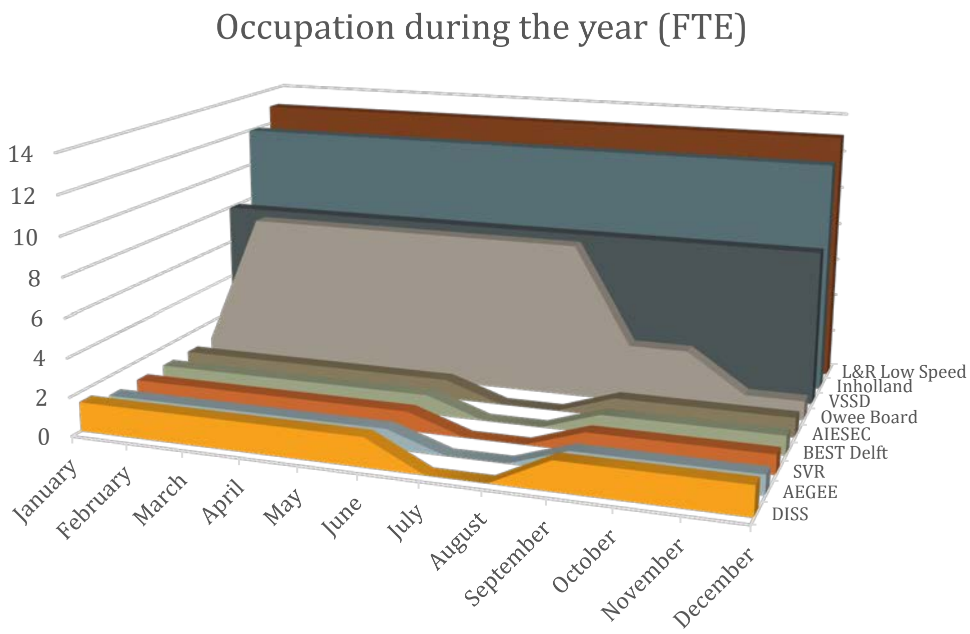


Figure 47: Occupation during the year (FTE)

6.5.ENERGY CONSUMPTION

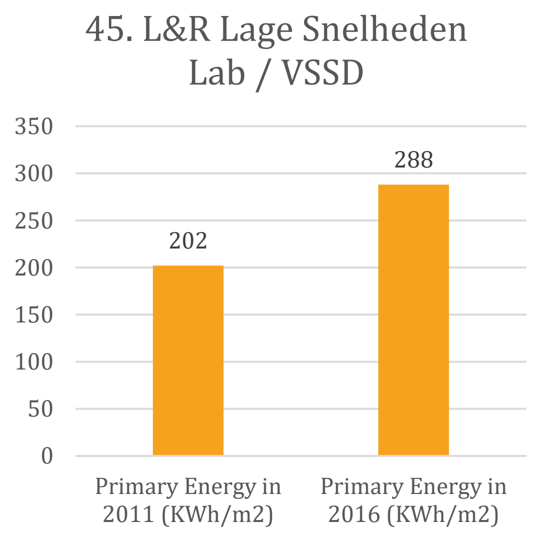
In chapter 4.2 the energy consumption of buildings on the TU Delft campus is described. In this chapter, that data is used to analyse the energy consumption of the LSL. Next to that, additional data of www.energymonitor.tudelft is made visual.

Key energy data for building 45. Low Speed Lab / VSSD includes (FMRE Energy, 2013):

GFA in m2	*3458*	*Primary energy in 2011 (KWh/m2)*	*202*
		Primary energy in 2016 (KWh/m2)	*288*
Heat (m3 a.e.)	*44431*	*Heat (KWh/m2)*	*155*
Natural gas (m3)	*0*	*Natural gas (KWh/m2)*	*0*
Electricity (MWh)	*220*	*Electricity (KWh/m2)*	*136*

Figure 49 gives a summary of the graphs in chapter 4.2. The increase in primary energy between 2011 and 2016 can be explained by the increase in building users. For example, Inholland moved to the building in 2015 and moved a dozen employees and numerous highly consuming machines.

On average, 45% percent of the primary energy of campus buildings is used for heating. The LSL only heats the building using the heat network at the campus. This indicates that 54% of the buildings energy is used for heating. There is no gas connection nor consumption.



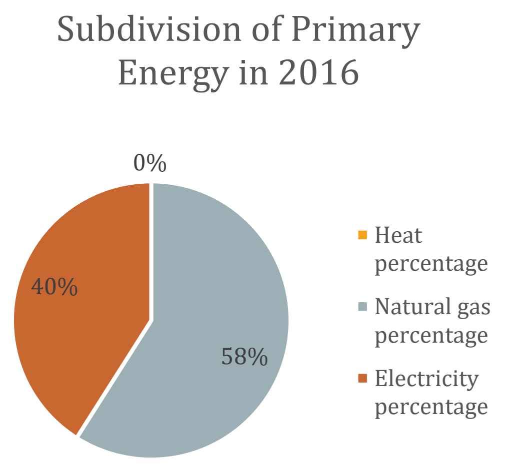
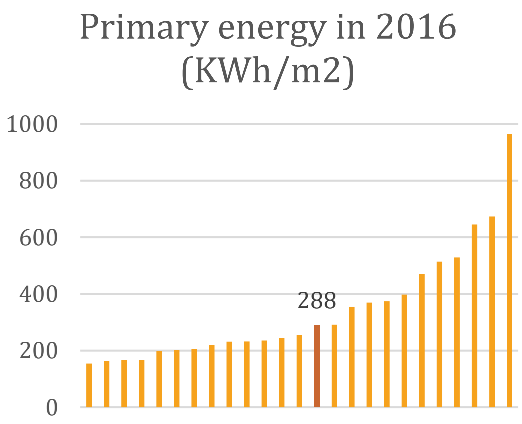


Figure 48: Primary energy consumption of building 45 in 2011 and 2016

Figure 49: Subdivision of Primary Energy

Figure 50 and Figure 51 show an energy comparison between the LSL and other campus buildings. The LSL is marked in red. The LSL is not one of the most consuming buildings.



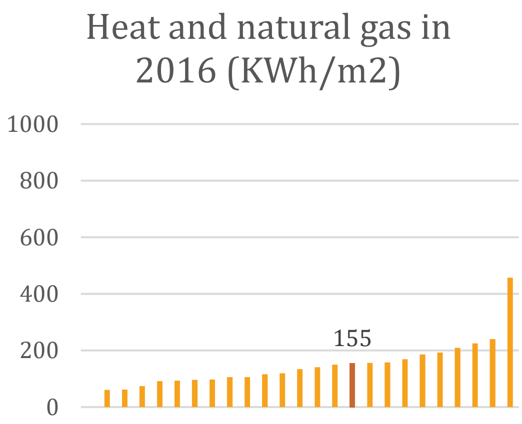
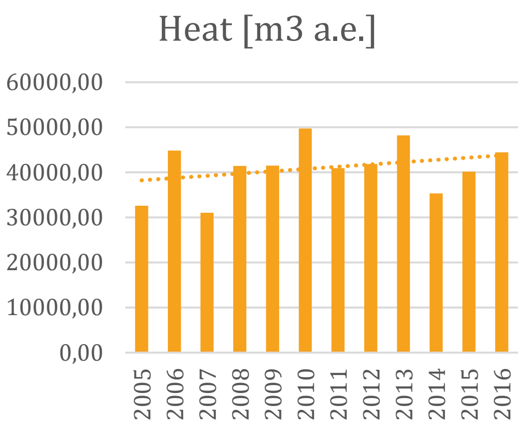


Figure 50: Primary energy consumption in 2016 in comparison to other campus buildings

Figure 51: Heat and natural gas consumption in 2016 in comparison to other campus buildings

There seems to be no changing trend in the heat consumption (Figure 52). The electricity consumption does show a clear trend between 2005 and 2016 (Figure 53). The period from 2013 to 2014 was a turning point. Up until then, the annual consumption decreased steadily, but since 2013 the electricity consumption has doubled. This could be explained by the construction works for Inholland and them moving in. In the years prior to their movement to LSL, the first floor was empty. Furthermore, can be concluded that the heat consumption has not increased much due to the arrival of Inholland, but the electricity consumption has.



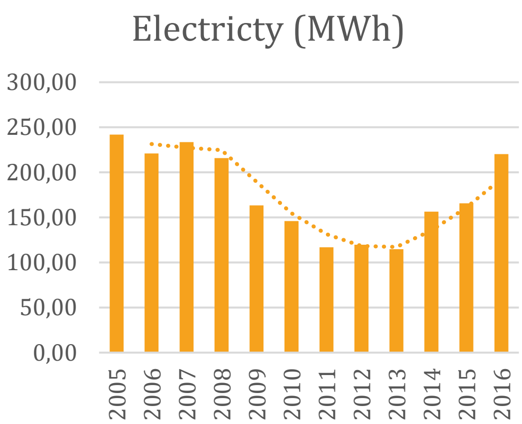


Figure 52: Heat consumption in the years 2005-2016 (FMRE Energy, 2013)

Figure 53: Electricity consumption in the years 2005-2016 (FMRE Energy, 2013)

Figure 54 presents a closer look at the energy consumption between 2013 and 2016. The amount of heat that is taken from the network varies per month, but the total per year is approximately the same each year. This variation is similar to other buildings: a peak in winter and the lowest point in summer. The consumption is often 0 m3 in July and August.

Both the heat and electricity consumption have increased since 2013, but the electricity pattern does not show a clear variation. Overall, the consumption increases. In general, the LSL consumes about as much heat and electricity as ten years ago. This does not correspond to the aim of TU Delft to bring down the total energy consumption.

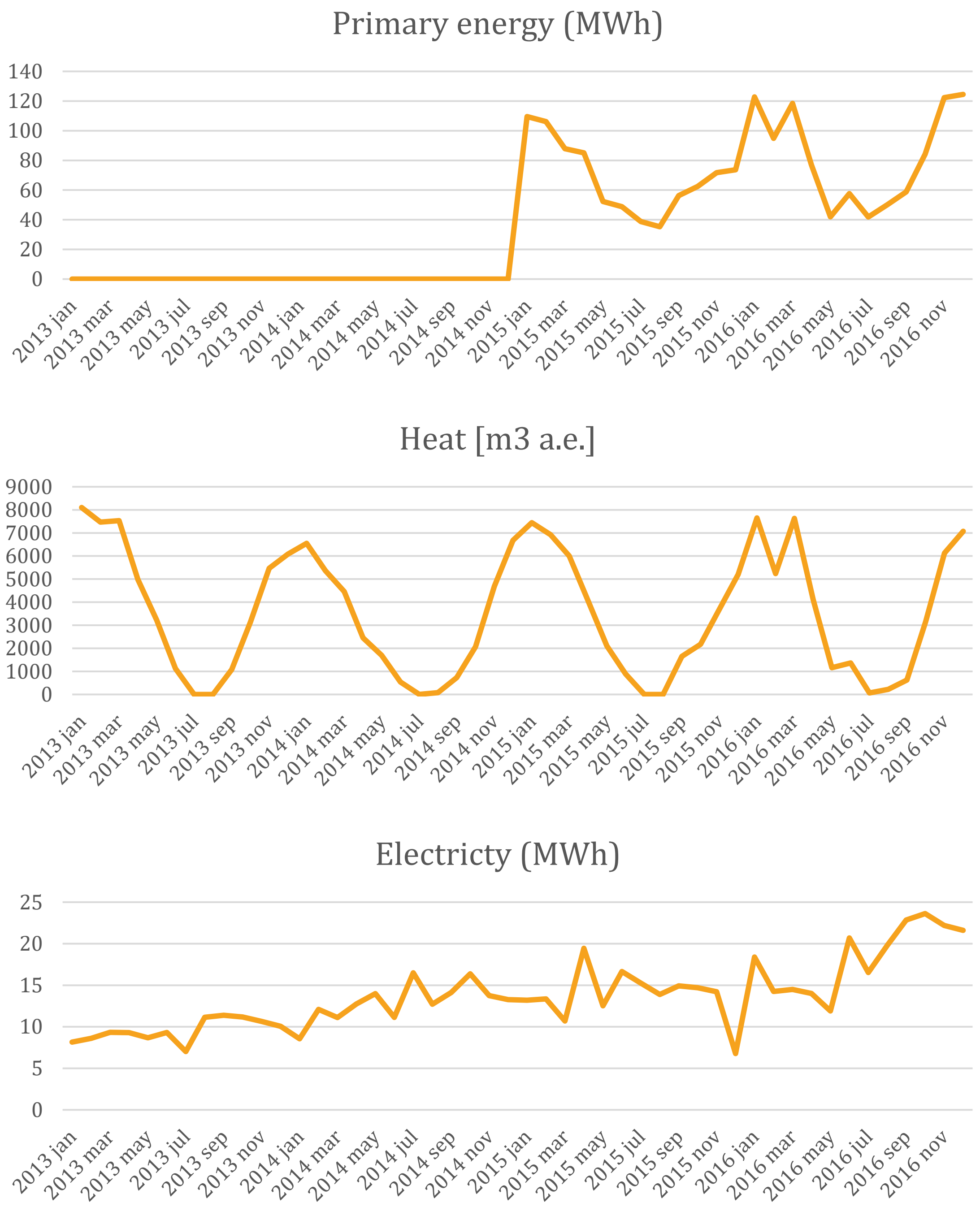


Figure 54: Primary energy, heat and electricity consumption per month (2013-2016)

6.6. BUILDING ANALYSIS

The following pages will show drawings with building analyses on different scales. Four scales are used: campus, district, building and detail.

- CAMPUS
  - Appearance
  - Building typology in 2015
  - Building typology in 2017
  - Relation to other buildings
- DISTRICT
  - Building typology
  - Solar study
  - Construction years (comparison)
  - Construction years
  - Entrances
  - Traffic in 2020
  - Water and green
- BUILDING
  - Users in 2017
  - Users from 1952 to 2017
  - Building phases
  - Walking routes
  - Solar study
  - Climate
  - Issues
  - Energy consumption
- DETAIL
  - Facades
  - Façade materials

Scale: 1:10000
Central area of the campus
Leeghwaterstraat project
Important buildings for the campus
Project area Leeghwaterstraat
Mekelpark
Kluyverpark

(left) Figure 55

CAMPUS – Appearance

TU Delft’s campus is very elongated and most faculties are located along a central axis: The Mekelpark. This 80-metre-wide park used to be a road and was transformed in to a public park about ten years ago. Since then it has become even more of a landmark for TU Delft. The oldest buildings at this campus are located along the Mekelpark. The green axis stretches to the southern part of the campus. The green park in the south is called Kluyverpark. This park is in between the faculty of Aerospace Engineering and building TNW-Zuid. Over time, more buildings will arise in this area and the importance of the Mekelpark might decrease.

However, the majority of the buildings do not face the Mekelpark and therefore do not belong to this landmark. They are located at the perimeter and are viewed upon less. So is building 45. L&R Low Speed Lab.

TU Delft wants to make the campus more attractive by creating a more extensive cycle and pedestrian network in a partly car-free area. Therefore, areas that currently have a lot of traffic and parking places, will have more greenery and space for cyclists and pedestrians. The Leeghwaterstraat is part of this change and will become a street for cyclists where cars can drive as 'guests'. Figure 56 shows a proposal for the area around the LSL, including a new multi-storey parking garage.

Strategy: Let the building fit into the new urban setting (bicycle lane, parking garage, park).

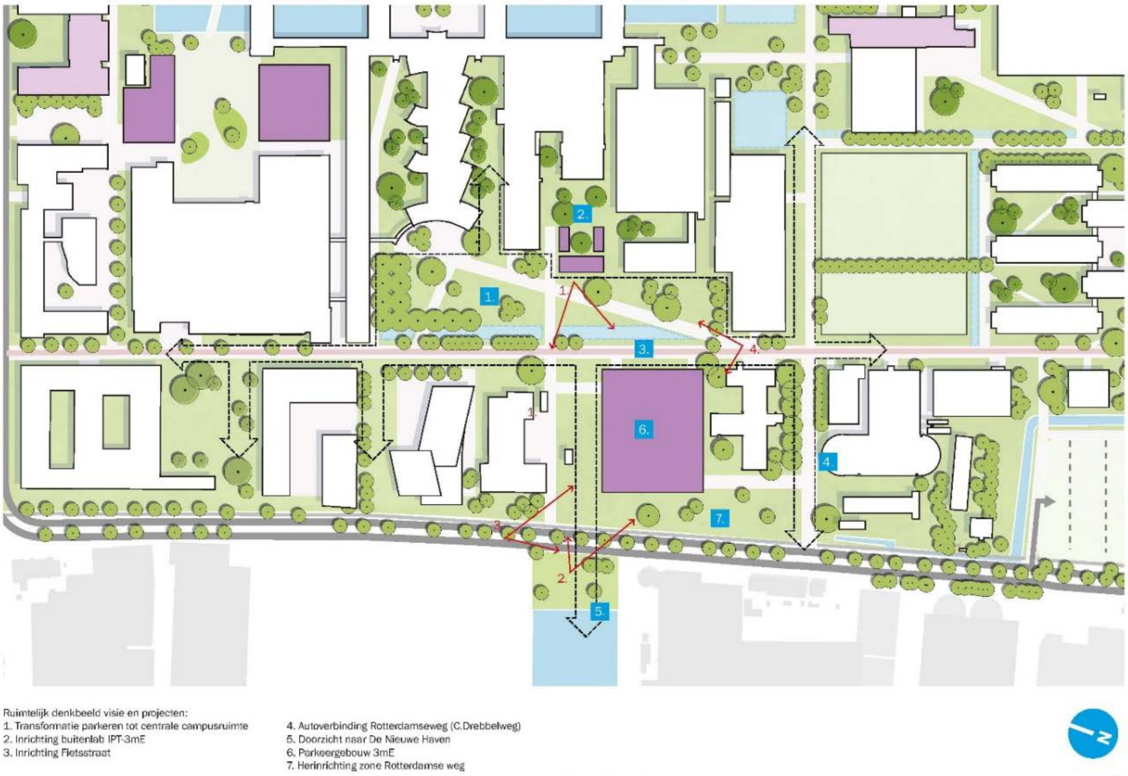


Figure 56: Proposal for park and parking garage (Karres+Brands, 2017)


Scale: 1:10000
Academic
TU Delft related companies
Housing
Sport & Leisure
Utility
TU-noord
TU-midden
TU-zuid /
Technopolis

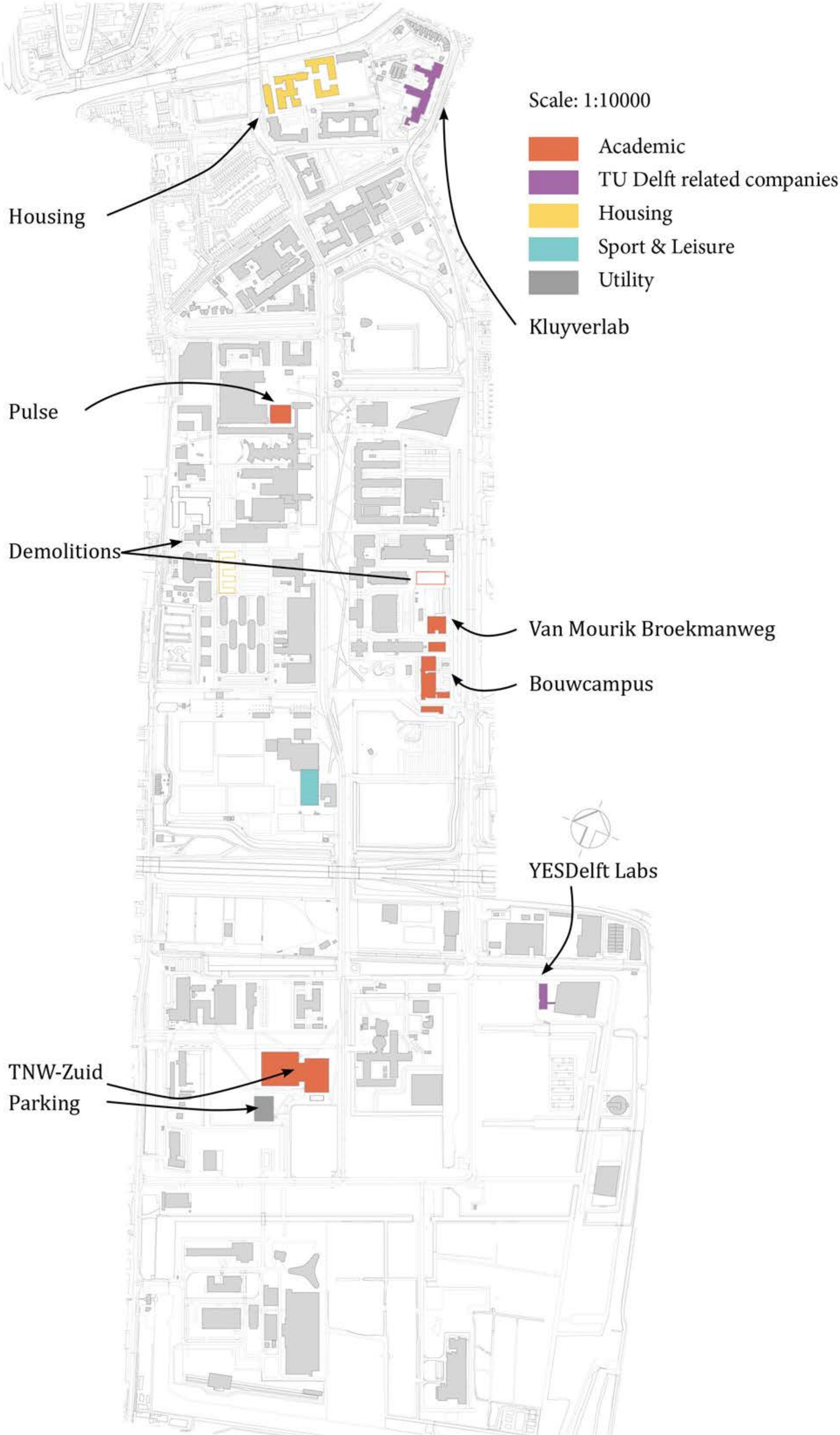
(left) Figure 57

CAMPUS – Building typology in 2015

The campus is divided in three areas: TU-noord, TU-midden and TU-zuid. The northern part is the oldest (1900-1950) and the southern part is the newest (1970-2017).

Most buildings at the campus are used for academic purposes (education, research, administration). In recent years, the campus has also become a place for TU Delft related companies. This varies from research institutes to buildings for start-ups. In 2015, nine student housing complexes were located on the campus, most of which are located in TU-midden.

Strategy: Improve the urban setting of the building.


Scale: 1:10000
Academic
TU Delft related companies
Housing
Sport & Leisure
Utility
Housing
Kluyverlab
Pulse
Demolitions
Van Mourik Broekmanweg
Bouwcampus
YESDelft Labs
TNW-Zuid
Parking

(left) Figure 58

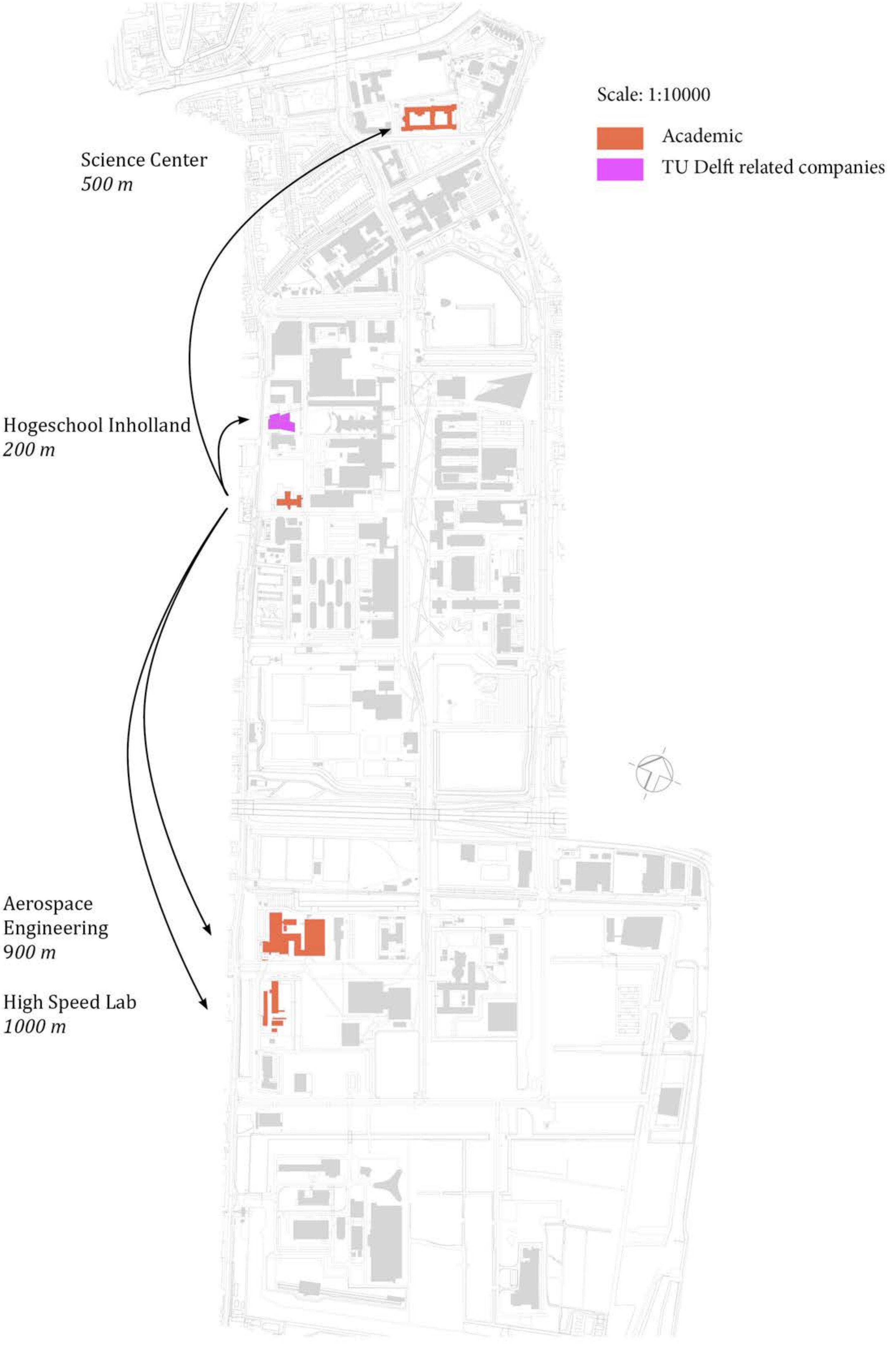
CAMPUS – Building typology in 2017

Quite a few changes to the building stock have taken place between 2015 and the end of 2017: six new buildings were built, three buildings were demolished and six buildings received a different function. Over time the campus will slowly shift to the southern part of the campus, but for now the focus is still on TU-Midden.

- In TU-noord three buildings changed function to student housing and the Kluyverlab, coloured purple, is no longer in use for academic purposes.
- In TU-midden, three buildings were demolished, two are being built and two have newly been added to the building stock.
- In TU-zuid, three new buildings have been built: a faculty, a parking garage and a building for start-ups.

The only changes that directly influence the LSL are two of the demolitions.

Strategy: Let the building fit into the new urban setting (bicycle lane, parking garage, park).



Scale: 1:10000
Academic
TU Delft related companies
Science Center
500 m
Hogeschool Inholland
200 m
Aerospace
Engineering
900 m
High Speed Lab
1000 m

(left) Figure 59

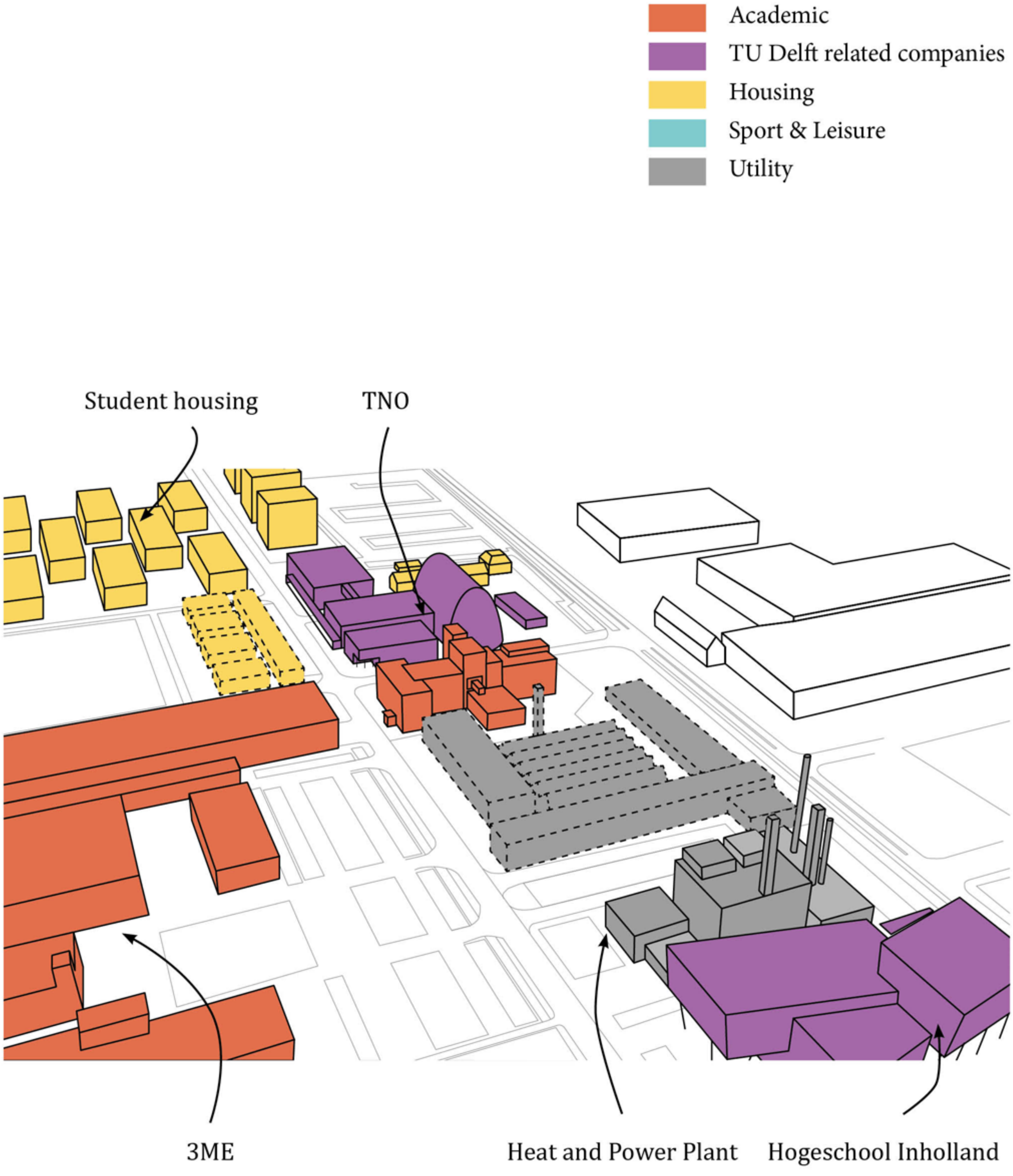
CAMPUS – Relation to other buildings

The Low Speed Lab is connected to four other buildings at the campus: Hogeschool Inholland, the faculty of Aerospace Engineering, the High Speed Lab and the Science Center.

Inholland is located at walking distance, but the others are not. The employees are required to travel in between buildings. At the moment, this is not easy for all building users as the morphology of the building does not allow for easy travel.

From a geological point of view, it would make more sense to move the LSL-group to TU-zuid, as all other Aerospace activities take place there too. However, the wind tunnel cannot simply be relocated.

Strategy: Make travelling between related buildings easier.


Academic
TU Delft related companies
Housing
Sport & Leisure
Utility
Student housing
TNO
3ME
Heat and Power Plant
Hogeschool Inholland

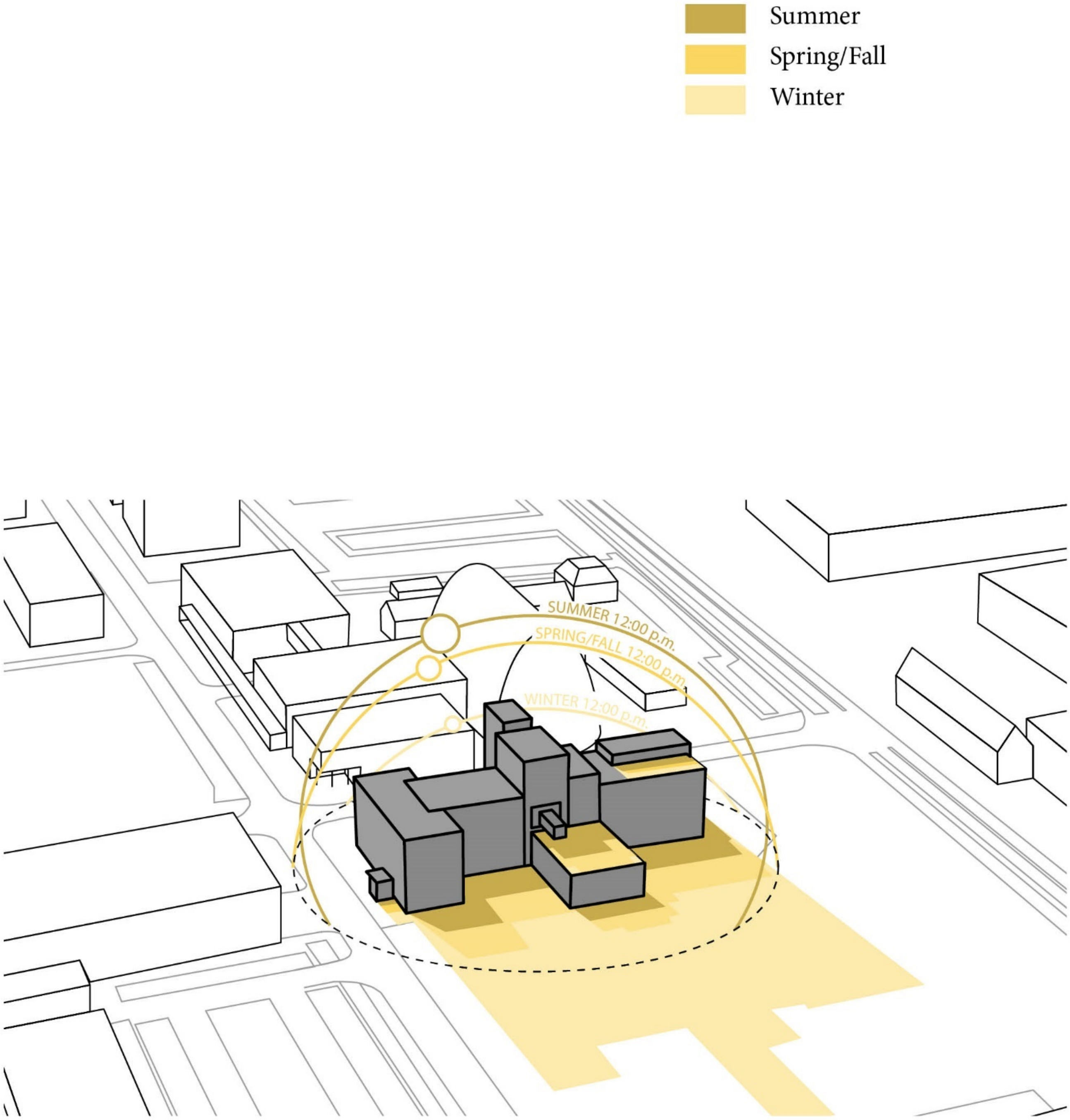
(left) Figure 60

DISTRICT – Building typology

The Low Speed lab and the surrounding buildings do not have matching building volumes. Neither do they match in materialisation, size, floor height or orientation. It looks like hardly any thought has been put in to the urban setting.

The LSL is located on an empty plot, because building 44 has been demolished. It's (new) neighbours are the Heat and Power Plant, study halls at the Drebbelweg and TNO.

Strategy: Let the building fit into the new urban setting (bicycle lane, parking garage, park).


Summer
Spring/Fall
Winter
SUMMER 12:00 p.m.
SPRING/FALL 12:00 p.m.
WINTER 12:00 p.m.

(left) Figure 61

DISTRICT – Solar study

The orientation of the building has carefully been studied in both building phases (1952 and 1979). The architects have put thought into keeping the heat out and letting northern light in, but failed to accomplish a balanced climate.

The north façade is shaded most of the year due to the building volume and surrounding buildings. The trees on the south side shade most of the roof surface in summer. While doing so, the trees partly protect the building from overheating.

	Winter solstice	Hours	**Spring/ Fall equinox**	Hours	**Summer solstice**	Hours
East	10:30-12:00	1:30	08:30-12:30	4:00	06:30-13:00	6:30
South	10:30-17:00	6:30	08:00-18:00	10:00	08:30-17:00	8:30
West	12:00-17:00	5:00	13:00-20:00	07:00	13:00-21:00	8:00
North	no	0:00	18:00-20:00	2:00	17:00-21:00	4:00

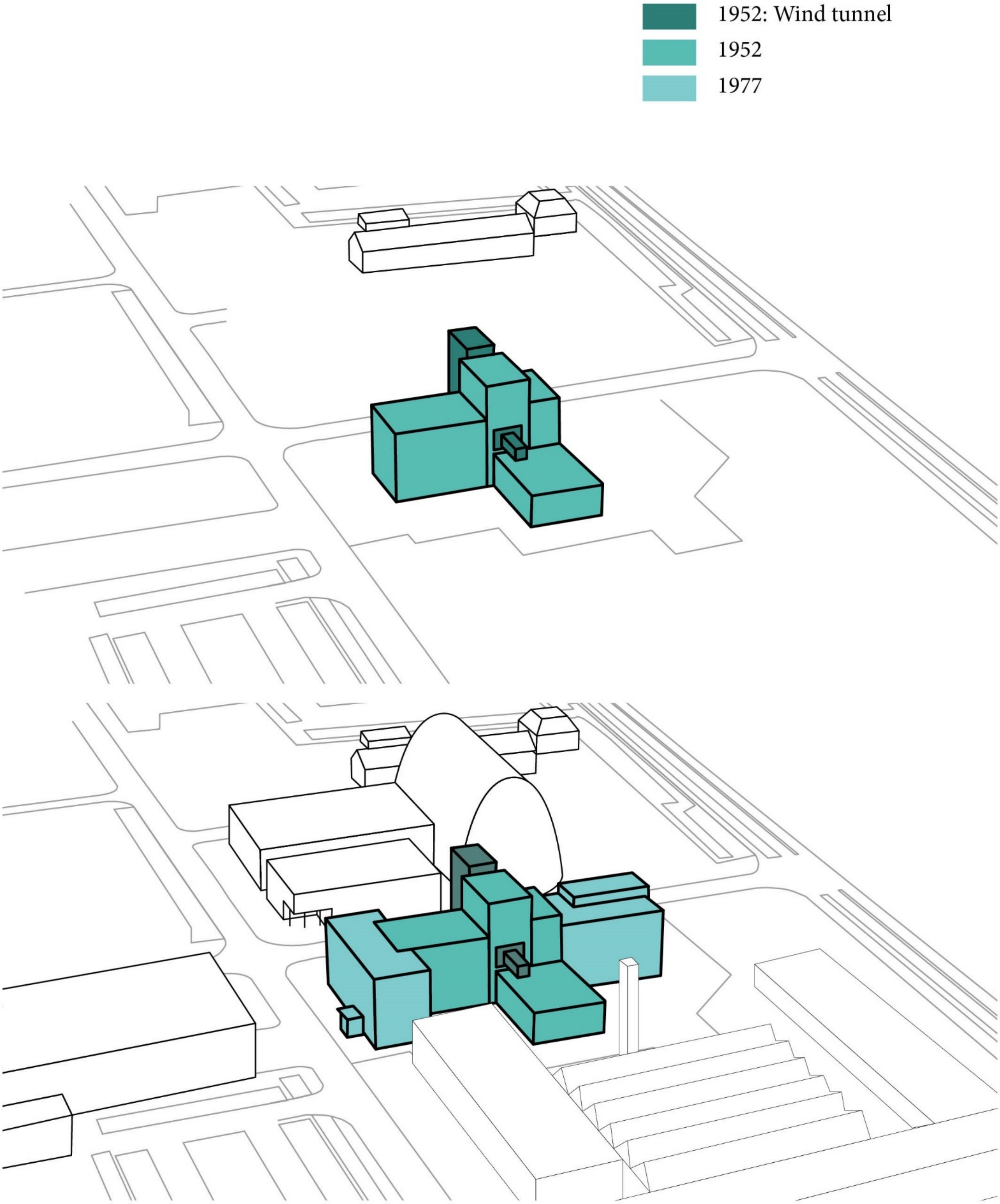
If over 50% of the façade is lit, the hours are counted.

Table 14: Hours of sunlight per façade and season, based on data of Revit.

The hours of light per façade are listed in Table 14. On summer mornings, the east wing has direct daylight. And from 17:00 till sunset, the north façade also has direct sunlight too. This is past working hours, but still heats up the building even more.

In fall and spring, sunlight hardly reaches the north facade. This is a benefit when it comes to glare protection, but not enough daylight reaches the offices located at the north side.

Strategy: Let in more daylight and reduce overheating


1952: Wind tunnel
1952
1977

(left) Figure 62

DISTRICT – Construction years (comparison)

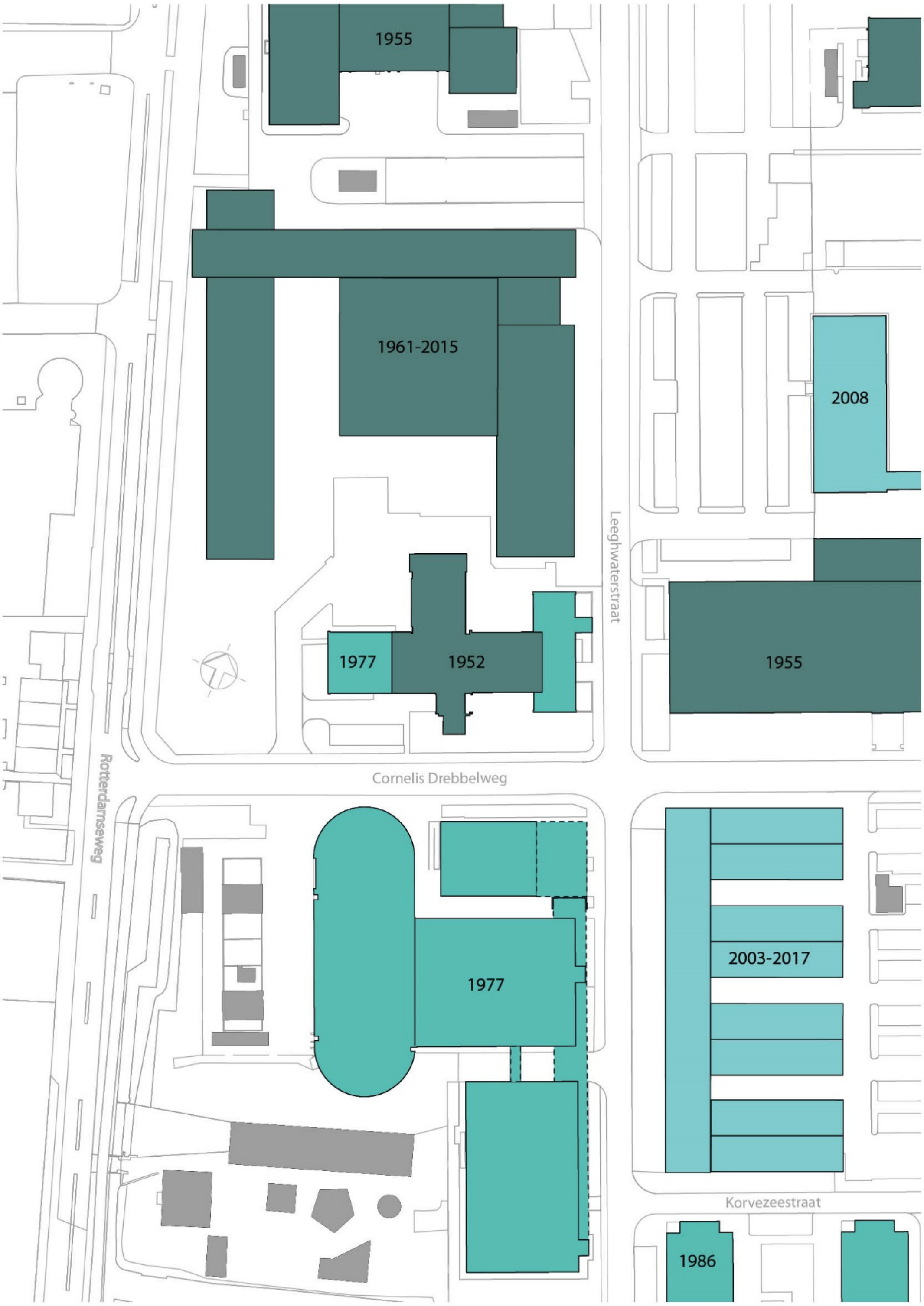
In 1952, the construction of this building took place on a greenfield. The nearest building was a farm. A few years later, the Combined Heat and Power Plant was built.

The construction of the building started with the construction of the monolithic wind tunnel. In fact, it is not attached to the building. Then the other volumes were built around it. These were solely used for research and preparation of the tests. The entrance was located at a logical place (symmetrical) at the Leeghwaterstraat.

In 1977, two building volumes have been added to the existing building. The main entrance remained at the Leeghwaterstraat, but slightly moved. The interior staircases changed a lot. The additions made it larger, but not better.

Strategy: Simplify building volumes and make the wind tunnel a focus point.

Scale: 1:1500


1955
1961-2015
2008
1977
1952
1955
Leeghwaterstraat
Rotterdamseweg
Cornelis Drebbelweg
1977
2003-2017
Korvezeestraat
1986

(left) Figure 63

DISTRICT – Construction years

Apart from the farm in the low left corner, the LSL is the oldest building in this district. The building ages of the surrounding buildings vary greatly. The LSL is built in two phases, exactly 25 years apart.

Two nearby buildings have been demolished in 2015 and 2016. This has a big influence on the context because two neighbouring buildings are suddenly missing. In the coming years the field on the north of the LSL will be filled with a new parking garage.

Strategy: Bring more unity in the urban setting.

Scale: 1:1500

Main entrance
Side entrance
Deliveries

(left) Figure 64

DISTRICT – Entrances

In contrast to the Mekelpark, the entrances in this district are not located along one axis. This makes it unclear where one should enter the buildings, including the LSL. Most buildings have a main entrance, multiple side entrances and one for deliveries.

TNO has several entrances and it remains unclear which ones are used most. The only entrance used to reach the Drebbelweg halls is located at the Drebbelweg. For this particular building it is very logical that it is located at this street. On the other side, the Combined Heat and Power Plant its entrance is not located at a street, but symmetrically placed in the building.

In the user interviews, the users mentioned that they would like to have a second entrance to reach the west wing of the LSL.

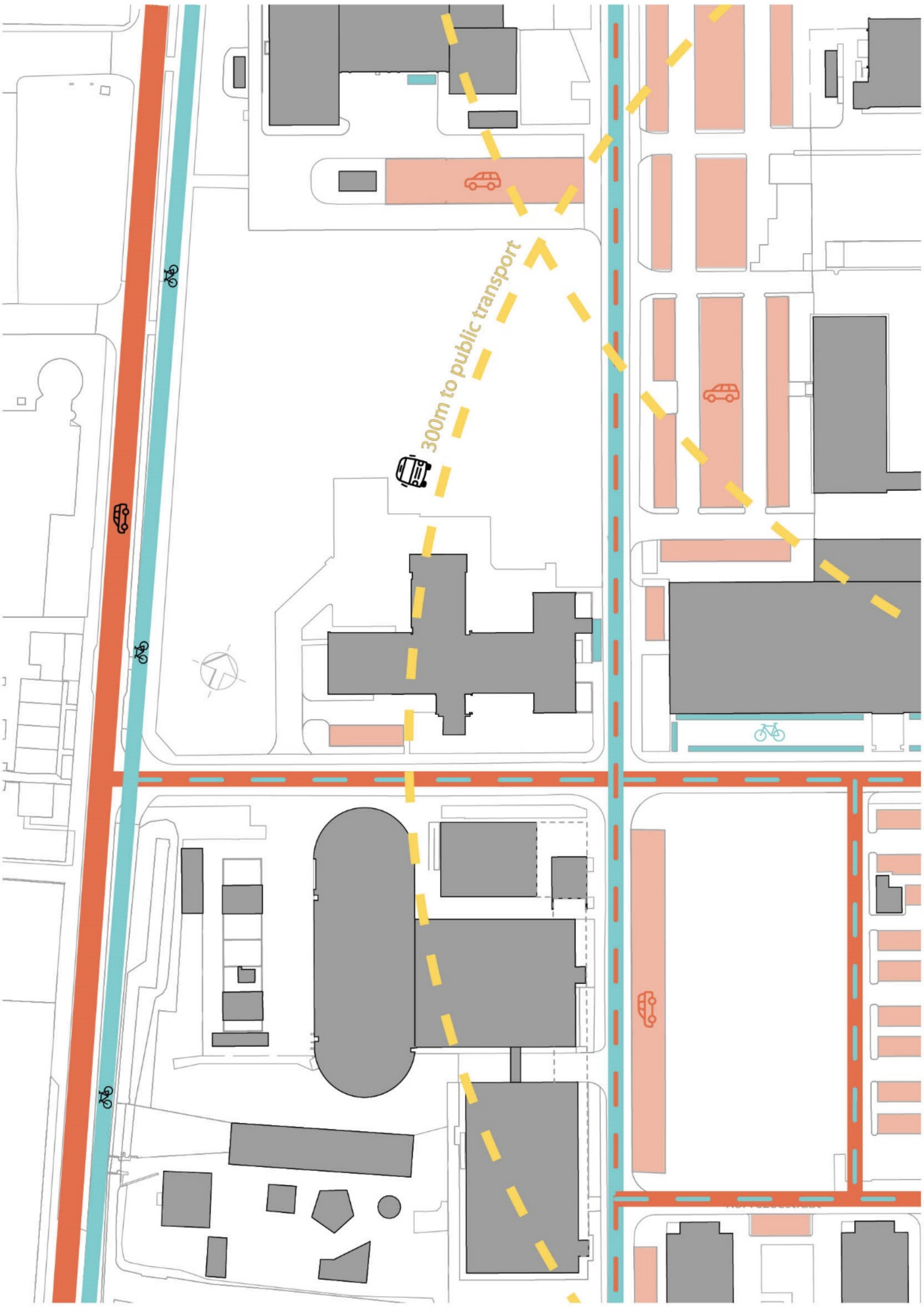
Strategy: Make an entrance that is logical for both users and visitors.

Scale: 1:1500

Car traffic

Bike traffic

Public transport



(left) Figure 65

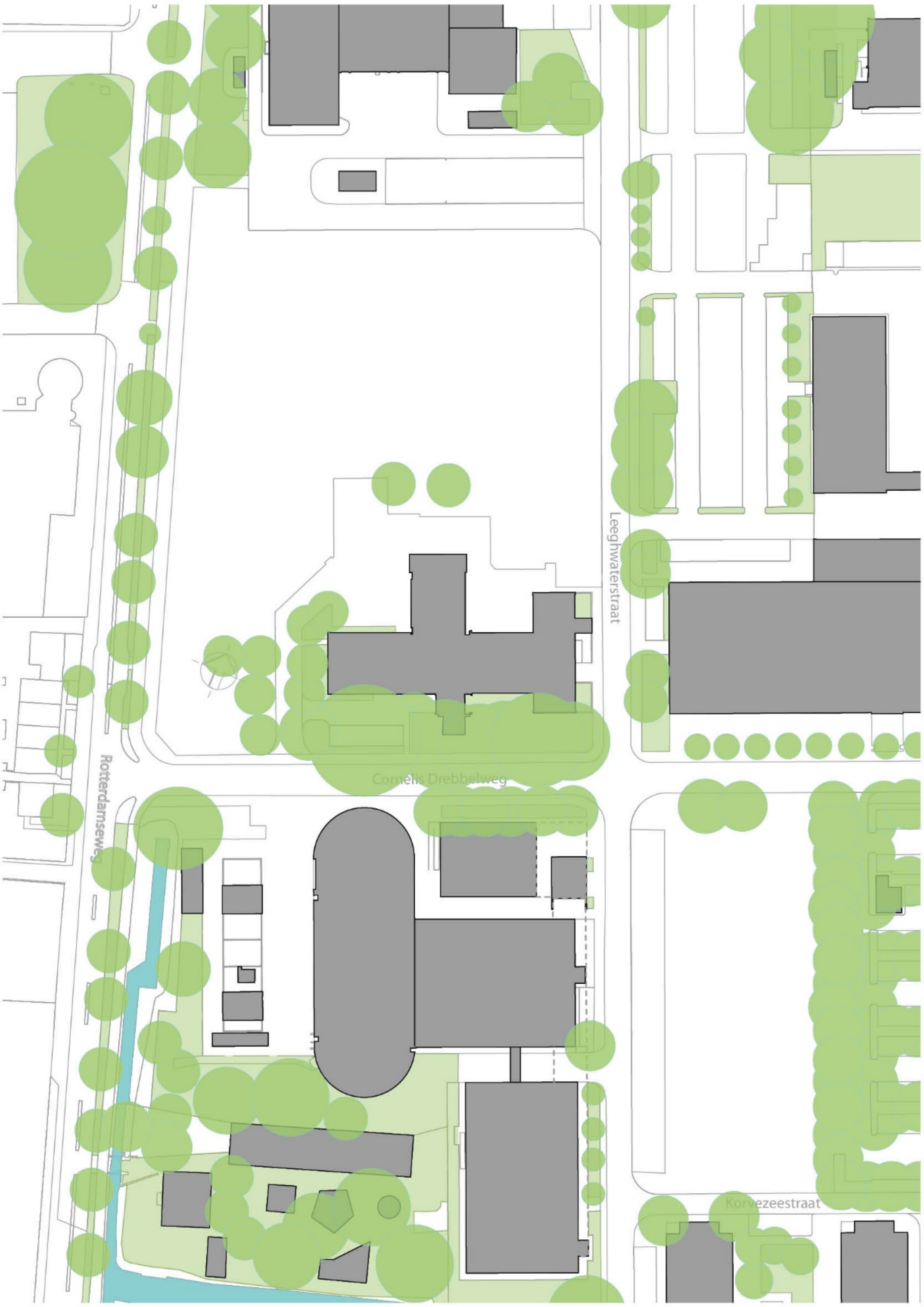
DISTRICT – Traffic in 2020

The Low Speed Lab can easily be reached by car, bicycle, foot and public transport. The Leeghwaterstraat will change between now and 2020 from a car street to a cycling street. It will become the third bicycle axis parallel to the Mekelpark. This also means car traffic will be banned to the perimeter.

Strategy: Make more bicycle parking places and prioritise cycling traffic over car traffic.

Figure 66: Impression of future bicycle lane at the Leeghwaterstraat (TU Delft, 2017)

Scale: 1:1500



Leeghwaterstraat
Rotterdamseweg
Cornelis Drebbelweg
Korvezeestraat

(left) Figure 67

DISTRICT – Water and green

At the south side of the LSL, many large trees are located. The amount of trees and public green are not well spread out over the area. And in comparison to the Mekelpark, there is hardly any space for public use. The current proposal for the redevelopment of the Leeghwaterstraat looks promising (Figure 56).

Strategy: Place more planting on the north side of the building.


Scale: 1:100
Low Speed Lab (Aerospace)
Inholland
Student organisations
OWee Bestuur
VSSD
Utility
Stairs and hallways

(left) Figure 68

BUILDING - Users

The building consists of five different user categories in the building and there are nine users in total. The Low Speed Lab uses the biggest floor area. Half of the ground floor is utility space. LSL and Inholland have spaces with a high ceiling height. The layout of these two users can only change so much. The others can change.

The OWee Bestuur has a room on the ground floor, right next to the entrance. They also have a shared meeting room on the first floor. As mentioned before, these users are not there all year round.

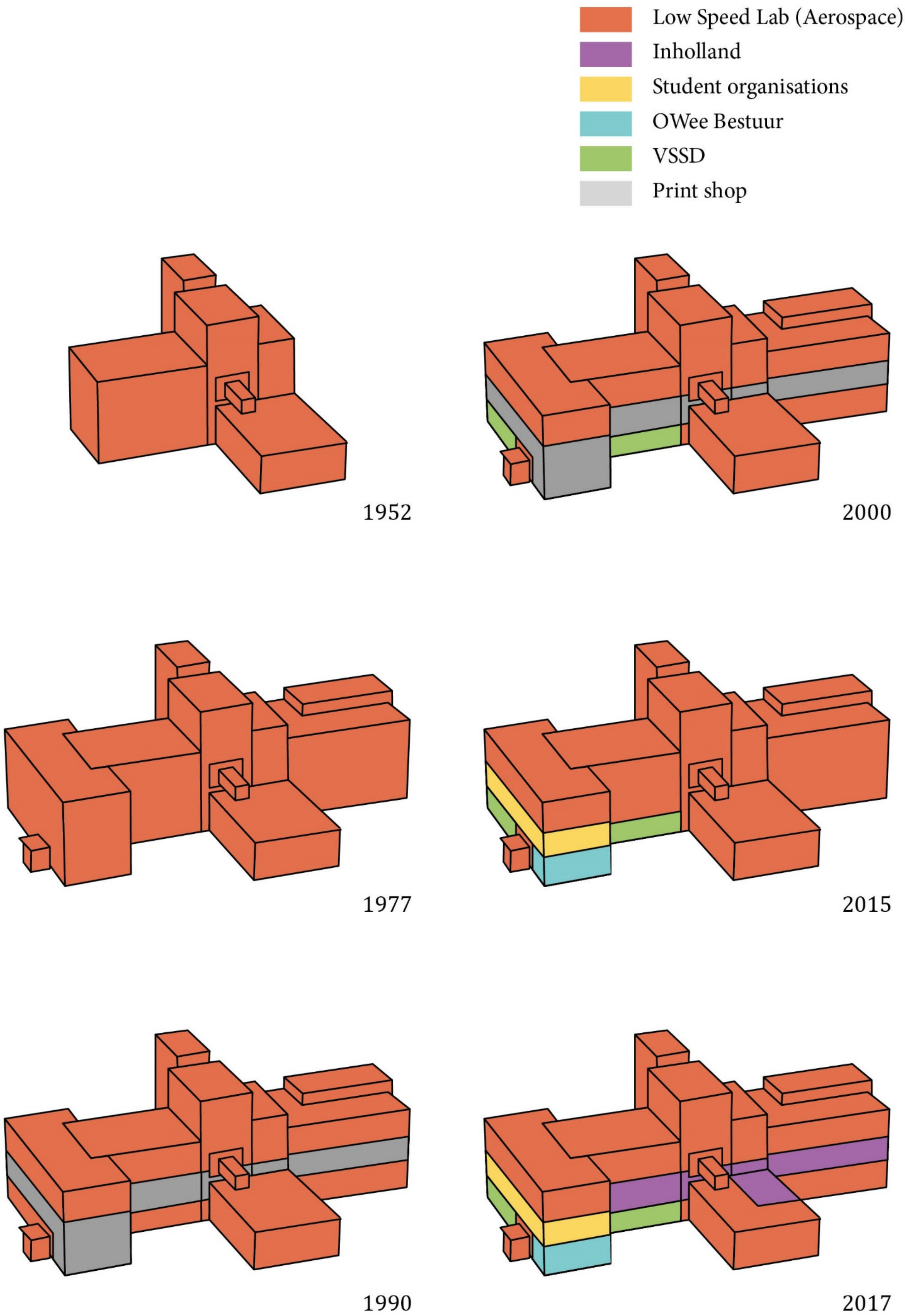
VSSD has a series of offices and rooms on the ground floor, some of these are at the entrance. One of the rooms is a meeting room and most others are offices or storage rooms. These offices have a low ceiling height and are relatively small.

The student organisations all have their own office at the first floor. They also share a kitchen and meeting room. The rooms are relatively small and have a low ceiling height.

Inholland rents most of the first floor, most of the technical room on the north side and the vertical wind tunnel. The office space is located on the west side of the building. The ceiling height is sufficient for a spacious office and the machine halls. including a small kitchen.

All grey coloured areas are technical, utility or storage space.

Strategy: Make the building flexible enough to accommodate different types of users.


Low Speed Lab (Aerospace)
Inholland
Student organisations
OWee Bestuur
VSSD
Print shop
1952
2000
1977
2015
1990
2017

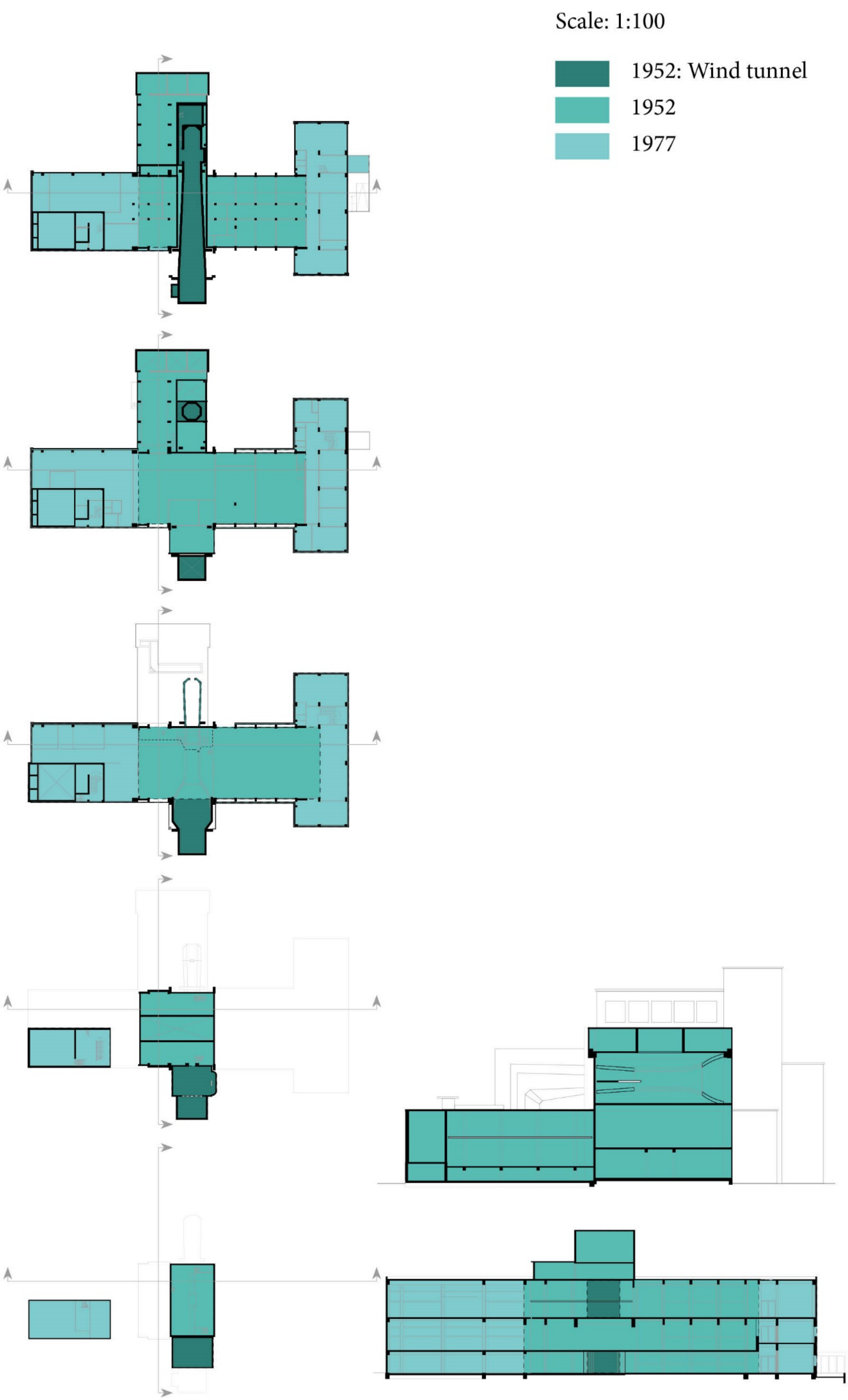
(left) Figure 69

BUILDING – Users from 1952 to 2017

The wind tunnel research group has always been the main user of this building, but has gained and lost space over time. The number of users has increased over the years from one to nine.

It is logical that the users will keep changing over time. The only constant factor is the presence of the wind tunnel research group.

Strategy: Make the building flexible enough to accommodate different types of users.


Scale: 1:100
1952: Wind tunnel
1952
1977

(left) Figure 70

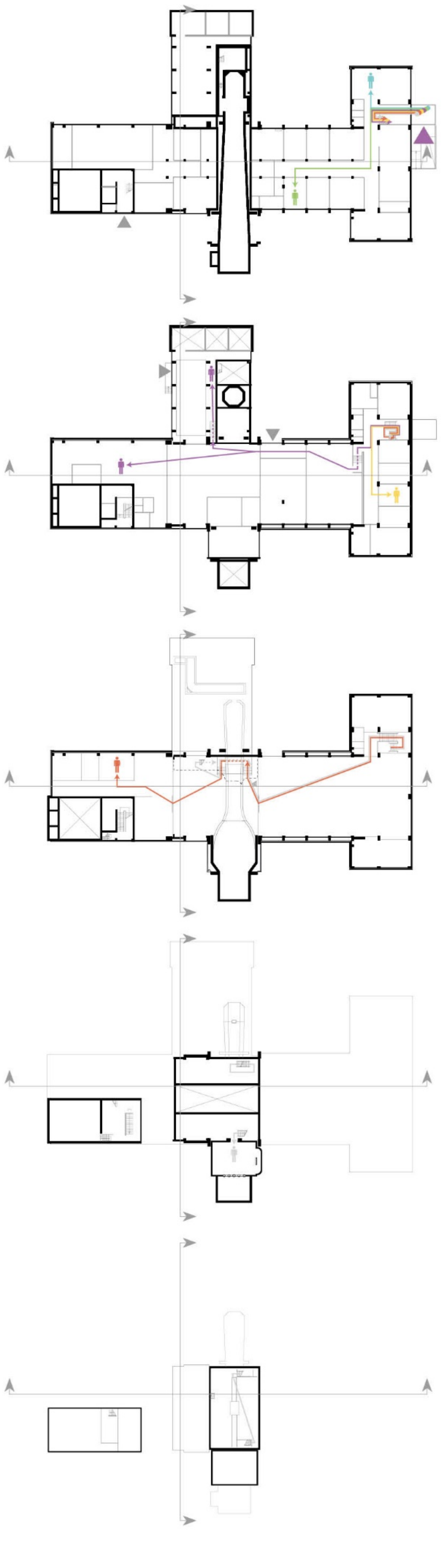
BUILDING – Building phases

The building was built in three phases. In 1977, the architects tried to cover up that it was built in these phases by cladding the façades in similar materials. Therefore, the different building ages are not well noticeable.

(left) Figure 70

Scale: 1:100

- Low Speed Lab (Aerospace)
- Inholland
- Student organisations
- OWee Bestuur
- VSSD
- Maintenance



(left) Figure 71

BUILDING – Routes

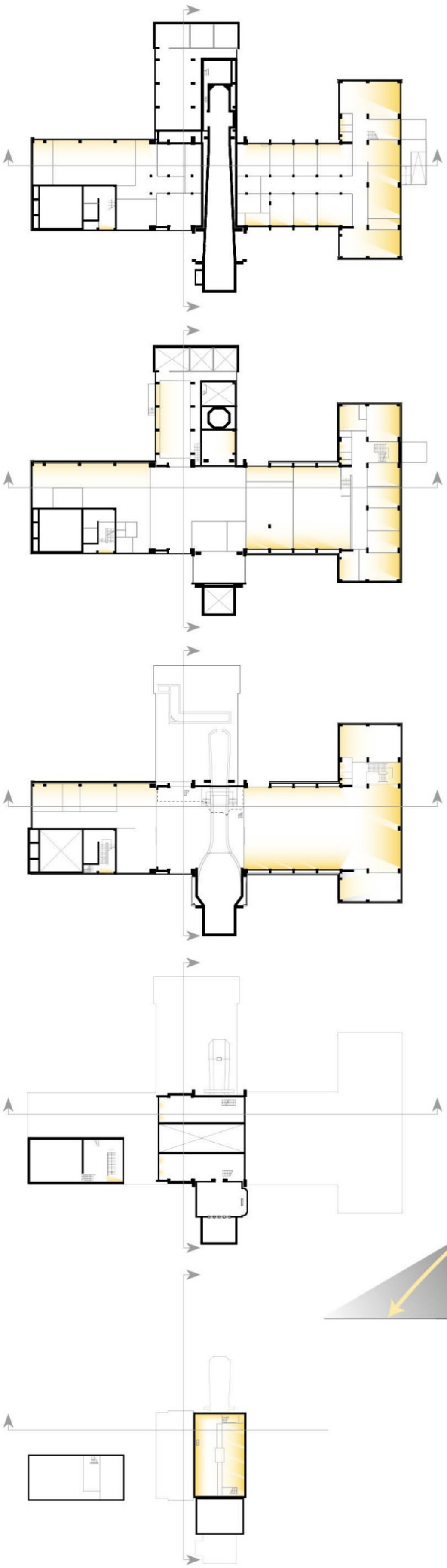
The LSL has a bad routing. The main cause for this is the increased number of users. The building was simply not designed for multiple users.

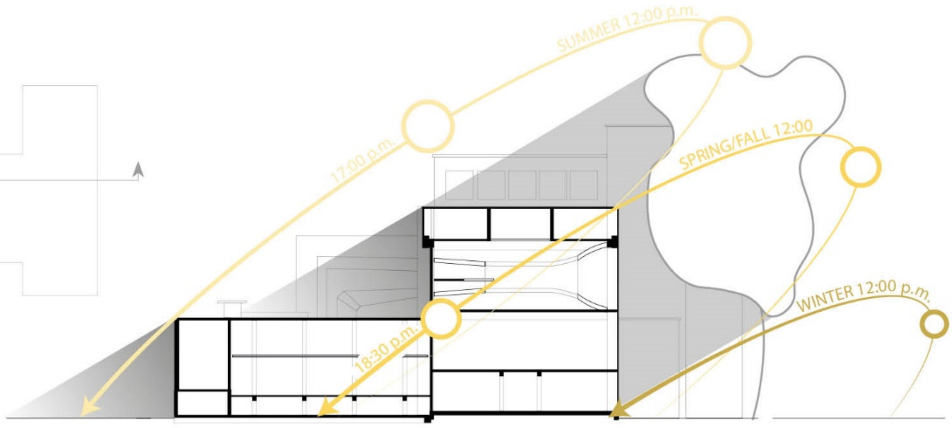
The only users that can easily reach their offices are the ones located in the east wing (student organisations, OWee Bestuur and VSSD). The others have to walk difficult routes (underneath the wind tunnel, from one end to the other and up and down).

Strategy: Make a new routing that is both logical for users and visitors.

Scale: 1:100

Winter
Spring/Fall
Summer





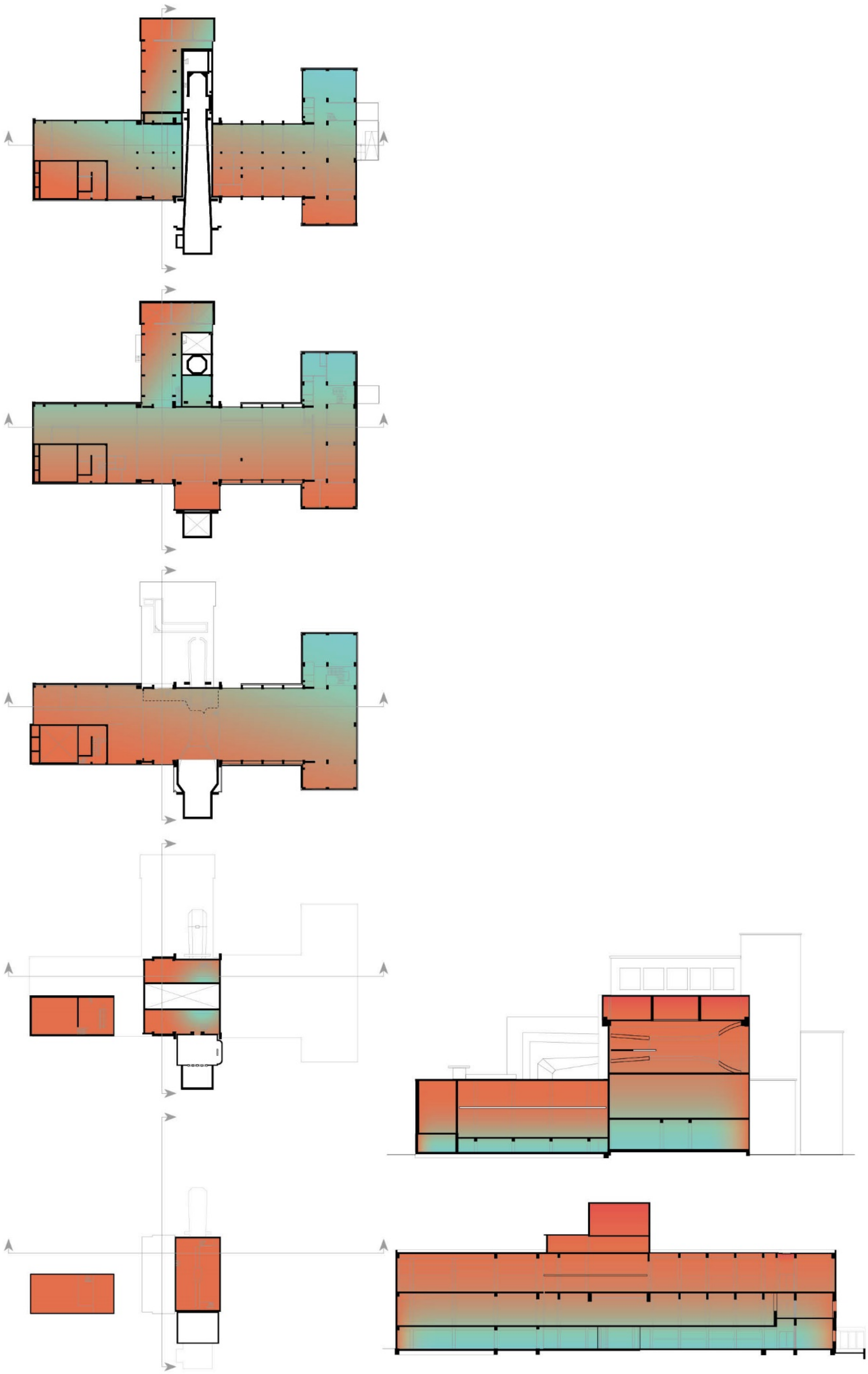
(left) Figure 72

BUILDING – Solar study and daylight penetration

Overall, the LSL does not let in sufficient daylight to suffice with normal office lighting. Some rooms do not have daylight because of their prior function. Overall, letting in enough daylight to suffice with sporadic lighting is better, as it saves energy.

Strategy: Let in more daylight.

Scale: 1:100

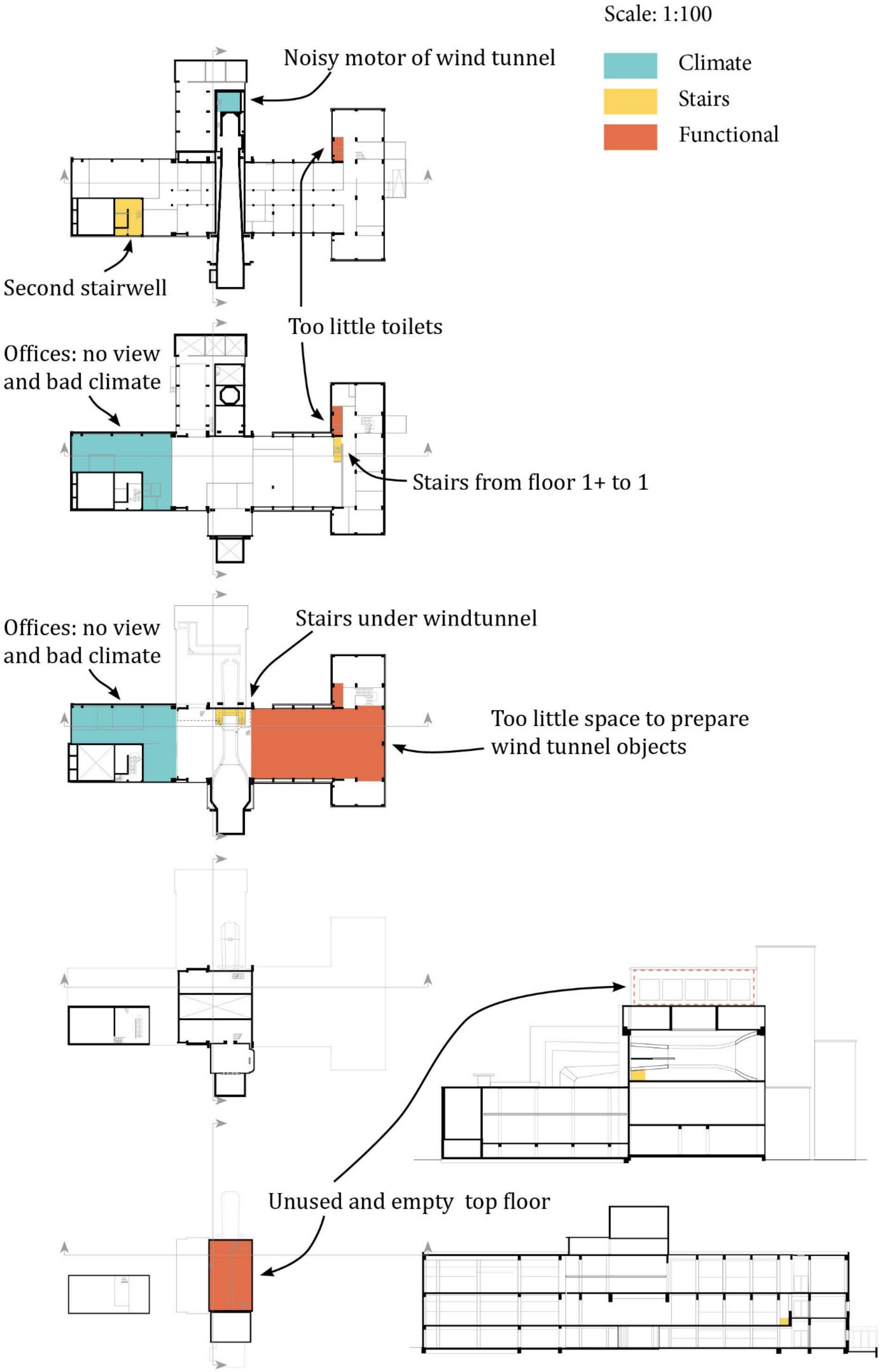


(left) Figure 73

BUILDING – Climate

Based on the user interviews, the ground floor always seems to be cold and the second floor and higher seem to be overheated several weeks a year. As the building has a high thermal mass, it takes a while for the structure to heat up. Due to this and because the ground floor is not insulated, it has the temperature of the ground for most of the year.

Strategy: Flatten out the heat curve.



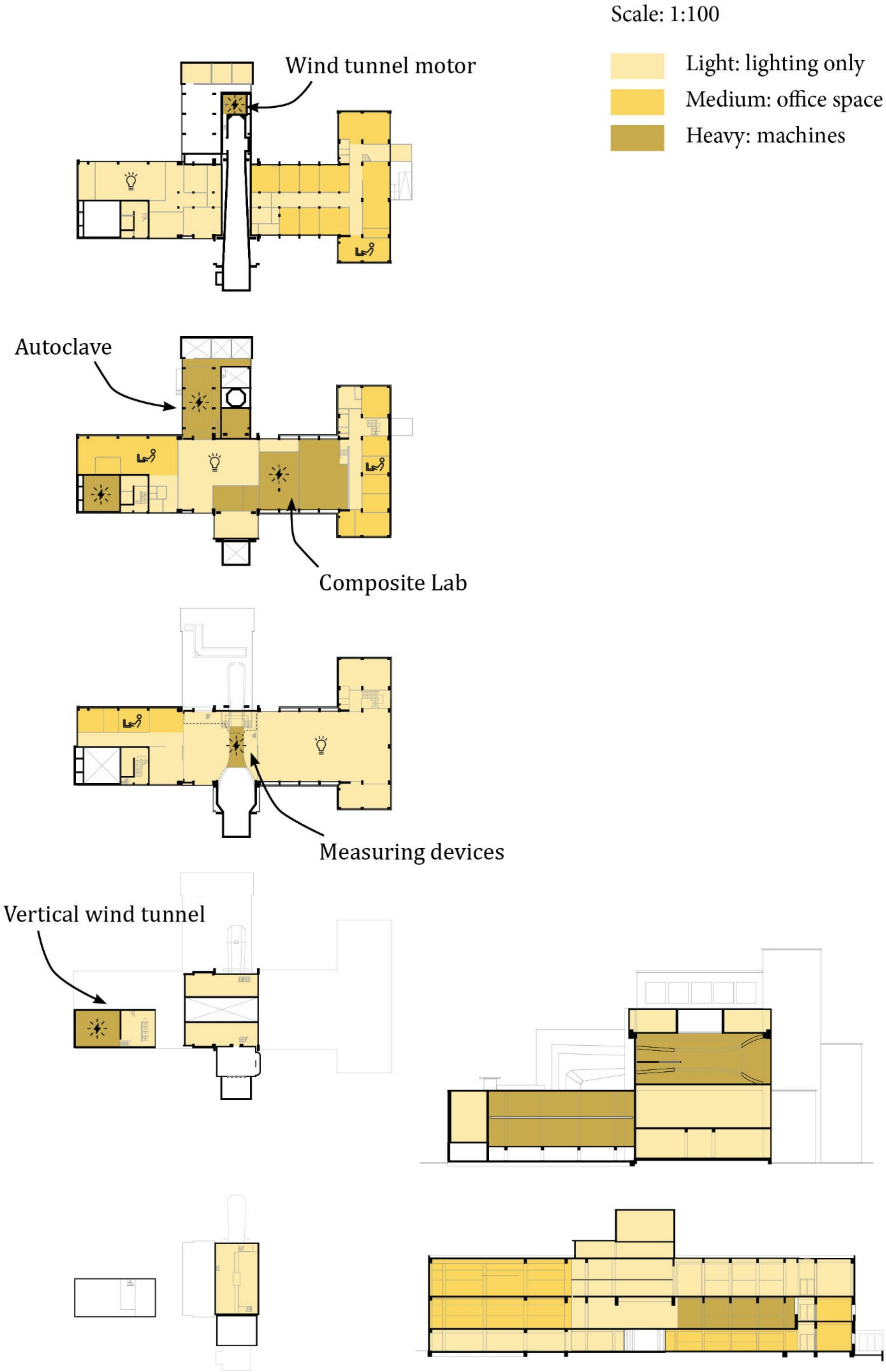
Scale: 1:100
Climate
Stairs
Functional
Noisy motor of wind tunnel
Second stairwell
Too little toilets
Offices: no view and bad climate
Stairs from floor 1+ to 1
Offices: no view and bad climate
Stairs under windtunnel
Too little space to prepare wind tunnel objects
Unused and empty top floor

(left) Figure 74

BUILDING – Issues

The building has a number of issues. These are divided in climate, stairs and functional issues.

Strategy: Solve the main issues.


Scale: 1:100
Light: lighting only
Medium: office space
Heavy: machines
Wind tunnel motor
Autoclave
Composite Lab
Measuring devices
Vertical wind tunnel

(left) Figure 75

BUILDING – Energy consumption

To get insight in the different environments in this building, the energy consumption has been categorised.

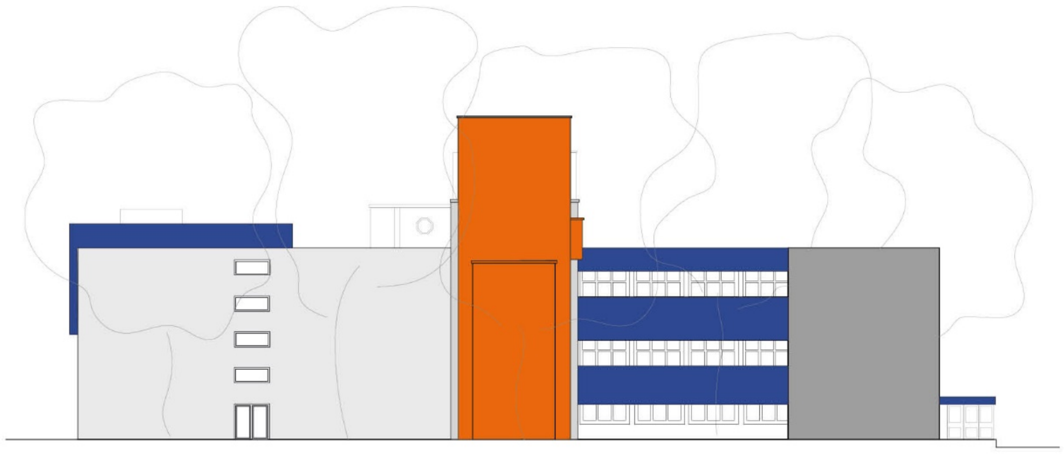
Strategy: Minimize the energy consumption.

Scale: 1:50

East

North

West



South

(left) Figure 76

FAÇADE – Facades

Current colours of the facades

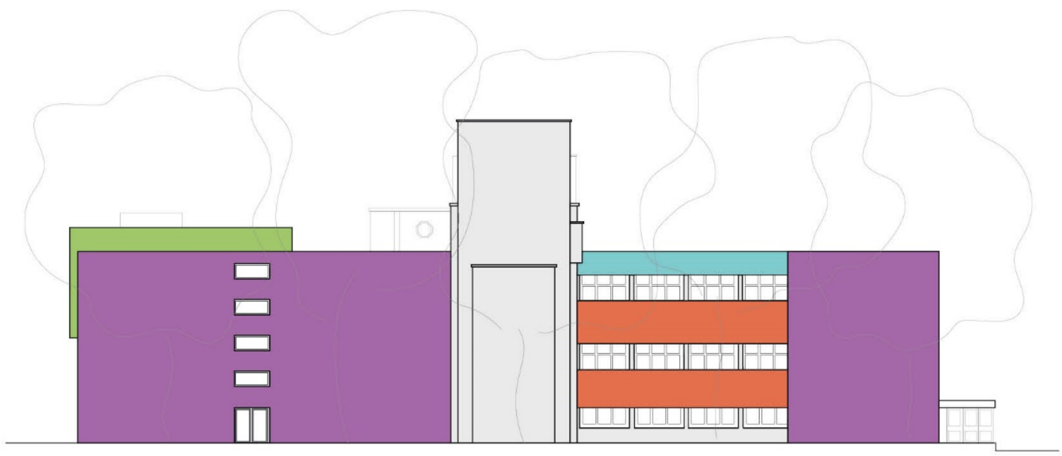
Scale: 1:50

- Corrugated metal
- Brick
- Insulated concrete panels
- Wood
- Corrugated metal - vertical
- Plaster

East

North

West



South

(left) Figure 77

FAÇADE - Façade materials

There are at least six different façade materials. In 1977, the building volume dating from 1952 was cladded with corrugated metal and wood to compensate for the lack of coherence.

Strategy: bring unity to the facade

6.7.THERMAL ENVELOPE

In the refurbishment of 1977, effort was put into insulating the building for both the new volumes and the old ones. Sadly, these designs are no longer sufficient.

A section along the entire building is shown in Figure 78. Most of the building wings are thermally insulated, apart from the ground floor and the top floors. The thermal bridges are mainly located at corners and façade connection points. The wind tunnel however, is not.

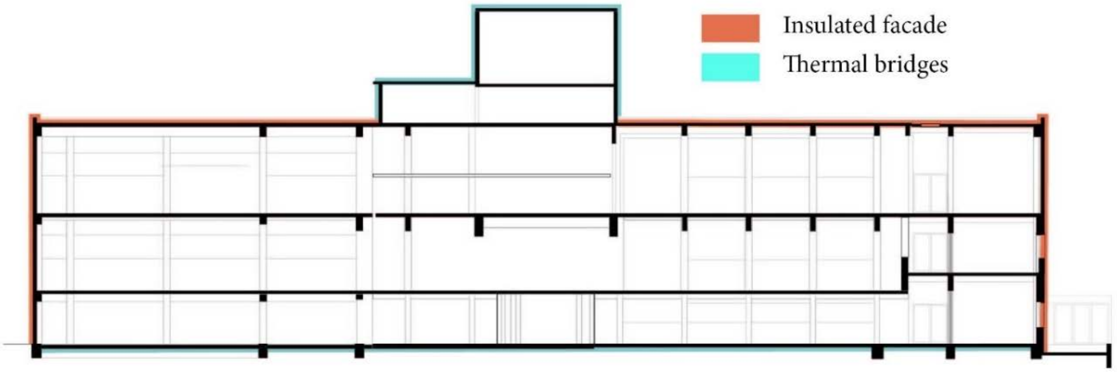


Figure 78: thermal insulation

Ten different facades and two types of roofs will be discussed. The original building (1952) only has one type of façade. In 1977, a whole range of façade materials and types was added to the building. In 1977, both the new volumes and the older volumes were cladded in the same materials to bring more unity to the building. Due to this, sometimes two façade types per material occur. For instance, there are two façade types with wooden panelling.

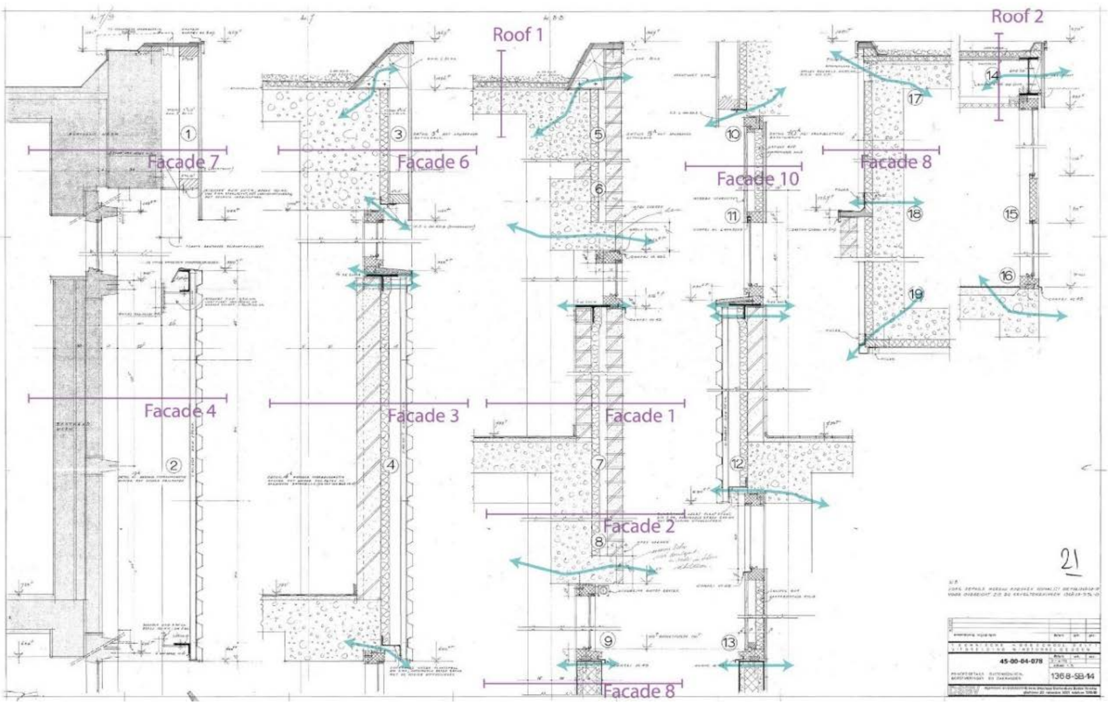


Figure 79: Façade types and location of thermal bridges.

The façade material that can be distinguished in the LSL are:

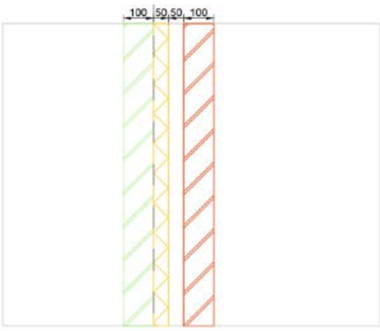
- Masonry — Façade 1 and 2
- Corrugated metal cladding — Façade 3, 4 and 5
- Wooden panelling — Façade 6 and 7
- Prefab concrete panel — Façade 8
- Plaster — Façade 9
- Opaque window elements — Façade 10

Table 15 lists the types.

Table 15: Summary of facade types and energy transmission

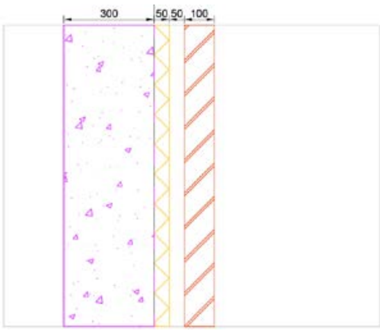
FACADE 1

Rc (m2.K/W)	1,540
U (W/m2.K)	0,649
∑ width (mm)	300



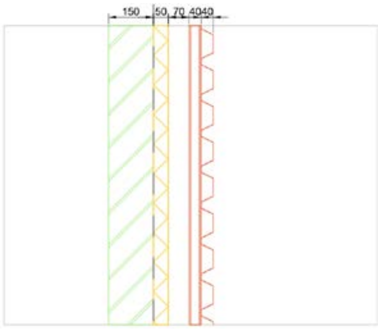
FACADE 2

Rc (m2.K/W)	1,590
U (W/m2.K)	0,629
∑ width (mm)	500



FACADE 3

Rc (m2.K/W)	1,490
U (W/m2.K)	0,671
∑ width (mm)	500

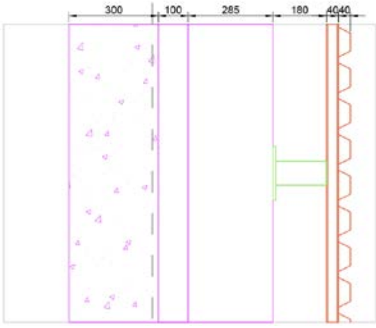


FACADE 4

Rc (m2.K/W) 0,300

U (W/m2.K) 3,333

∑ width (mm) 945

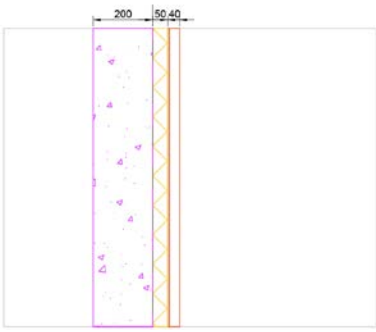


FACADE 5

Rc (m2.K/W) 1,351

U (W/m2.K) 0,740

∑ width (mm) 290

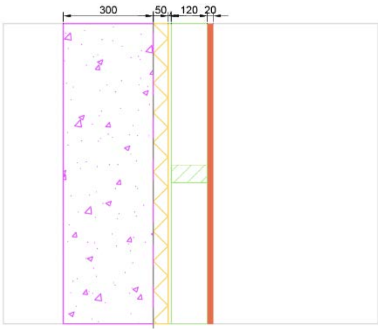


FACADE 6

Rc (m2.K/W) 1,769

U (W/m2.K) 0,565

∑ width (mm) 500

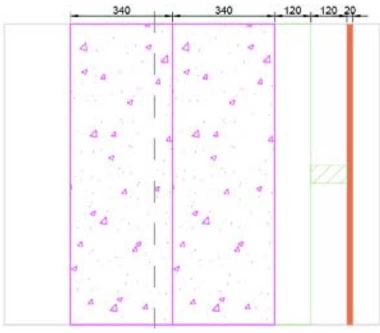


FACADE 7

Rc (m2.K/W) 0,861

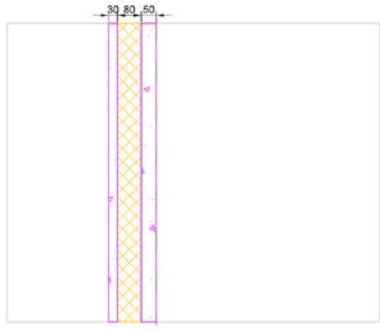
U (W/m2.K) 1,162

∑ width (mm) 940



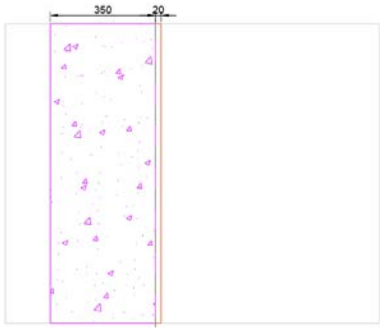
FACADE 8

Rc (m2.K/W)	2,326
U (W/m2.K)	0,430
∑ width (mm)	160



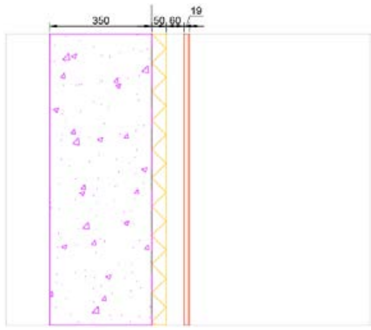
FACADE 9

Rc (m2.K/W)	0,200
U (W/m2.K)	5,000
Total width (mm)	370



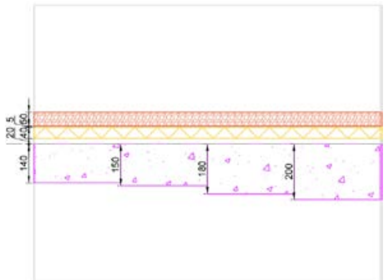
FACADE 10

Rc (m2.K/W)	1,642
U (W/m2.K)	0,609
∑ width (mm)	479



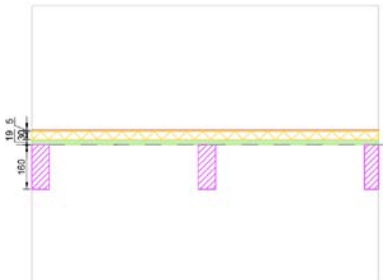
ROOF 1

Rc (m2.K/W)	1,853
U (W/m2.K)	0,540
∑ width (mm)	255



ROOF 2

Rc (m2.K/W)	1,460
U (W/m2.K)	0,685
∑ width (mm)	214



There are several areas in the façade of the Low Speed Lab that do not have any thermal insulation. Most of these were built in 1952. The inner structure of façade 4 remains unknown, but it is assumed to be a brick cavity wall. The insulation thickness for the facades that were insulated is 50 mm.

Figure 80 shows thermal insulation values for the LSL. The average R-value of the facades is 1,307 m2.K/W and 1,657 m2.K/W for the roofs. This average is mainly influenced by type 4, 7 and 9, because the construction of the facades originating from 1952 was not clear.

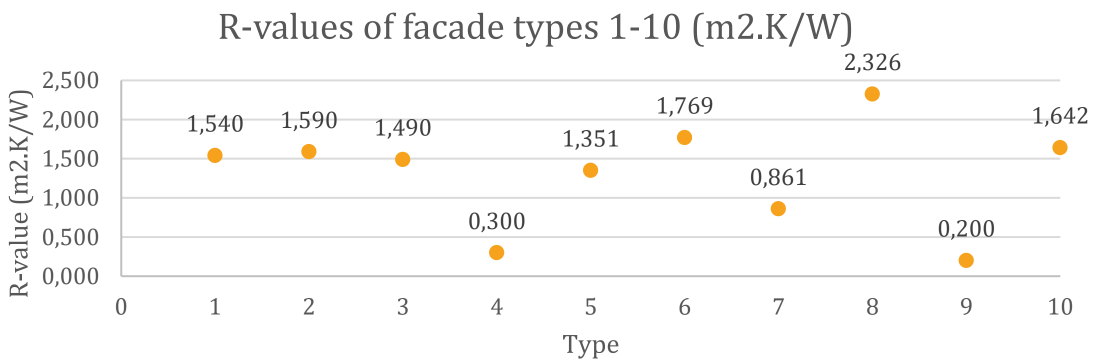


Figure 80: R-values of façade types 1-10

6.8. MATERIAL INVENTORY

In this chapter, the most prevalent materials façade and structure(s) are discussed. The material inventory can be used as a basis for a Material Passport. To complete this passport, additional information has to be gathered. The inventory contains information on the:

- Material
- Category
- Age of a component
- Number of items
- Area (m2)
- Volume (m3)

If this inventory would be used for a Material Passport, at least the following additional information should be collected:

- Quality
- Location within the building
- Life expectance
- Embodied energy
- Recycling method
- Connection method
- Costs
- Future purpose

QUANTITY

In the appendices, a complete list of the materials and components can be found. Figure 81 to Figure 84 give a summary of the inventory.

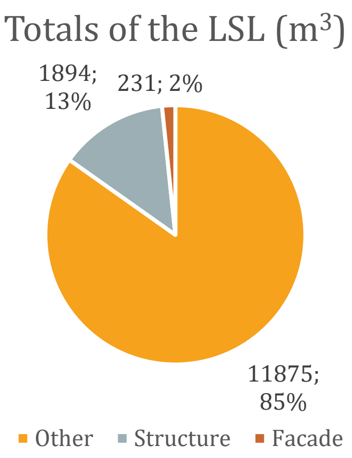


Figure 81: Total material volumes of the Low Speed Lab

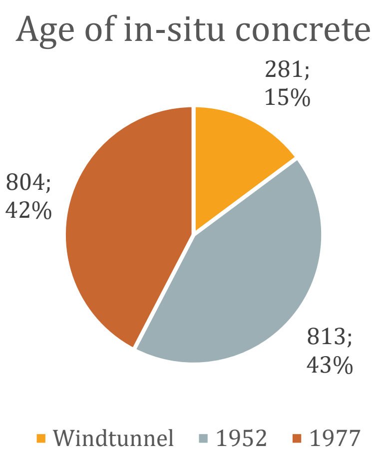


Figure 82: Age of in-situ concrete in m³

The total volume of the Low Speed Lab is about 14 000 m³, of which about 15% encompass the structure and façade (Figure 82). The structure solely exists of concrete and accounts for 1894 m³. Concrete is the most widely used material in the building. 15% of the concrete is put in the wind tunnel, 43% in the building volumes from 1952 and 43% in the volumes dating from 1977. This means 43% of the concrete is 40 years old and 58% is more than 65 years old.

Figure 83 shows masonry is the most used façade type. This façade type consists of so called 'splitsteen'. Windows account for the single biggest area in the facades.

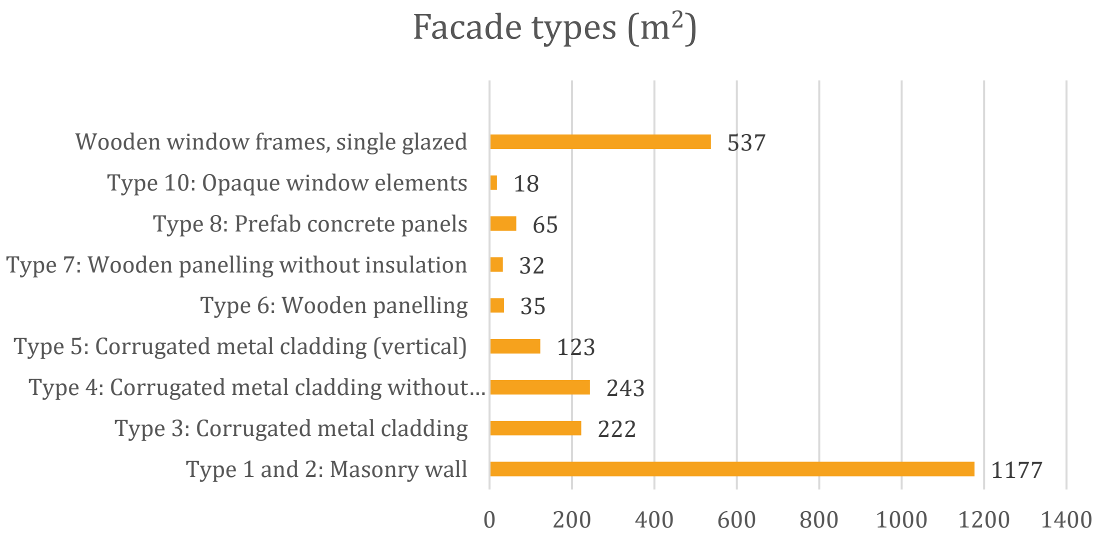


Figure 83: Façade types (m2)

This makes that masonry is the most widely used material in the façade (Figure 84), followed by insulation. In comparison to the amount of concrete in the building, these amounts account for a fraction.

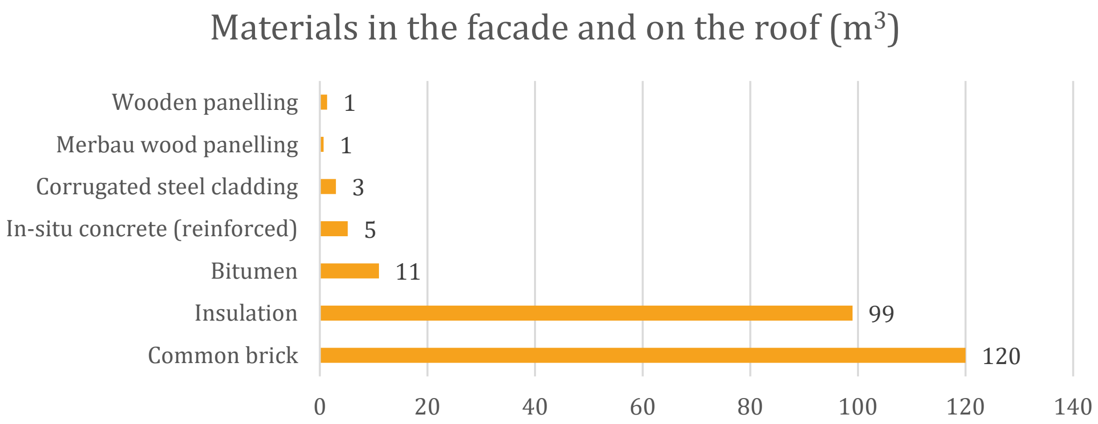


Figure 84: Materials in the facade and on the roof (m3)

REUSE

As shown above, there are many materials in the façade and load-bearing structure of the building. In order to know what these can contribute to the new design, the (recycling) potential of these materials is investigated. The most frequent materials and components are discussed in this chapter (Table 16). Appendix: material inventory (chapter 14.5) contains a list of materials that are used in the façade and load-bearing structure of the building.

Source of information:

- Service life and waste scenario (NIBE, 2017)
- Future purpose (GreenSpec, 2017)
- Embodied Energy and embodied carbon (Hammond & Jones, 2011)

Table 16: Reusability of materials

INSULATION (ROCKWOOL)

Amount/volume	99 m^3	
Service life	75 years The insulation values can decrease due to wetting and compaction.	
Component age	40 years	
Efficiency	40 mm of insulation, which is too little	
Waste scenario	Landfill Incineration Recycling Reuse 'Eigenprofiel'	85,0% 5,0% 10,0% 0,0% 0,0%
Future purpose	Additive for the production of bricks or plastics	
Embodied Energy	16,8 MJ/Kg	
Embodied Carbon	1,12 Kg CO2e/Kg	
Conclusion	If the thermal conductivity has not changed significantly and the new design allows for it, it is best to leave the insulation in the building. 90% of the material will be burnt or landfilled. Possible options include: adding extra insulation or replacing the panel.	

IN-SITU (REINFORCED) CONCRETE

Amount	1894 m^3	
Service life	75-150 years	
Component age	40 and 65 years	
Efficiency	Monolithic structure, many large open spaces, high ceilings.	
Waste scenario	Landfill Incineration Recycling Reuse 'Eigenprofiel'	1,0% 0,0% 98,6% 0,4% 0,0%
Future purpose	After treatment (breaking, sieving and cleaning), concrete can be reused as aggregate in new concrete	
Embodied Energy	0,75 MJ/Kg	
Embodied Carbon	0,107 Kg CO2e/Kg	
Conclusion	The recycling potential is high and demolition is allowed in small volumes.	

MASONRY ('SPLITSTEEN')

Amount	120 m^3	
Service life	100 years	
Component age	40 years	
Efficiency	-	
Waste scenario	Landfill	31,8%
	Incineration	0,0%
	Recycling	68,2%
	Reuse	0,0%
	'Eigenprofiel'	0,0%
Future purpose	Not many bricks are reclaimed, most are crushed. The bricks cannot be reclaimed if a cement mortar is used. This is the case in the LSL. Heavy material, expensive to transport.	
Embodied Energy	3,0 MJ/Kg	
Embodied Carbon	0,24 Kg CO2e/Kg	
Conclusion	Reuse of the bricks seems difficult. Recycling seems to be the best option. However, using them on site is the best option.	

BITUMEN

Amount	11 m^3	
Service life	20-30 years	
Component age	unknown	
Efficiency	Resistance to weathering, mechanical damage, puncturing and tearing (GreenSpec).	
Waste scenario	Landfill	5,0%
	Incineration	90,2%
	Recycling	4,7%
	Reuse	0,1%
	'Eigenprofiel'	0,0%
Future purpose	In theory, bitumen can be recycled by shredding and heating the substances. For that, it may not be contaminated (wood, gravel) and not glued to the subsurface (insulation).	
Embodied Energy	51 MJ/Kg	
Embodied Carbon	0,43-0,55 Kg CO2e/Kg	
Conclusion	The amount of thermal insulation underneath the bitumen is not sufficient. Either way, the bitumen has to be (temporarily) removed.	

PREFAB CONCRETE PANELS

Amount	5 m^3 of concrete and 4 m^3 of insulation	
Service life	75 years	
Component age	40 years	
Efficiency	R-value of 2,326, which is too low	
Waste scenario	Landfill	1,1%
	Incineration	0,7%
	Recycling	98,2%
	Reuse	0,0%
	'Eigenprofiel'	0,0%
Future purpose	Recycling of both concrete and unknown insulation material. Potential reuse, but the R-value is only 2,326.	
Embodied Energy	unknown	

Embodied Carbon	unknown
Conclusion	The options are: adding extra insulation or replacing the panel

SINGLE GLAZED WOODEN WINDOW FRAMES

Amount	537 m^2	
Service life	50 years	
Component age	40 and 65 years	
Efficiency	Not sufficient	
Waste scenario	Landfill	4,6%
	Incineration	95,3%
	Recycling	0,1%
	Reuse	0,0%
	'Eigenprofiel'	0,0%
Future purpose	The windows contain wood, glass, metal and sealants. Most of the recycled wooden frames are incinerated. Float glass can be recycled. Most of the recycled content is used for the production float glass (4%), packaging glass (73%) and rock wool (19%) (Vlakglas Recycling Nederland, 2017).	
Embodied Energy	286 MJ/window (1200x1200 mm)	
Embodied Carbon	14,6 Kg CO2e/window (1200x1200mm)	
Conclusion	The window frames cannot be upgraded. The best option is replacing them and reuse as many on site for interior purposes.	

CORRUGATED STEEL PLATES

Amount	222 m^2	
Service life	30 years	
Component age	40 years	
Efficiency	Still works as a façade material, but blocks too much daylight.	
Waste scenario	Landfill	5,0%
	Incineration	13,7%
	Recycling	81,3%
	Reuse	0,0%
	'Eigenprofiel'	0,0%
Future purpose	These plates contain steel, zinc or zinc–aluminium alloy and paint. When the plates are taken of the façade, the connection points often damage, resulting in larger holes and making them non-reusable.	
Embodied Energy	25,10 MJ/Kg	
Embodied Carbon	1,55 Kg CO2e/Kg	
Conclusion	These plates have to come off to improve the thermal insulation. By that, they will likely be damaged up to the point that these plates can no longer be used. Reuse in the interior of the building or recycling might be best.	

Figure 85 gives a summary of the recycling and reuse potential. Overall, the materials listed above are hardly reused. Therefore, it is important to maintain the materials or find a use for them on site. This will save material and transportation costs.

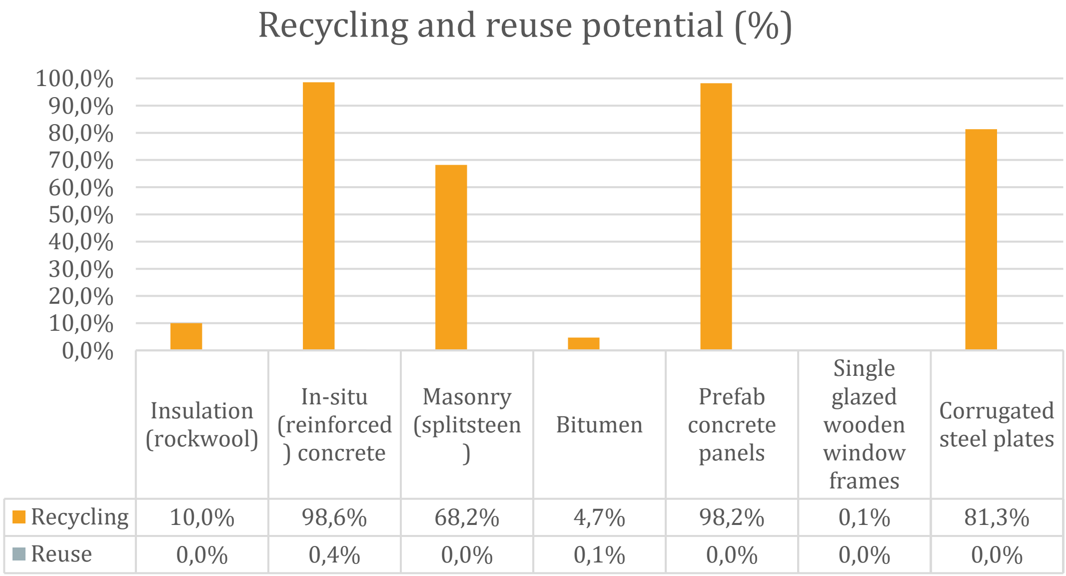


Figure 85: Recycling and reuse potential of common materials

7. STRATEGY AND BUILDING OPTIONS

In this chapter, the design phase will be discussed. In this phase, several methods are used to generate design options. First, the problems and assets of the building will be discussed. Then, a design strategy will be chosen. Last, three techniques for generating design options are used.

7.1. PROBLEMS, ASSETS AND REQUIREMENTS

As was discussed in chapter 3.2, a building has to fulfil a great variety of requirements. In principle, these are feasibility and flexibility. The building analysis resulted in a list of problems and assets. The largest problems of the Low Speed Lab are that it consumes too much energy, it does not provide a comfortable indoor climate and the morphology is defect.

ENERGY CONSUMPTION AND COMFORT

The current building does not follow any of the steps of the New Stepped Strategy: the building consumes more energy than desired, does not make use of waste streams and makes no use of renewable energy. The problems include:

- Too little insulation -> cold rooms -> energy loss
- Too little insulation -> warm rooms -> overheating
- Too little daylight -> lighting turned on -> energy loss
- No view -> poor office quality -> unused (but heated and maintained) space
- Poor ventilation -> poor office quality -> complaints

Quantifiable requirements that derive from these problems are (discussed in chapter 3.8):

- Thermal insulation: ground floor 7,0 m2K/W, façade 9,0 m2K/W and roof 10,0 m2K/W.
- Air infiltration: reducing the infiltration to 0,2 dm3/s.m2
- Strive for NZEB:A and Site ZEB
- Occupation and ventilation: 70 people in the building

MORPHOLOGY AND ROUTING

From an architectural and functional point of view, there is a larger problem: the building is chaotic. The number of varieties illustrates this. At the moment, the building encompasses:

- 5 façade colours
- 20 façade materials
- 3 building axes
- 16 column sizes
- Two first floor levels
- 9 building blocks
- And many routes

The result of this is that the building is hard to understand and people get lost. The wind tunnel splits the building up in two pieces, creates dead-end roads and complicates walking routes.

ASSETS

On the other hand, the building has a number of assets that make it worth keeping. First, the wind tunnel itself. It is a unique object at the TU Delft and has an interesting shape. The load-bearing structure is hard to adapt, but creates many large open spaces and covers wide spans. Additionally, the load-bearing structure gives the building a high thermal mass, which has a beneficial effect on the climate of the building.

The high poplars at the south side of the building also contribute to the climate of the building. In summer, the leaves shade the about half of the building. And in winter, the leafless tress let through about 40% of the light and allow the building to heat up.

REQUIREMENTS

The aim of this graduation project is to make a refurbishment proposal and method for the TU Delft. Besides making an architecturally appealing and feasible building, net-zero energy and making use of circular building materials are key aspects.

Therefore, the design phase deals with three fields of study (Figure 86): energy, circularity and architecture. These categories are not mutually exclusive, but are a good representation of the decision process.

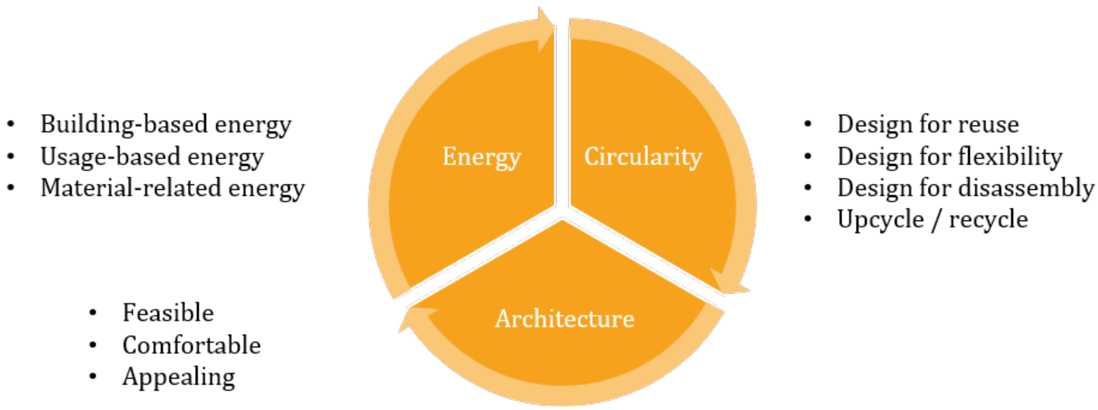


Figure 86: The three fields of study

The design process must be a careful consideration of these three fields. Because, in order to make a good design, the fields must all be included in the argumentation. Each refurbishment intervention will score differently on energy, circularity and architecture. The key is to find the best balance. In the next chapters some of these considerations and decisions will be explained. This will contribute to understanding of the developed method.

7.2.STRATEGY

The Low Speed wind tunnel is the most important component in this building, both architecturally and financially. Therefore, this wind tunnel should stand out and be the central axis of the building (Figure 87). At the moment, it is neither. To accomplish a building that scores well on architecture, energy and circularity, the following strategies are pursued.

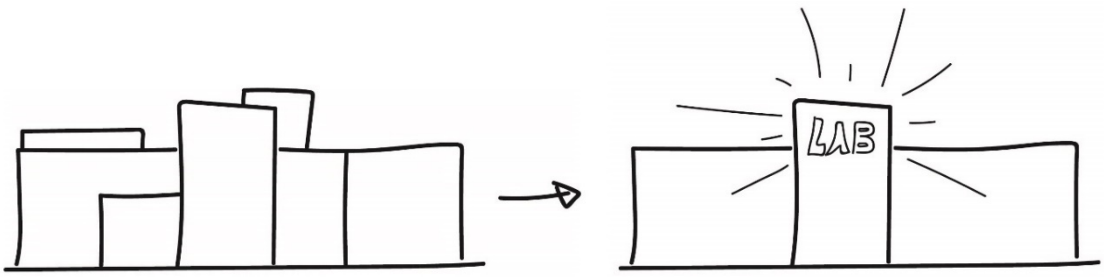


Figure 87: Wind tunnel as focus point

1. SIMPLIFICATION

In order to make the wind tunnel the focus point, the building should be simplified in:

- Volume
- Axis
- Routing
- Materials and colours

This can for instance be achieved by:

- Adding volumes
- Making one entrance and staircase
- Adding walking routes
- Cladding the façade in one material
- Using the same materials as adjacent buildings
- Branding the LSL as a multifunctional building

2. DECREASE CONSUMPTION AND INCREASE REUSE

The consumption of the building should be decreased and the reuse and generation should be increased. This applies to both energy and materials.

3. INCREASE FLEXIBILITY

To make a future-proof building that can accommodate changes (e.g. users, functions).

4. STRENGTHEN RELATIONSHIP WITH URBAN CONTEXT

The analysis in chapter 6.6 Building Analysis showed that the building does not fit in nor correspond with its surroundings. Therefore, the design should also include a site proposal.

7.3.METHOD 1: KONSTANTINOU

Both the methods of Ebbert and Konstantinou have been used to determine the current status and provide building options. Konstantinou (2014) has developed a theoretical framework and toolbox to define refurbishment options for the residential market. However, it is also applicable to this research. The theoretical framework exists of thee decision levels and sublevels (Figure 88):

1. Refurbishment strategies
2. Material
3. Retrofitting measures

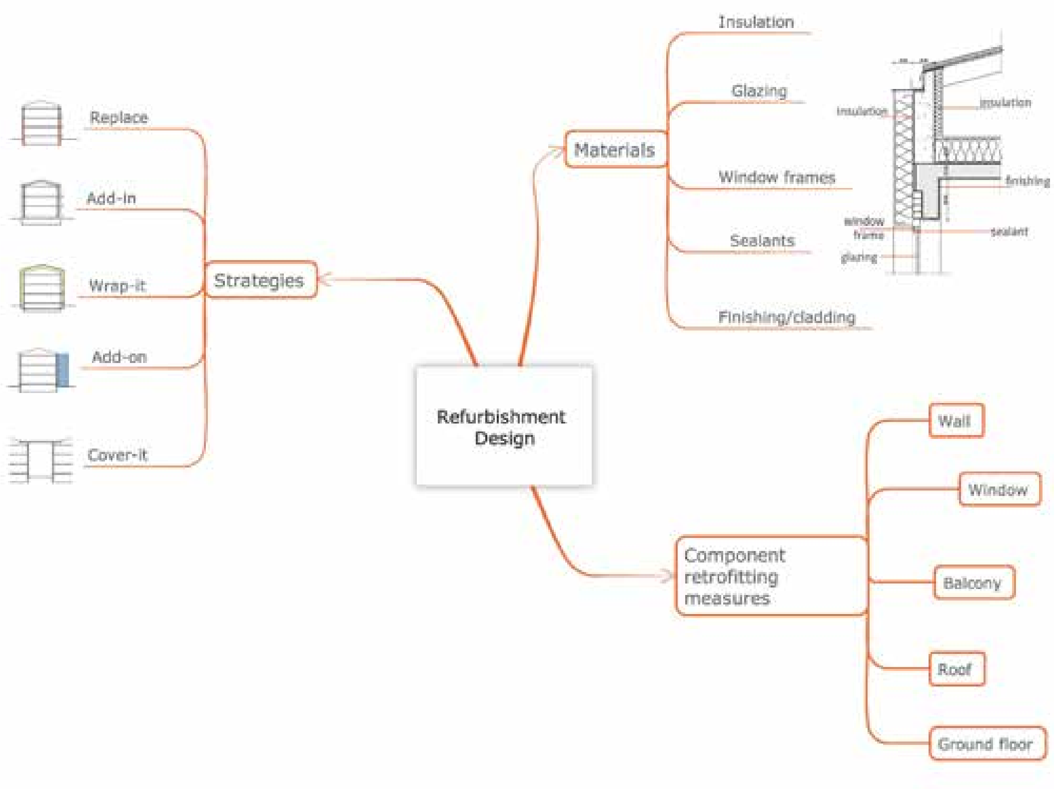


Figure 88: Schematic representation of the three decision levels (Konstantinou, 2014, fig. 4.3)

Studying these three levels and the building, results in a filled in toolbox matrix. This matrix shows refurbishment possibilities for each building component. The measures can be combined to an integrated refurbishment strategy.

In previous chapters some decision levels have already been discussed. For instance, facades and materials. Most interesting for this project are the filled in toolbox matrices. Figure 89 shows a filled in toolbox matrix for building 45. LSL. The matrix combines the current situation (in red) and retrofitting measures (in purple). The column for balconies is blank, because the LSL does not have any. As there is not just one, but 10 façade types, the matrix does not give a clear output for exterior walls. Figure 90 therefore shows the measures per façade type.

	Building envelope					Building Systems	
	Exterior wall	Window	Balcony	Roof	Ground floor	Ventilation	Heat source
Existing construction	Masonry/ cavity wall no insulation	Single glazing	Continuous slab, no insulation	Pitched roof, timber rafters no insulation/ occupied loft	Slab on ground, no insulation	Natural ventilation	Gas stove
	Lightweight concrete/ hollow brick, no insulation	Early, double-glazing	Separate slab no/little insulation	Pitched roof, timber rafters no insulation/ unheated loft	Basement unheated. Concrete slab, no insulation		Fossil fuel boiler in each dwelling
	Little/outdated insulation			Concrete slab, no/little/ outdated insulation	Little/outdated insulation	Trickle ventilation	Fossil fuel boiler per block
Retrofitting measures	Cavity insulation	Upgrade windows	Insulate balcony slab	Pitched roof, no insulation/ unheated loft	Insulation on top of ground/ first floor slab	Natural inlet/ mechanical exhaust	Replace existing boiler in each dwelling, high efficiency
	Internal insulation	Secondary glazing single	Cut off balcony	Pitch roof insulation	Insulation under existing floor	Mechanical inlet/ natural exhaust	Replace existing boiler per block, high efficiency
	Exterior Insulation and Finishing Systems (EIFS)	Secondary glazing double	Balcony cladding - Single glazing	Insulation of top floor slab		Mechanical ventilation	CHP installation
	Ventilated façade		Balcony cladding - Double glazing	Flat roof		Ventilation system with heat recovery (HR)	Heat pump
	Timber-frame wall	Replace windows (Double pane)		Green roof			
	Second Façade/ Single glazing	Replace windows (Triple pane)					
	Second Façade/ Double glazing	Shading adjustable					Biomass boiler
RES	BIPV's			Photovoltaic			Solar collectors
spatial interventions	Additional space/ Second façade integrated	Shading fixed	Integrated balcony				Geothermy
	Lift addition	Enlarged windows	New balcony	Additional floor/ occupied loft	Additional floor/occupied basement		District/ community heating

Table 5.8

The toolbox matrix

Figure 89: Filled in toolbox matrix, adapted from (Konstantinou, 2014, fig. 5.8)

LOAD-BEARING STRUCTURE

The load-bearing structure is made of in-situ reinforced concrete. Floors, columns, walls, stairs and spandrel and parapet are all joint together. Apart from two places with load-bearing walls (the wind tunnel and the vertical wind tunnel), the building is a concrete skeleton. This enhances the possibilities for alteration. At the first and second floor, the floors span from façade to façade, making large open spaces. The load-bearing structure makes up the majority of the thermal bridges.

WINDOWS

All windows in the building are wooden single glazed frames. The windows are 40 and 65 years old. The windows will be replaced with double or triple glazed elements, because the thermal conduction of these types is low enough. All listed options are technically possible, but most will likely result in insufficient thermal conductivity. As the windows are taken out, the size and location should be reconsidered too. This to ensure sufficient daylight coming in and having a view from all workplaces.

ROOF

The roofs consist of a concrete slab with little or no insulation and a finish of bitumen. None of the flat roofs have a sufficient U-value and none of the parapets are insulated. Insulation on top is therefore the most logical option. Adding a green roof to help climatize the building and PV to generate renewable energy is also an option.

GROUND FLOOR

According to the building drawings, there is no insulation below the ground floor slab. Presumably there is a crawl space of 600 mm in height. There are many beams below the ground floor slab. These are part of the concrete structure and are very large thermal bridges. This is the reason that users at the ground floor (VSSD) complain about cold rooms. Insulating the foundation is not a feasible option, but insulating on top or below the floor slabs is.

VENTILATION

There is no central ventilation system in the building. Most of the building is naturally ventilated, apart from the wind tunnels, the spaces of Inholland and the wind tunnel research group. The building installations are located at the top floor, nearby the vertical wind tunnel. Replacing the whole system for mechanical ventilation with heat recovery seems the best option for this refurbishment. This can be combined with passive measures and preheating of ventilation air.

HEAT SOURCE

In the current system, the LSL gets its heat from the Combined Heat and Power Plant. This is no longer an option for the to be refurbished building. Solar collectors and a heat pump are better alternatives. The heat that is collected can be used for floor heating and preheating or cooling of ventilation air. The installations for this (heat pump and earth tube's) can be located at the large empty plot next to the building at which a new parking garage will be built.

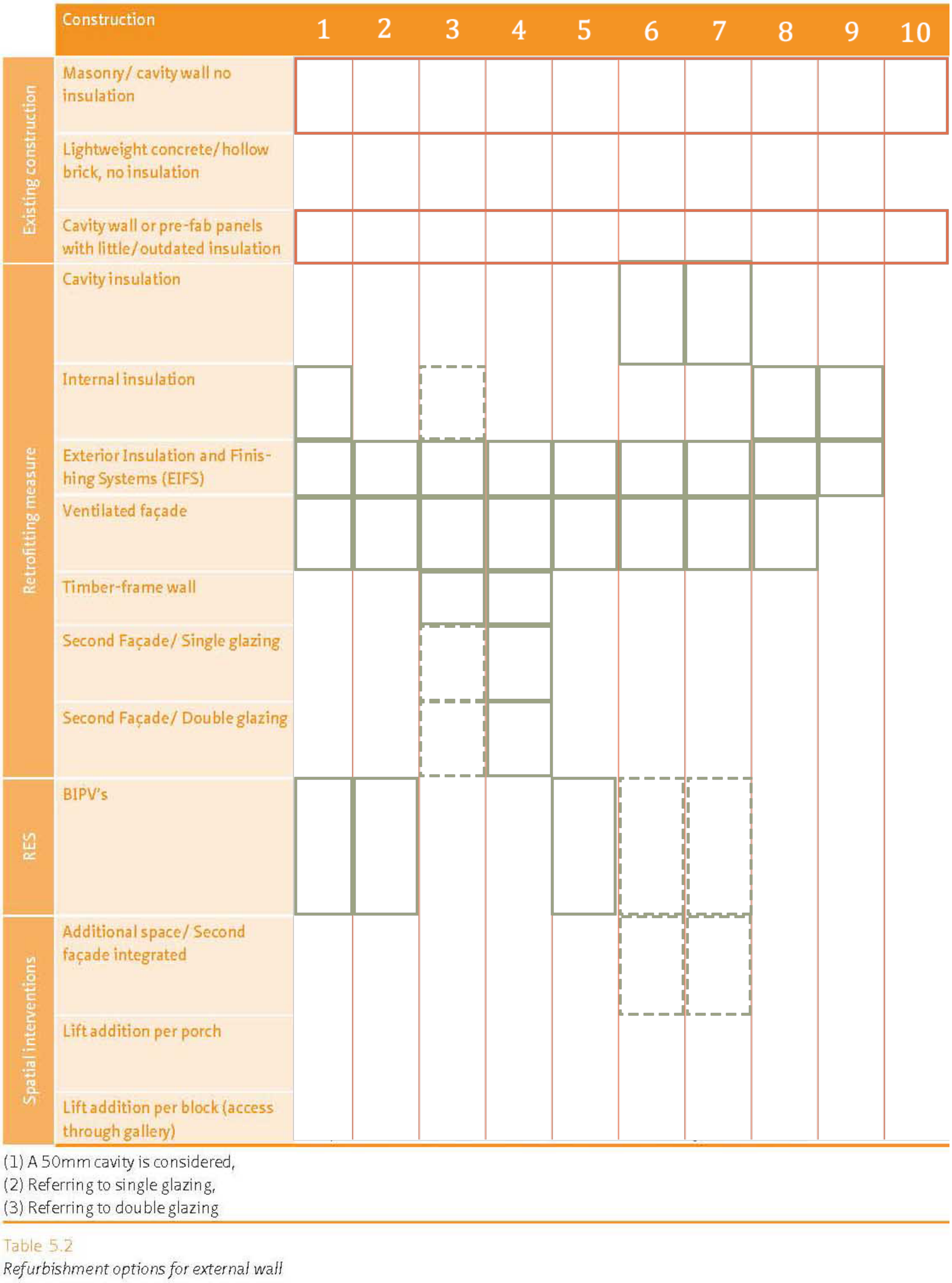


Figure 90: Refurbishment options for external wall, adapted from (Konstantinou, 2014, fig. 5.2)

FACADES

There are general strategies than can be applied to the Low Speed Lab, like internal insulation or replacing all facades. However, it could well be that those cost more Embodied Energy, as new materials are added. It is best to investigate custom solutions.

At the moment, the façades can be categorised as masonry, cavity walls or pre-fab panels with no/little/outdated insulation. Insulation is not the only problem. Other problems include: daylight penetration, thermal bridges, component age, chaotic appearance and lack of view. The biggest limitation in the façade are spandrels, parapets and columns (Figure 91).

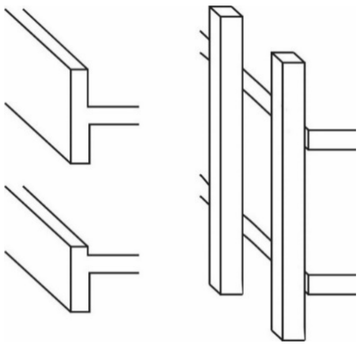


Figure 91: Limitations of façade replacement due to parapets, spandrels and columns

One by one, the facades are discussed in Table 17. After this research, it can be concluded that three strategies are applicable to most façade types: adding layers, replacing layers and replacing the entire façade.

Table 17: Refurbishment options for external wall

FACADE 1		
Rc (m2.K/W)	1,540	Masonry wall with too little insulation. The most used façade type. The building contains blind walls and walls with windows in it. At the South and West façade, there are surfaces that are blind and worth considering for BIPV's. Possible options that can result in the desired R-value: a. Internal insulation b. Removing the entire façade c. Removing the outer leaf, adding insulation and placing a new outer leaf d. Adding EIFS on top of masonry
U (W/m2.K)	0,649	
∑ width (mm)	300	

FACADE 2		
Rc (m2.K/W)	1,590	Similar to type 1. Options b, c and d can be applied. Option a is not possible, because the parapet and floors are located here.
U (W/m2.K)	0,629	
∑ width (mm)	500	

FACADE 3		
Rc (m2.K/W)	1,490	Corrugated metal (1977): Cavity wall with too little insulation. a. Internal insulation b. Fill cavity will additional insulation c. Remove corrugated façade panels and add EIFS d. Remove corrugated façade panels and make ventilated façade e. Demolition to carcass and add timber-frame wall
U (W/m2.K)	0,671	
∑ width (mm)	500	

FACADE 4		
Rc (m2.K/W)	0,300	Corrugated metal (1952): Cavity wall with no insulation and placed on the outside of a cavity wall with too little insulation. Total wall thickness of 945 mm, causing the ground floor spaces to have little daylight. Options: a. Remove corrugated façade panels and add EIFS b. Remove corrugated façade panels and make a new ventilated façade c. Demolition to carcass and replace facade d. Add second façade
U (W/m2.K)	3,333	
∑ width (mm)	945	

FACADE 5		
Rc (m2.K/W)	1,351	Vertical corrugated metal (1977): located at the vertical wind tunnel in the South-West corner of the building. Simple structure, but too little insulation. Removing the current façade panels seems most logical. The South and West façade of this façade type are both highly suitable for BIPV's. a. Remove façade panels and add EIFS b. Remove façade panels, add insulation and make ventilated façade c. Remove façade panels and add timber-frame wall
U (W/m2.K)	0,740	
∑ width (mm)	290	

FACADE 6		
Rc (m2.K/W)	1,769	Wooden cladding: along roof trims. Depending in the location there's no or too little insulation. BIPV's are possible for East, South and West façade. Options: a. Cavity insulation b. Remove wooden cladding and add EIFS c. Remove wooden cladding and add new ventilated façade d. Add second facade
U (W/m2.K)	0,565	
∑ width (mm)	500	

FACADE 7		
Rc (m2.K/W)	0,861	Same as type 6
U (W/m2.K)	1,162	
∑ width (mm)	940	

FACADE 8		
Rc (m2.K/W)	2,326	Insulated concrete panels: concrete sandwich panels with thermal bridges and insufficient U-value. Options: a. Insulate internally (less preferred) b. Add EIFS c. Add ventilated façade d. Replace
U (W/m2.K)	0,430	
∑ width (mm)	160	

FACADE 9		
Rc (m2.K/W)	0,200	Concrete render: non-insulated technical building facades. Adding an exterior layer seems most logical, but there are more options: a. Keep it non-insulated b. Internal insulation c. EIFS
U (W/m2.K)	5,000	
Total width (mm)	370	

FACADE 10		
Rc (m2.K/W)	1,642	Wooden panelling in windows. Option: a. Replace windows and opaque elements.
U (W/m2.K)	0,609	
∑ width (mm)	479	

7.4.METHOD 2: EBBERT

A second method from the literature study has been tested too. Ebbert (2010) describes a method to refurbish office facades based on occurring typologies in The Netherlands, UK and Germany. The method describes a four-step approach:

1. Read in to refurbishment strategies
2. Read in to and choose a façade construction principle that matches the building
3. Look up what strategies match with the current façade construction principle
4. Read in to the potentials of the different strategies

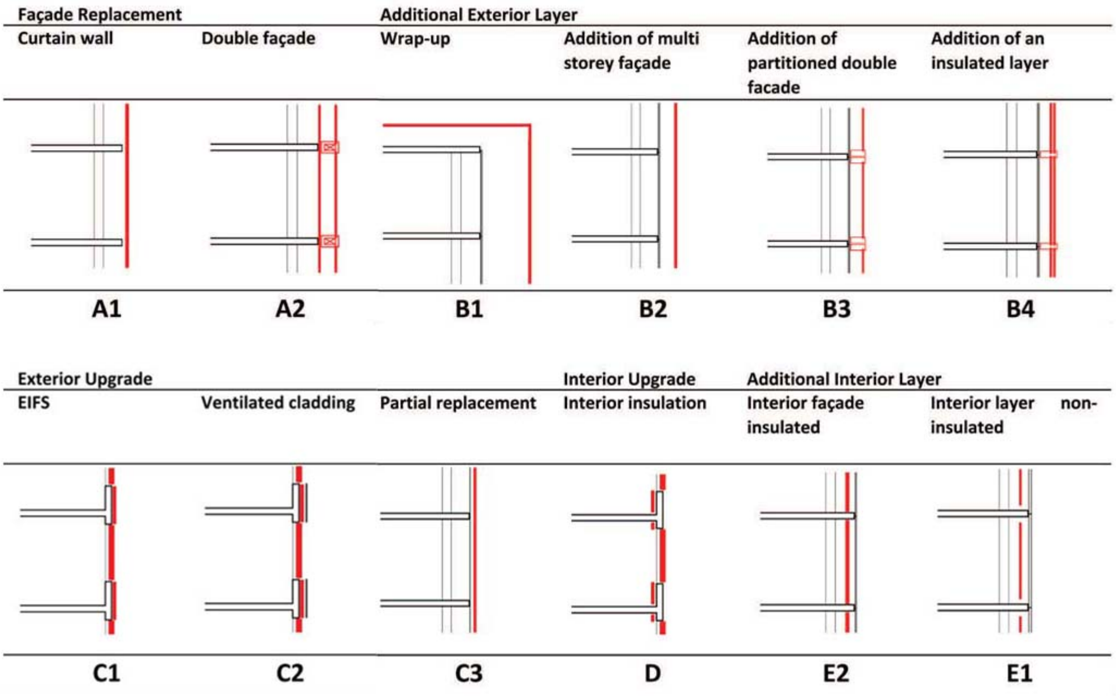


Figure 92: Overview of refurbishment strategies in current practice, based on (Ebbert, 2010, fig. 2.4)

Figure 92 shows the first step of the approach. Ebbert (2010) sorts refurbishment strategies and presents an overview matrix. These twelve strategies are comparable to the five Konstantinou presents (Figure 88).

Once the different approaches are clear, one should match its building with common façade types. Step 2 is shown in Figure 93. The classification is based on three levels: structure, form and layers.

The Low Speed Lab has a structure comparable to principle 4: the façade is located along the outside of the structure. The form is comparable to both planar and skeleton, which makes is difficult. The load-bearing structure is a concrete skeleton, but also contains high beams and spandrels. Last, the number of layers. This is one. This results in:

- Type 4.2.1. Concrete and steel. Facing of metal cladding, masonry, wood, natural stone, plastic.

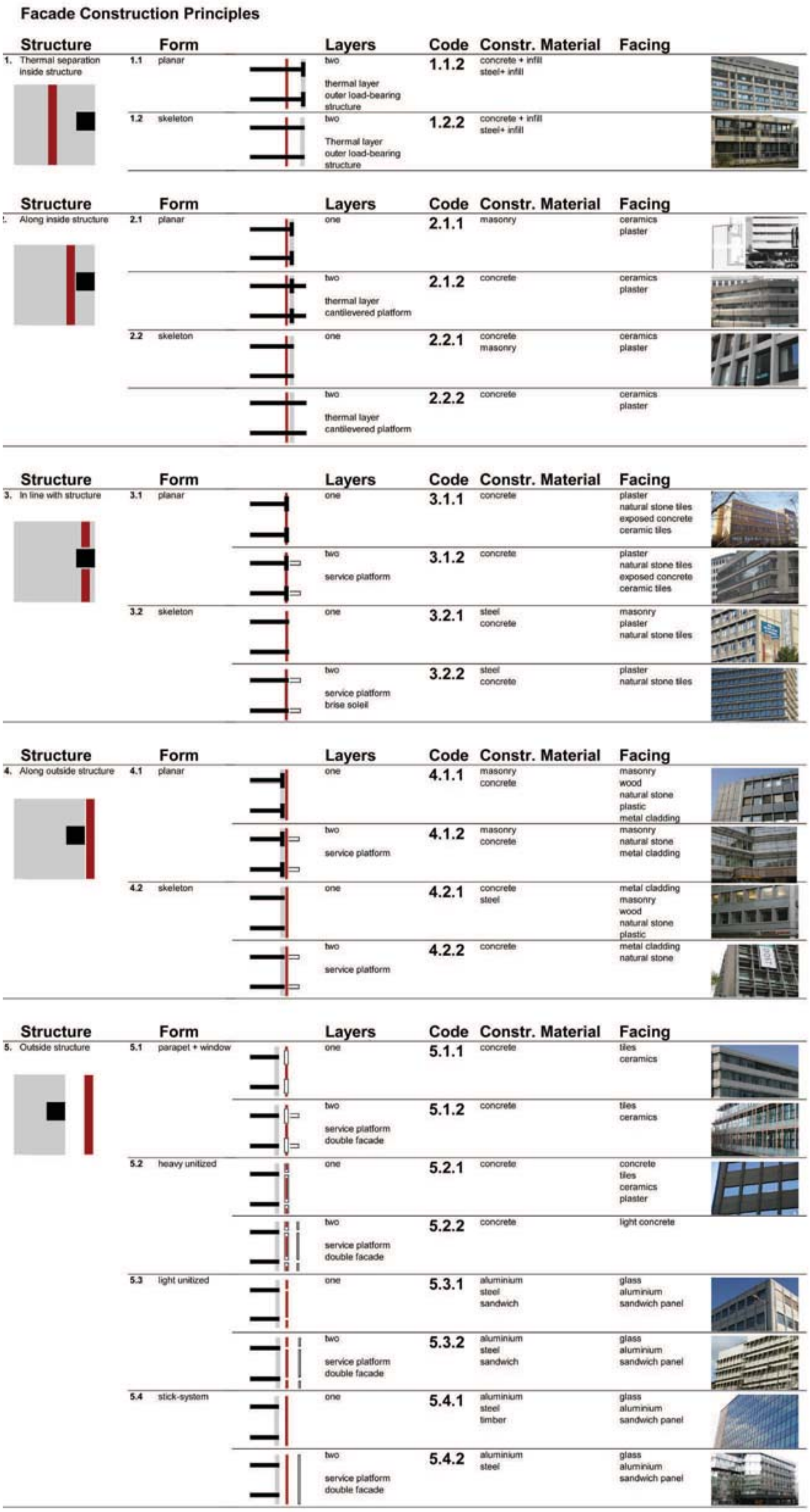


Figure 93: Overview of the common post war facade types (Ebbert, 2010, fig. 3.3)

Step 3 includes looking at the options that remain. Figure 94 shows a summary of the result.

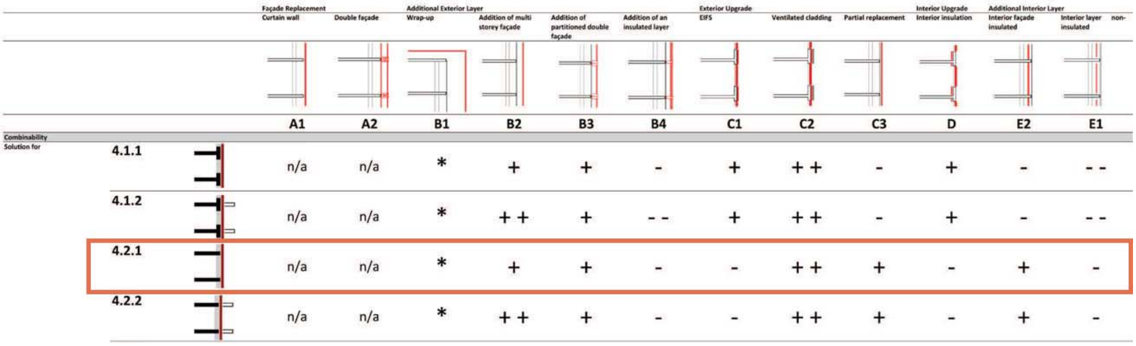


Figure 94: Applicability of refurbishment strategies to different facade types (Ebbert, 2010, fig. 6.1)

It shows that type 4.2.1 combines very well with strategy C2.

- B1 Additional Exterior Layer Wrap-up *
- B2 Additional Exterior Layer Addition of multi storey façade +
- B3 Additional Exterior Layer Addition of portioned double façade +
- **C2 Exterior upgrade Ventilated cladding ++**
- C3 Exterior upgrade Partial replacement +
- E2 Additional interior layer Interior facade insulated +

In short, the method of Ebbert (2010) advices an additional exterior layer, an exterior upgrade or an additional interior layer.

Step 4 includes a long list of advantages and disadvantages of the strategies. This information is divided in the following topics: Architecture and Function, Material and Energy, Comfort, Combination with HVAC and Economic aspects.

B1 WRAP UP

In this strategy, the original façade can remain and an additional layer is added to the façade. This is an advantage if you consider that the building can stay in use during construction, there is much freedom in design and it provides a solution for thermal bridges. However, it does not solve insufficient daylight penetration, consumes more materials than replacing the façade and atriums tend to overheat. It does not seem feasible to wrap the entire façade in an additional layer.

B2 ADDITION OF MULTI STOREY FAÇADE

The addition of a multi storey façade is a relatively simple addition and overheating is less of an issue. Moreover, this type does demand an improvement of the façade. Important disadvantages are that the reuse potential of this type is low and windows cannot be opened. This type does not seem suitable for the building.

B3 ADDITION OF PORTIONED DOUBLE FACADE

Similar arguments as type B2, except that the windows can be opened and the addition of a portioned double façade is more difficult, because the loads are brought into the floor slabs.

C2 VENTILATED CLADDING

Advantages of this type are that there is a wide range of cladding materials, the thermal resistance can be easily improved, components can be designed re-usable, the position of the windows can be changed, overheating does not often occur, it combines well with night cooling and the construction costs are relatively cheap. Disadvantages include low potential of material reuse, eccentric loads on the structure and low marketability. Moreover, this type demands carrying walls. Some facades of the building have this as substructure, but the majority of the surface does not. Overall, this option seems suitable.

C3 PARTIAL REPLACEMENT

Advantages are that this replacement does not consume a lot of materials, the thermal resistance can be easily improved and the construction costs are low. Disadvantages include a limited freedom in design, that the position of the windows cannot be changed, no prevention of overheating as little mass is added and the energy saving potential is low. This type seems less sufficient than type C2.

E2 INTERIOR FACADE INSULATED

This option can be eliminated, because it does not provide a good solution for increasing the thermal resistance and solving thermal bridges.

Based on the information that is presented in the list, type B2 and E2 are eliminated.

7.5.METHOD 3: RESEARCH BY DRAWING

Both methods of determining façade interventions did not provide the ultimate approach nor answer, but brought the design a step further. After that, research by drawing seemed to be the most viable option. The outline for this was the concept. The following topics were explored:

- Location of the axis
- Demolition
- Addition
- Routing and stairs
- Office concept, where is what possible
- Daylight penetration
- Insulation location
- Reduction of façade area
- Façade replacement options
- Ventilation options
- Heating options

Some of these are discussed in the following paragraphs.

LOCATION OF THE CENTRAL AXIS

There are two logical axes and entrance locations. Preferably, both the entrance, symmetry and routing are located along the axis. As traffic (mostly pedestrians and cyclists) approaches the building from two sides, choosing is not as easy. The entrance can be located at three orientations: East, South and North.

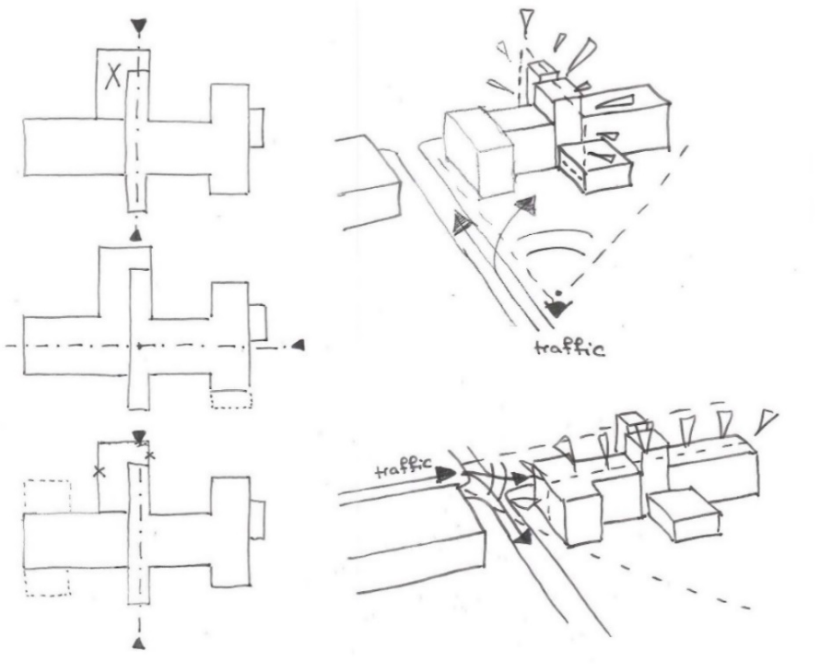


Figure 95: Location of the central axis

ROUTING

The location of the axis also determines where the entrance should be placed. The entrance should be located at the focus point.

Figure 96 shows some options for the entrance and staircases.

1. Entrance stays where it is at the moment and a second entrance is made near the second staircase. By this, the building will be seen as two buildings.
2. Entrance at axis through wind tunnel. Entrances and staircases at both sides. Giving more confusion, but better access.
3. Entrance at current location + additional volume.
   Or entrance in southern part of the east wing + additional volume. No clear building axis, but the entrances are located at the corners of the building and are therefore well visible. Demolition works necessary.
4. Axis through the wind tunnel and entrance at the north side. Large new addition to accommodate stairs.
5. Axis across length of the building. New entrance asymmetrical to east wing, but symmetrical to largest part of the building. Corridor across full length of the building. Demolition works necessary.

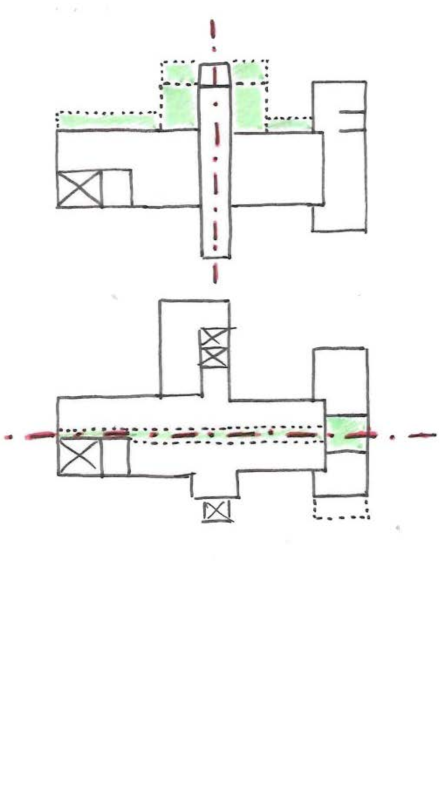


Figure 96: Routing and location of the entrance

INSULATION

The current situation is sketched on the left. At the moment, most of the building that was built in 1952 is not insulated.

1. Current situation. The wind tunnel is not insulated.
2. 'Simplify'. Demolish some of these uninsulated volumes and insulate everything else.
3. 'Cover all'. Insulate the entire building.
4. 'Exclude wind tunnel' insulated everything except the wind tunnel.

At the right, a section with possible floor insulation choices has been drawn.

1. Current situation. Cold all year round.
2. Insulate below floor. Assumed crawl space of 600 mm. Insulate with chips, plates or cushions.
3. Insulate on top of the floor. Rigid insulation. Floor-to-floor-height will decrease.
4. Leave it uninsulated and insulate first floor. This will not lead to a comfortable indoor climate. Therefore, the ground floor can then not be used.

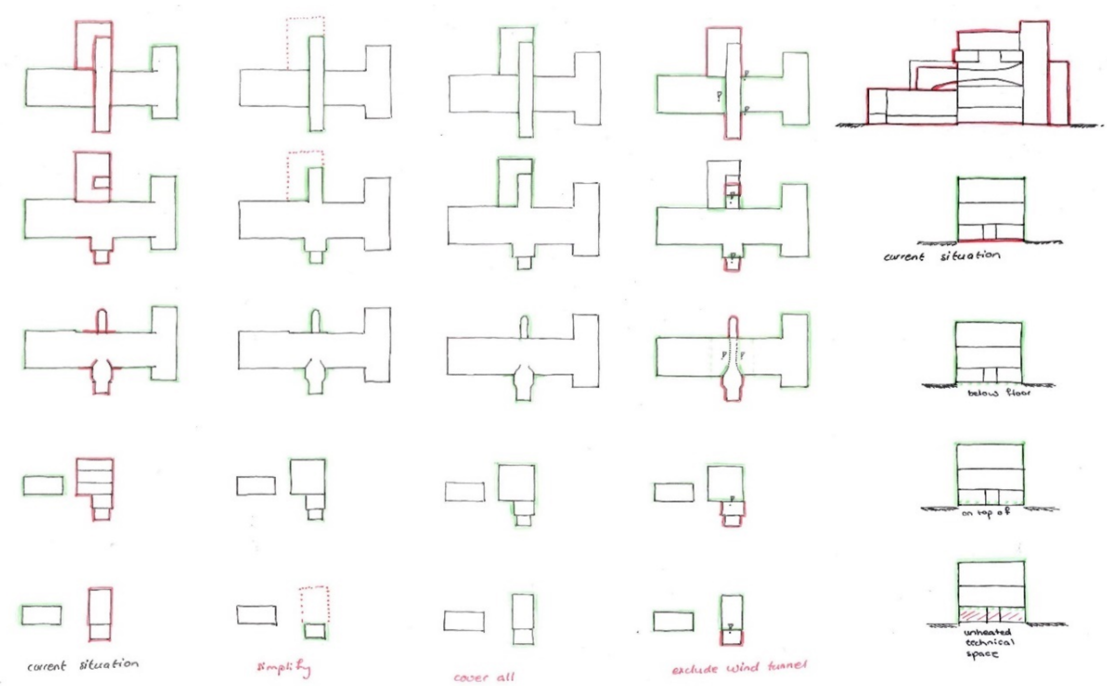


Figure 97: Location of thermal insulation

DEMOLITIONS AND ADDITIONS

There are several reasons for proposing demolitions and additions (Figure 98). These include:

- reducing the amount of space (m^2 and m^3) that has to be heated, maintained, rent out
  - add volumes to reduce façade area
  - remove volumes
- symmetry
- simplification
- provide extra space for functions that do not fit well at the moment
  - (routing, toilets, common space, elevator)

The drawings show a range of (non)successful proposals. On the bottom-right you will see the best combination. This variant provides both symmetry, simplification and a bit of extra space on the top floor. But more importantly, the wind tunnel can be observed better.

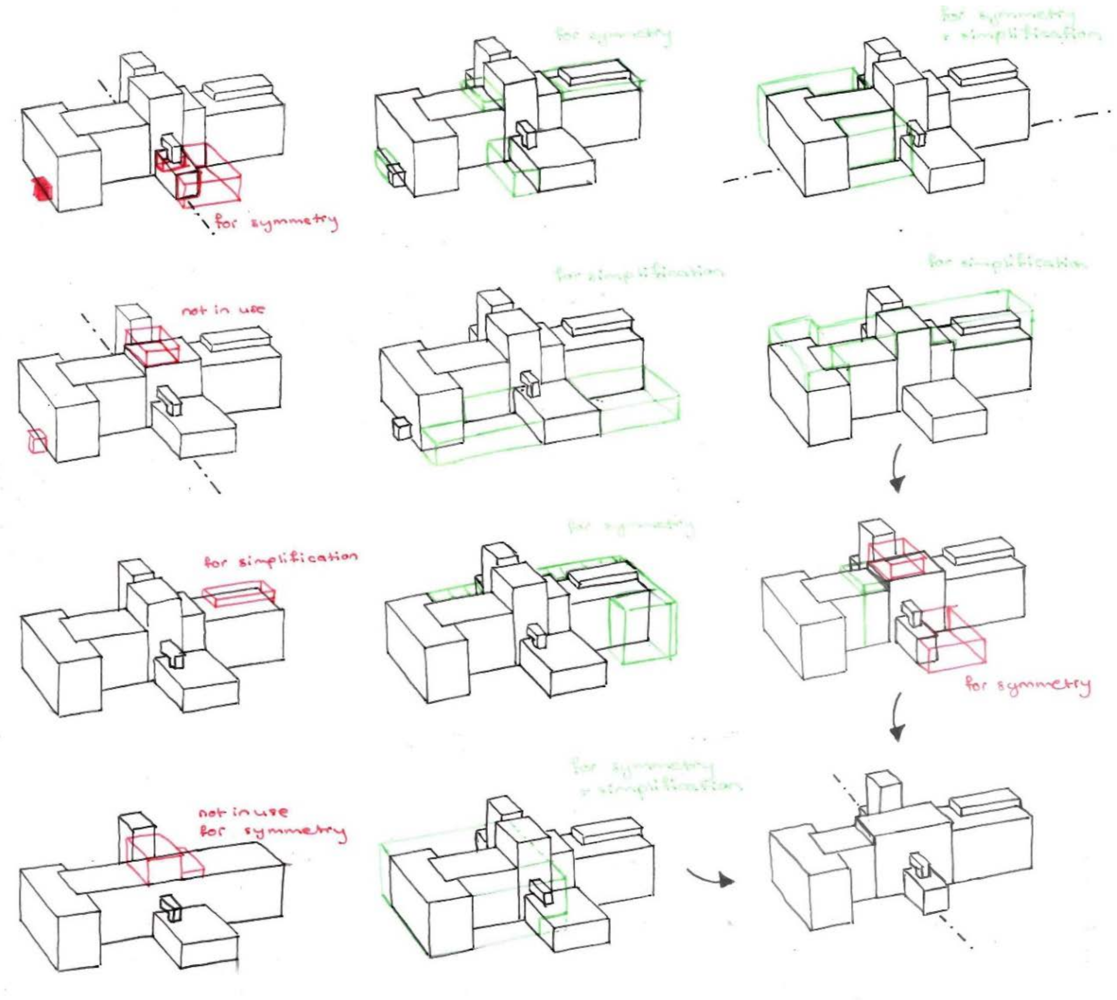


Figure 98: Options for demolition and addition. Demolitions are marked red and additions are marked green.

DAYLIGHT PENETRATION

Figure 99 shows what walls have to be kept and which can be opened up. It shows the ground floor (top) to second floor (bottom). Only the wind tunnel and the vertical wind tunnel have to remain closed areas. The wind tunnel measurement room, in particular, has to be closed off from the rest of the building during laser tests. This, of course, complicates the routing.

The south-west corner of the building can very well be used for BIPV, as these walls are blind.

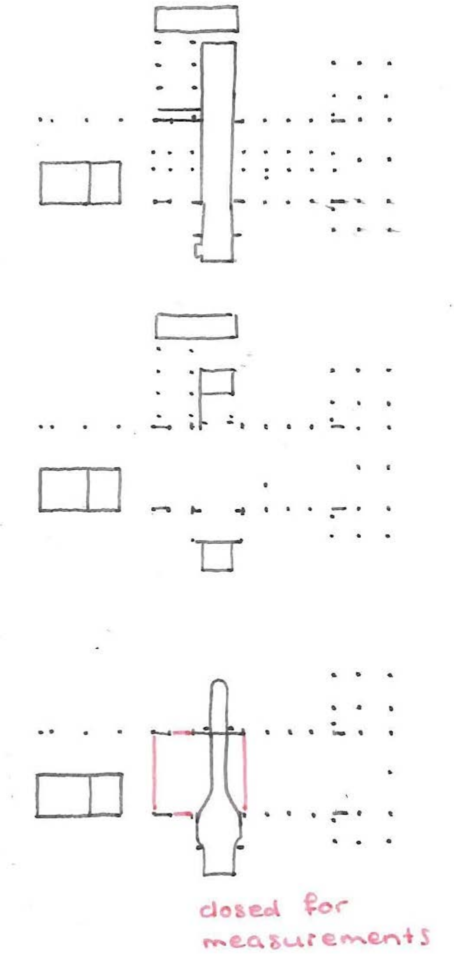


Figure 99: Daylight penetration

FAÇADE OPTIONS

At several places along the façade, there are concrete spandrels and parapets that limit the design. Figure 100 shows some options.

1. Keep inner sand-lime blocks (sometimes masonry) and keep the existing size of the window frames.
2. Replace the façade and enlarge the windows. For instance, as high as possible.
3. Replace the façade and place prefab panels that span floor to floor.
4. Add-on. Add a second façade and leave in the current façade. Disadvantage is that the windows are still placed too high.
5. Wrap it. Add a second façade and leave in the current façade. Disadvantage is that the windows are still placed too high.

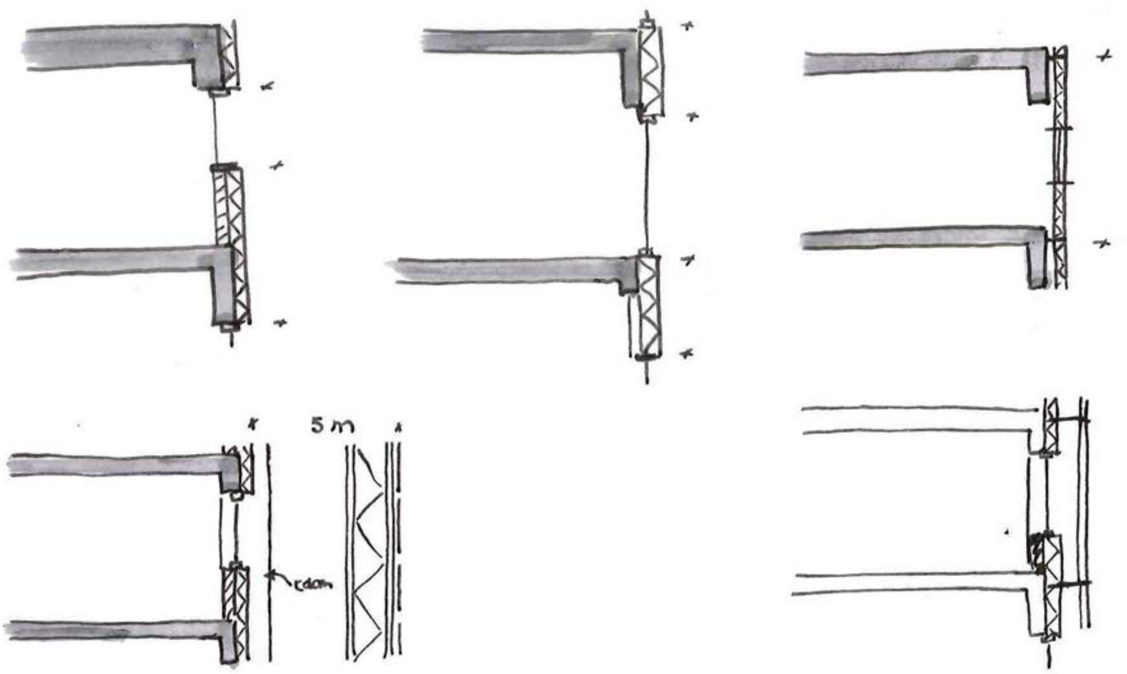


Figure 100: Facade options

PASSIVE AND ACTIVE CLIMATE OPTIONS

Some choices regarding heat loss have already been made. The ventilation, for instance, will make use of heat recovery. Natural ventilation all year round is therefore excluded. There has to be a location for shafts and a technical space for the installations. So far, the fourth floor, above the wind tunnel research lab, seems logical (centre of the building).

It has also been decided that the windows in the façade have to be able to be opened, because it is more comfortable for the users and the building will make use of night ventilation.

The aim is to design a NZEB:A, but options that harvest renewable energy within the site footprint (NZEB:B) are also investigated. These include, for instance, an earth tube, heat pump and PV-cells on adjacent buildings.

The book 'Architectuur als klimaatmachine' (Yanovshtchinsky et al., 2012) was used for the definitions and explanations below.

1. Solar glass house
   Add-on of a transparent façade to the south side of the building. The temperature of this glass house increases during the day and becomes a thermal buffer. Additionally, fresh ventilation air can be led through this glass house to be preheated. In winter, the deciduous trees let trough about 40% of the daylight and in summer almost all is blocked. This is advantage of the building.
2. Solar chimney and earth tube
   Passive ventilation principle. Make a solar chimney in the façade or on the roof, that heats up and thereby sucks air out of the building. The inlet can be a series of earth tubes. Attention has to be paid to the shade that is caused by the trees.
3. Solar chimney
   Same principle as described in option 2, but in this case the wind tunnel is made into a solar chimney. The highest tower of the wind tunnel, which is a technical space, can be turned in to a solar chimney by adding a second façade. The height is sufficient. However, the trees endanger the efficiency of the principle. This option has to be combined with mechanical ventilation as well.
4. Fiwihex heat exchangers
   A compact ventilation unit that contains a heat exchanger and is highly efficient.
5. Ventilated atrium
   An atrium can be used to guide exhaust ventilation. This can be designed both passive and active. At the moment, there is no central atrium in the building.
6. Low temperature floor heating
   Low temperature heating is suitable for well insulated buildings and often consists of floor or wall heating. The water temperature in these systems is <55 degrees Celsius and the systems spread the heat equally.
   The building has several large open spaces without many walls and a high ceiling height. Floor heating seems the most logical option. The building also has a high thermal mass. This

combined makes that low temperature floor heating seems to be very suitable for this building.

7. Asphalt collectors
   The top floor of the new parking garage will either become an open parking roof or will be covered in a PV-roof. If it becomes and open roof, asphalt collectors can be placed. In combination with a heat pump, the generated heat can be stored and used for heating the building. Asphalt collectors have a low efficiency, but the surface of the parking garage is large.
8. Photovoltaic roof or facade
   The top floor of the parking garage can be covered in a photovoltaic roof. The facades can also be covered in photovoltaic panels.
9. Horizontal closed loop heat pump
   Geothermal system that pumps a mixture of water and anti-freeze through horizontally laid pipes in the ground (large surface). Heat or cold is extracted from the ground (depending on the season) and are often combined with LTH-systems in the building.
10. Vertical closed loop heat pump
    Geothermal system that pumps a mixture of water and anti-freeze through vertically drilled pipes in the ground (high depth). Heat or cold is extracted from the ground (depending on the season) and are often combined with LTH-systems in the building.

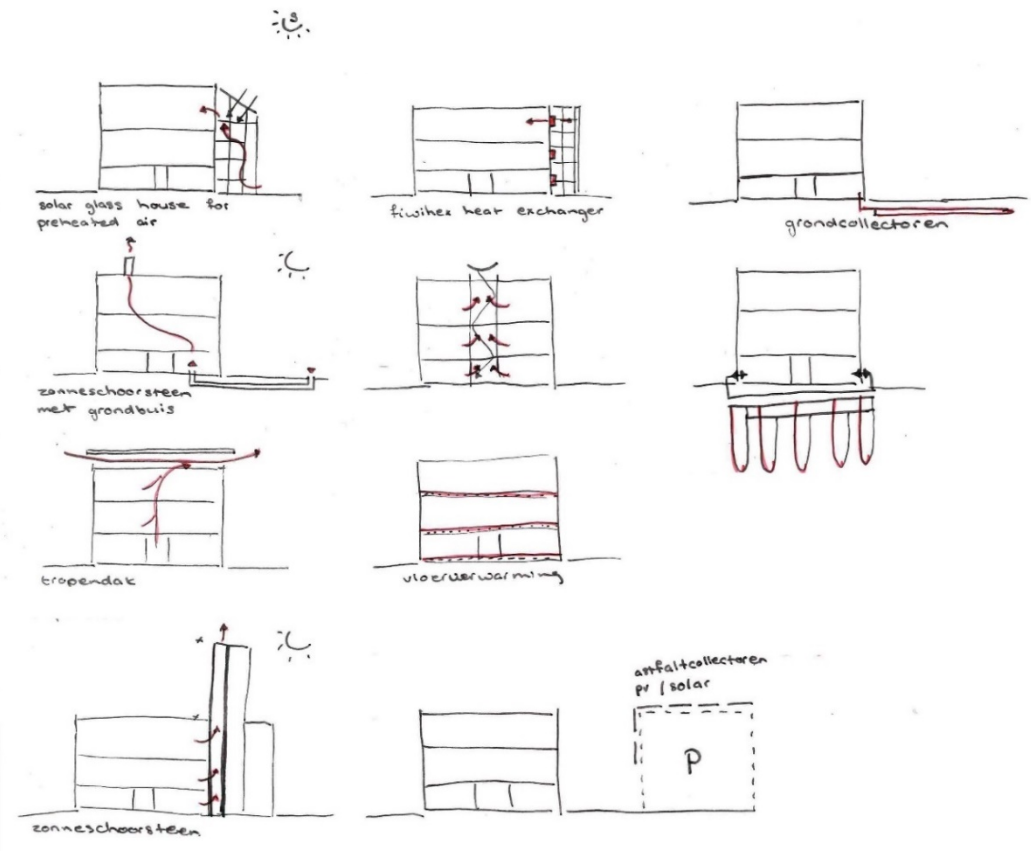


Figure 101: Examples of passive and active climate options

8. DESIGN

In this chapter, the numerous design options presented in the previous chapter are used to make design decisions. To test and evaluate whether these measures combine well, they are tested alternately in section and on building scale. In this design process, four stages were conducted (Figure 102).

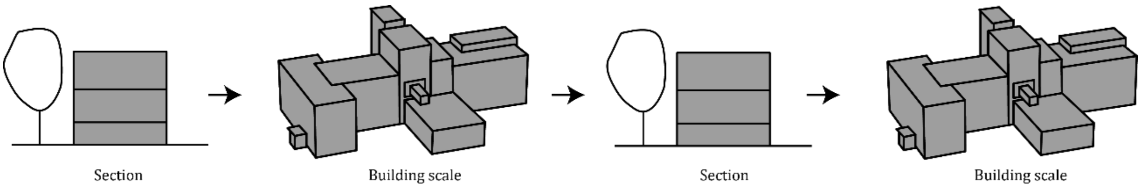


Figure 102: Design process of the LSL

In the first stage, the design decisions and corresponding measures are applied in a typical section of the building. The section that is used in this chapter cuts through the oldest part of the building (Figure 103).

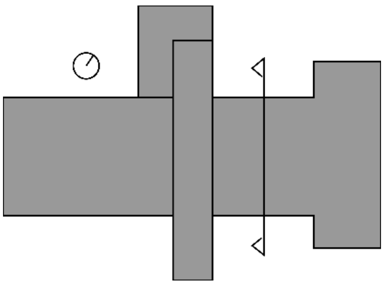


Figure 103: Location of the section

In the next phase, it will be evaluated whether the measures in section can be applied to the entire building. Also, the design choices will be compared to the strategy. Presumably, testing this will result in changes in measures. In phase three, the combination of interventions is checked in section. And in phase four, the exterior and landscape are considered too. Each phase will discuss the same categories, being:

- Functional
- Façade
- Façade openings
- Floors
- Heating
- Ventilation
- Electricity generation

Decisions are taken, as described in chapter 7.1, with energy, circularity and architecture in mind.

8.1.ADAPTATION 1: SECTION

The proposed measures that are discussed in this chapter are shown in Figure 104. In the following paragraphs, design decisions are taken and applied to this section. Together, these should make a holistic design and complement rather than contradict one another.

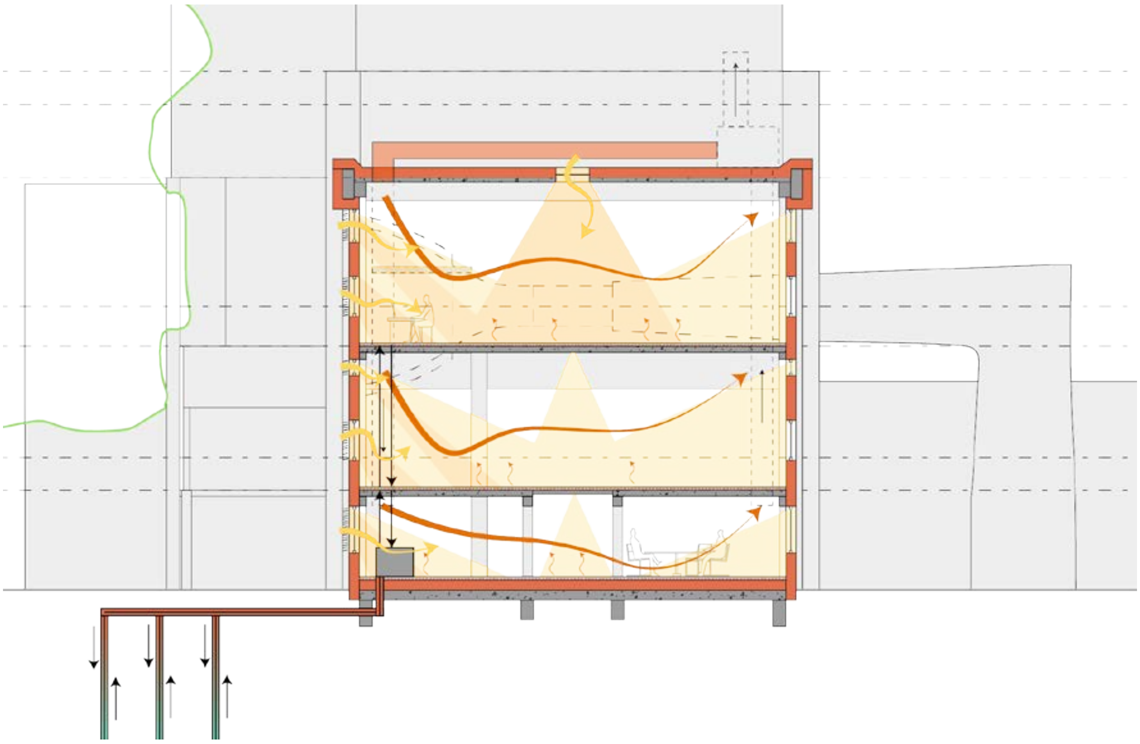


Figure 104: Typical section of the Low Speed Lab with proposed measures

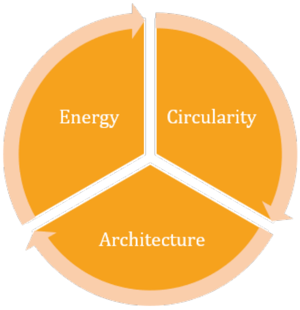
FUNCTION(AL)

Making architectural and spatial design decisions in section is difficult. However, some decisions have already been made. First, to increase the flexibility of this building, spaces will be designed so they can be offices as well as machine halls. Also, the second floor of the building has a headroom of 4865 to 4925 mm, which makes it possible to build a mezzanine and increase the functional (office) space. This has implications for requirements about daylight, temperature and view.

FAÇADE

The thermal resistance of the opaque façade surfaces will be increased to 9,0 m2K/W. To achieve this R-value, an insulation thickness of 300-400 mm is required. There are several options to get to this value, including adding layers, replacing layers, replace the entire façade and adding a second façade. For a number of reasons, it has been decided to replace the entire façade for a system that spans floor to floor. The considerations are listed in Table 18.

Table 18: Design criteria: façade system



Energy	A comfortable indoor climate can be designed from scratch.
Circularity	The current façade materials will be removed from the building and downcycled. Design for Disassembly is easier to implement.
Architecture	Largest design freedom. Building must be emptied during refurbishment

FAÇADE OPENINGS

The building does not let sufficient daylight in to turn off the artificial lighting. However, turning the lighting off would save energy. Also, the windows at the first and second floor are placed too high to make comfortable workplaces. To solve both the lack daylight and view, a window concept has been developed. Figure 105 shows this concept. The proposition is to make two windows per floor. The lower window lets in daylight and provides a view for both standing and sitting people, while the upper window lets in additional daylight. The width of these windows can be decided in the next design phase (building scale).

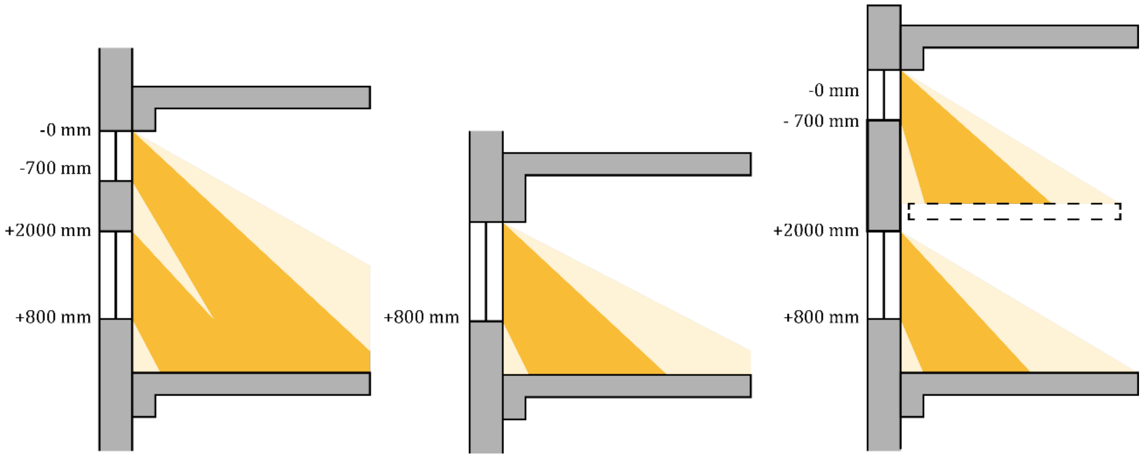


Figure 105: Window concept (left) and two alternatives

As the floor-to-floor height and height of the spandrels vary in the building, the figure also shows how to change the concept for other floors. In the middle, a room with lower height and a high spandrel is drawn. The solution is to still keep the window sill at 800mm, but make the head piece as high as the spandrel. The third illustration shows a floor that with a larger floor-to-floor height. A mezzanine is optional. Therefore, the height of the upper window is increased to allow the people at the mezzanine to have a view. Overall, the number of windows sizes will be limited to improve reusability.

The double or triple glazed windows will have at least one openable pane per window. By this, the users will feel more comfortable. However, the downside is that the mechanical ventilation works less well when windows are opened. In addition to the openable windows, ventilation openings are placed above the windows. This will make night cooling possible, by which the building can be cooled after hot days.

To limit overheating during the day, adjustable louvers are placed in front of the windows on the east, south and west façade. The north façade will be excluded, because the hours of sunlight are limited. Instead, the north façade windows are equipped with insulated shutters. These can be closed at night to improve the thermal resistance of the façade openings.

Also, extra skylights are made in the roof to let in light and compensate for the depth of the building (13m). Additionally, solar tubes are placed at well-considered locations (not obstructing large open spaces) to provide the lower floors with daylight.

FLOORS

The thermal resistance of the roof and ground floor will be increased to 10,0 and 7,0 m2K/W. The floors in the building are made of in-situ reinforced concrete and the thickness varies from 140 to 200 mm. At the moment, the roof is only insulated with 40mm of rockwool.

To accomplish an R-value of 7,0 m2K/W, the ground floor has to be insulated below or on top of the floor slab. Figure 106 shows the amount of concrete and thermal bridges in the ground floor. The beams below the floor slab make up a larger surface (thermal bridging) than the columns on top of the floor slab. And it is not certain whether the entire building has an (accessible) crawl space. Based on this, it was decided to insulate on top of the ground floor. This will raise the floor level by 250-300 mm.

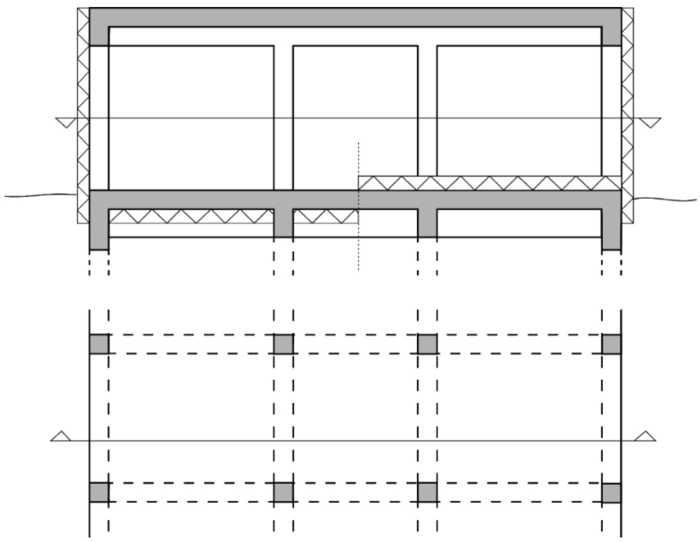


Figure 106: Comparison of insulation on top or below of ground floor slab

HEATING

As mentioned in the past chapter, the building will be heated with low temperature floor heating. Installing floor heating will increase the floor thickness by an additional 100mm. Floor heating can be made as a wet and dry system. The largest advantage of the wet system is that it adds extra thermal mass. And the largest advantage of the dry system is that most systems are modular and can be taken apart. As the thermal mass is already high and reusability is important in this refurbishment, the dry system is chosen. In time, the floor heating can be taken apart again.

The fluid that runs through the floor system exchanges its heat with the fluid in a vertical closed loop heat pump. For this site, a vertical heat pump is a better option as the space is limited by the new parking garage. A closed loop system has been chosen as local regulations limit the use of open systems.

VENTILATION

At the moment, most spaces in the building are ventilated naturally. However, natural ventilation is no longer wise after the refurbishment, because it does not make use of heat recovery. And heat recovery is a perfect example of reusing waste streams. Therefore, there will be mechanical ventilation and it will be equipped with heat recovery. For now, the section contains ventilation ducts for both the inlet and exhaust.

ELECTRICITY GENERATION

For this building, electricity can best be generated with photovoltaic panels on the roof, the façade (BIPV) and if necessary on the new parking garage. The orientation, surrounding buildings and especially the trees limit the efficiency of these panels. Large parts of the façade and roof are shaded because of these three limiting factors. Therefore, photovoltaic panels are only placed at the north side of the roof.

8.2.ADAPTATION 2: BUILDING SCALE

In this chapter, it will be tested whether the measures presented in section (**Fout! Verwijzingsbron niet gevonden.**) can be applied to the entire building and whether all problems are solved. The main strategies for this building are: follow the New Stepped Strategy, simplify the building, add flexibility and make the wind tunnel the focus point.

FUNCTIONAL

The proposed measures do not provide a solution for simplification, symmetry and routing. This has to be solved in 3D rather than 2D. As the central axis of the building will be located at the wind tunnel, the entrance can best be placed there too. The dashed area in Figure 107 shows the possible location of the new entrance.

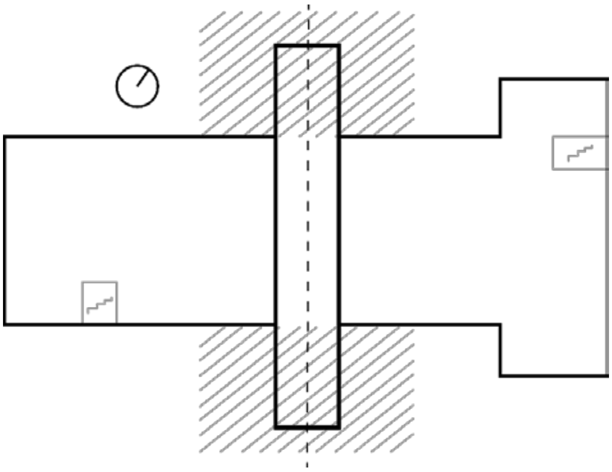


Figure 107: Location of the central axis and location of the entrance with staircases

The morphology of the building is complicated and the main reason for that is the wind tunnel. The wind tunnel obstructs solutions for routing. After various studies, the best options for simplifying and solving the routing is going around the wind tunnel at all floor levels. The dashed and hatched areas in Figure 107, Figure 108 and Figure 109 represents where the routing can go around the wind tunnel. The existing staircases are shown too.

Figure 108: Photos of the north (left) and south (right) facade of the LSL

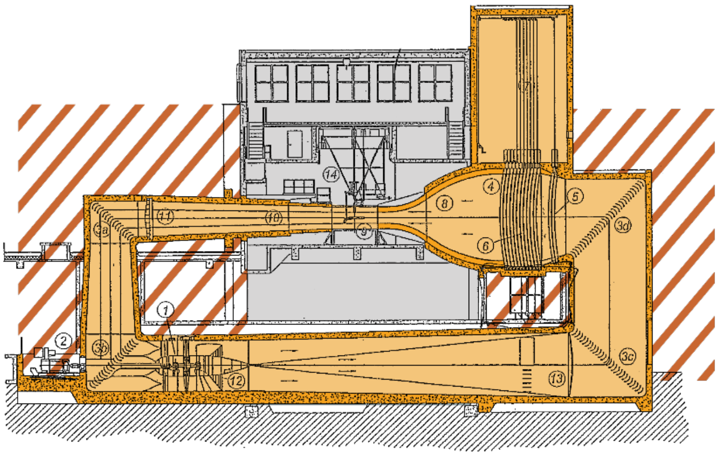


Figure 109: Possibilities for routing around the wind tunnel

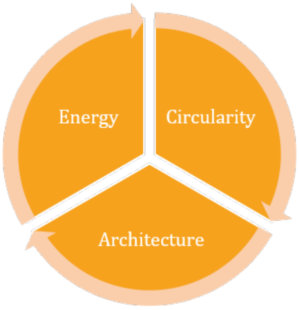
For a number of reasons, three volumes of the building are considered for demolition. These include the empty room on the 3rd floor, the machine hall at the ground floor and the current entrance. This will mean 239,77 m^3 of concrete is taken out of the building, but 1145 m^3 no longer has to be heated and 704 m^2 less façade has to be insulated with new materials (Table 19).

Table 19: Overview of quantities in two of the to be demolished volumes, data taken from Revit

Room	Area (m^2)	Volume (m^3)
Demolition 3rd floor	**100**	**425**
Floors	223	35,29
Structural Columns	0	0
Walls	161	32,35
Demolition machine hall	**160**	**720**
Floors	498	88,51
Structural Columns	118	10,89
Walls	283	72,73

The current entrance does not contain any concrete and is removed as the entrance will move to the new axis. Deconstructing these three volumes comes with a number of design considerations, as shown in Table 20. The energy consumption for heating and lighting will decrease (energy) and the amount of new materials for insulating the building is also lower. However, chapter concluded that most materials that are taken off this building are not recyclable. Deconstructing these volumes is a waste of energy and materials (circularity). On the other hand, removing the 3rd floor and machine hall result in more symmetry and allows the entrance to be located near the new axis (architecture). The benefits of deconstruction compensate for the disadvantages and it seems best to deconstruct these volumes.

Table 20: Design criteria: demolition of volumes



Energy	Less heating Less maintenance
Circularity	Material waste New materials
Architecture	Symmetry Simplification Less GFA to rent

Also, an extra volume will be added to the third floor for symmetry and make room for the installations. The result is shown in Figure 110.

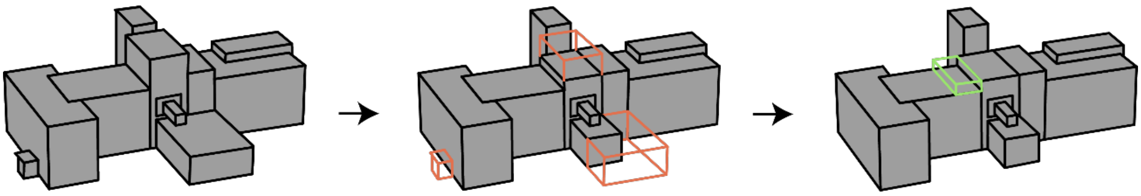


Figure 110: Demolition and addition of building volumes

This results in two locations for the entrance and staircases: at the north side and at the south side. The building is made more flexible by dividing it in four volumes, as is shown in Figure 111. The division is based on the building layout and age. By creating zones, four lettable spaces are made per floor (12 in total). These can be combined to larger spaces if desired, but can function on their own as well.

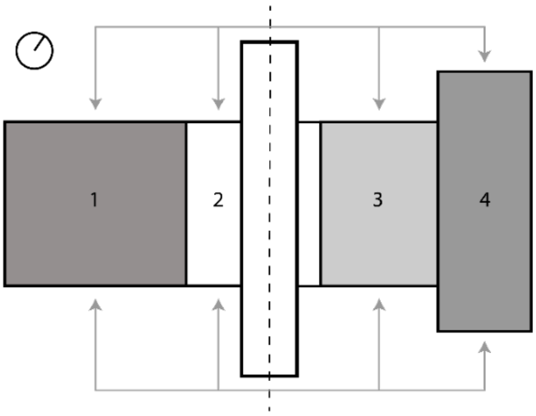


Figure 111: Division of the building in four volumes and proposed accessibility via north or south

At the moment, some spaces are only accessible through other let-out spaces. This is not acceptable in a flexible building. These volumes have to be directly accessible from the entrance. Figure 111 shows the proposed entrances and walking paths that make the volumes accessible.

These walking paths cannot be placed in the building. It is therefore logical to make an addition to either the north or south side. This addition could only contain walking paths, stairs and an elevator, but can also contribute to the success of the building. At the moment, the building does not have enough toilets and lacks common space. Therefore, an addition of 4-5 m is designed. This width creates sufficient space for functions aside a walking path and fits in the current grid.

The possibilities and limitations of both options were investigated and are shown in Table 21.

Table 21: Comparison of north and south side addition.

North side	South side
Excellent accessibility to parking garage	No access to parking garage
Moderate accessibility from the street	Excellent accessibility from the street
Large space for bicycle parking	Limited space for bicycle parking
Low window-to-wall ratio	High window-to-wall ratio (solar glass house)
Large obstruction of daylight	Small obstruction of daylight
Limited solar heat gain	Extensive solar heat gain
Insignificant reduction of exposed facade	Significant reduction of exposed facade
Excellent wind tunnel experience	Moderate wind tunnel experience
Shared space next to parking garage	Shared space next to trees
High freedom of stair design	Moderate freedom of stair design
Direct connection to one flight staircase	Direct connection to one flight staircase
Easy routes for ducts	Difficult routes for ducts

Based on the above-mentioned characteristics it has been decided that the entrance will be made at the north side.

FAÇADE

The chosen façade type gives much design freedom and can be easily applied to the entire building. Some locations provide difficulties, including inner corners, roof trims and the wind tunnel. Simplifying window distances seems possible, although the building has varying grid sizes.

The wind tunnel will be insulated too, because it is a major thermal leak. The wind tunnel is structurally disconnected from the rest of the concrete load-bearing structure and so will the façade. For now, an exterior insulation finishing system (EIFS) is added to the wind tunnel. This façade system can best make use of the same insulation material with the same thickness, as this increases future reusability.

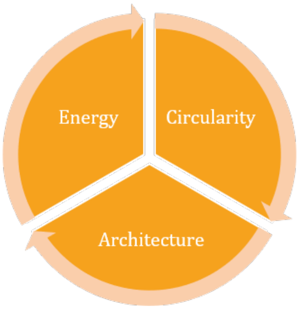
FAÇADE OPENINGS

The window height has been determined in section, but the width has not yet been established. Windows have a lower R-value than opaque façade surfaces and can best not be over dimensioned. A high window-to-wall ratio would result in a lower R-vale of the entire façade. Therefore, the window location needs to be chosen carefully.

Placing the windows at a fixed location in the panels has advantages and disadvantages (Table 31).

Also, the number of unique façade elements can be decreased by placing the windows at well-considered locations. Extra limitations are the blind walls of the wind tunnel and vertical wind tunnel.

Table 22: Design criteria: standardisation of façade panels



Energy	Easier to construct
Circularity	Higher reusability of panels, as they do not differ much
Architecture	Less design freedom Risk of losing appeal

FLOORS

All floor levels will be raised by the addition of floor heating and the ground floor will also be raised by the addition of thermal insulation. These changes have the largest implications for the ground floor, as both the floor-to-floor height decrease and the surrounding terrain has to be raised to match the new floor level. Half of the ground floor has openable doors to the surrounding park.

HEATING

To supply the building with hot or cold water, a vertical closed loop heat pump is drilled. Figure 112 shows where the vertical tubes of the heat pump can be drilled. An area of 700 m^2 on the west side of the LSL is available to drill the vertical tubes. For now, it is assumed five tubes need to be placed.

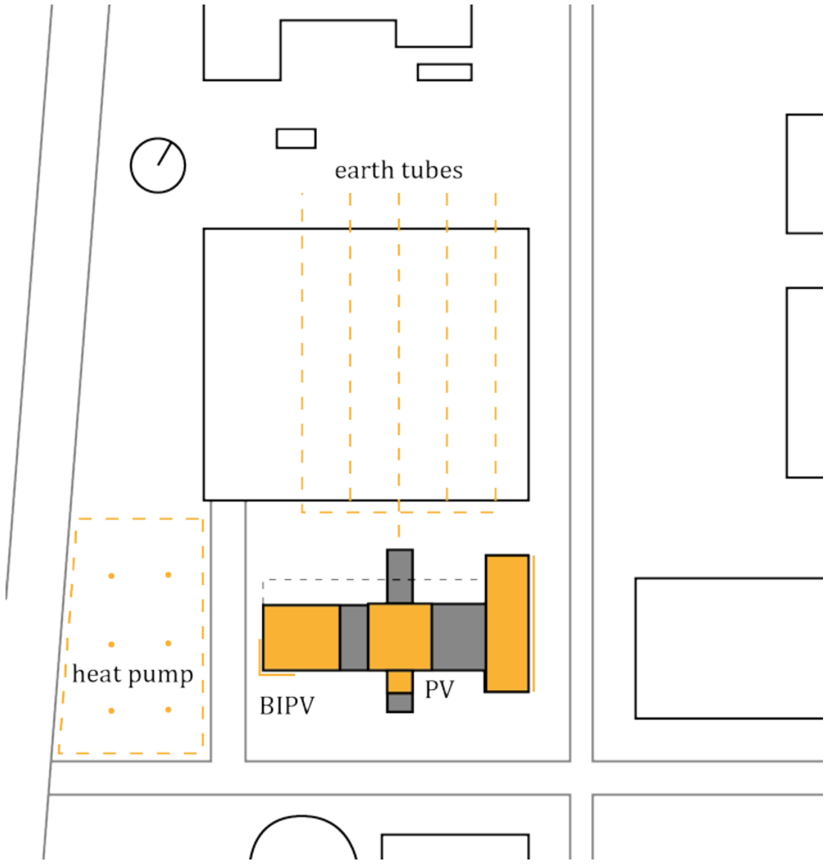


Figure 112: Renewable energy generation on site

VENTILATION

Right next to the wind tunnel, there are two spaces where the installations of the building can be placed: on the ground floor and in the newly added volume. As these two rooms are moved to the centre of the building, the distances are shortened. Most ducts for ventilation can be placed in the addition on the north side.

To decrease the energy consumption for pre-treatment of ventilation air, a series of earth tubes will preheat or cool the fresh air, depending on the season (Figure 112). By this, the temperature difference between inlet and room temperature is decreased. Often, earth tubes are laid around a building, but there are too many roots in the ground around the LSL. Fortunately, these earth tubes can be laid on the north side of the LSL, at the recently cleaned building site. A length of 90 m^1 is possible and the tubes can be laid in between the foundation of the new parking garage.

ELECTRICITY GENERATION

The annual electricty consumption of the building ia likely to decrease, because the lighting and installations are more efficient. Also, the consumption throughout the day is expected to change. In the refurbished building, the consumption will no longer be limited to working hours as the floor heating and installations are also making use of electricity. The consumption is expected to be spread out over the day. Therefore, spreading out electricty generation is also wise. Although the LSL is connected to the electricity grid, making the building dependent on the electricity grid is not durabe. The more energy can be consumed when generated, the less has to be stored.

User occupancy has a great influence on the energy consumption in a building. In chapter 6.4 the occupancy schedules of the current users were discussed. The LSL research group and Inholland seem to use the most electricity and have the most FTE (Figure 113). Changing their operating hours will therefore have the largest influence.

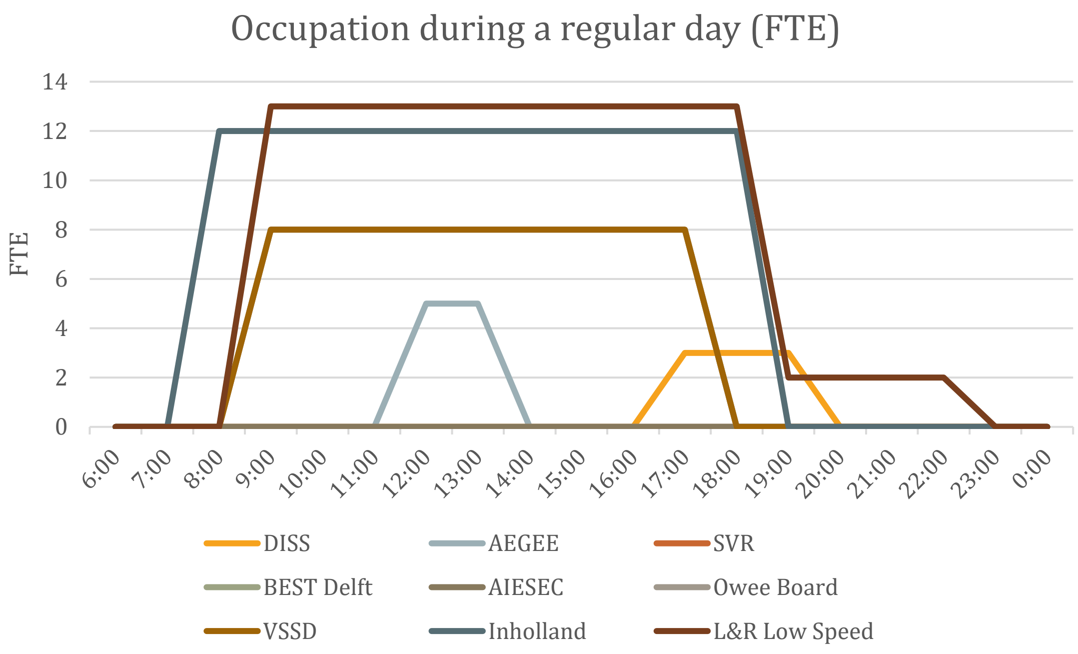


Figure 113: Occupation of the LSL during a regular day (FTE)

To match the electricity generation and consumption, the orientation and inclination of photovoltaic panels is very important. In fact, the proposal in section does not work for the entire building, as the LSL is not a rectangular and simple building volume. Orienting all panels as proposed in section would result in peak generation, rather than spread out generation.

In practice, photovoltaic panels can be placed in the façade as well. When deciding the location of PV-panels, it is important to consider hours of light, intensity and peak production. Placing all PV-panels at an optimal orientation and inclination will surely result in the highest revenues, but has peak hours in the generation. The electricity generation can be well spread by placing panels at all orientations and thereby producing electricity for a longer time span a day.

As the LSL has a complicated building shape and a row of high poplars on the south side, the placement should be carefully considered. The total roof area adds ups to 1130 m^2, of which a large part is shaded by the building itself. Table 14 shows how many hours of sunlight each façade gets per season. Shading caused by trees is not taken into account in this table.

Recurrence of Table 12: Hours of sunlight per façade and season, based on data of Revit.

	Winter solstice	Hours	Spring/ Fall equinox	Hours	Summer solstice	Hours
East	10:30-12:00	1:30	08:30-12:30	4:00	06:30-13:00	6:30
South	10:30-17:00	6:30	08:00-18:00	10:00	08:30-17:00	8:30
West	12:00-17:00	5:00	13:00-20:00	07:00	13:00-21:00	8:00
North	no	0:00	18:00-20:00	2:00	17:00-21:00	4:00

If over 50% of the façade is lit, the hours are counted.

The south façade of this building gets the most hours of sunlight, followed by the west façade. As the north façade receives only four hours of sun a day at best, this façade is excluded from electricity generation. The south façade receives the most solar irradiation, but is shaded by threes. These poplars block 40-50% of the light in the winter and 95-100% in summer. The generation will not be enough to compensate for the Embodied Energy of these panels. Therefore, the surface of the south façade that is shaded by the trees is excluded too.

However, the east façade of the building is not shaded by trees, nor shaded by the building itself. Although the number of hours of light are limited, the surface is large. In total, this façade measures 360 m^2. The south-west corner of the building is also very suitable for photovoltaic panels, because there are only small trees there and it is a blind wall (no windows). Figure 112 shows the location of these BIPV surfaces. Around 200 m^2 of PV can be placed on this façade.

Placing PV-panels on roofs is more common than BIPV, but for the LSL the placement is rather difficult. Figure 112 shows the four proposed locations. The main reason why the roof will not only be covered in PV is threefold:

- The roofs do not make a flat surface and shade each other
- The trees shade large parts of the roof
- A roof with photovoltaics does not have water buffering capacity and a sedum roof does

8.3.ADAPTATION 3: SECTION

The changes in 3D also affect the building in section (Figure 114). In this chapter, the changes will be discussed.

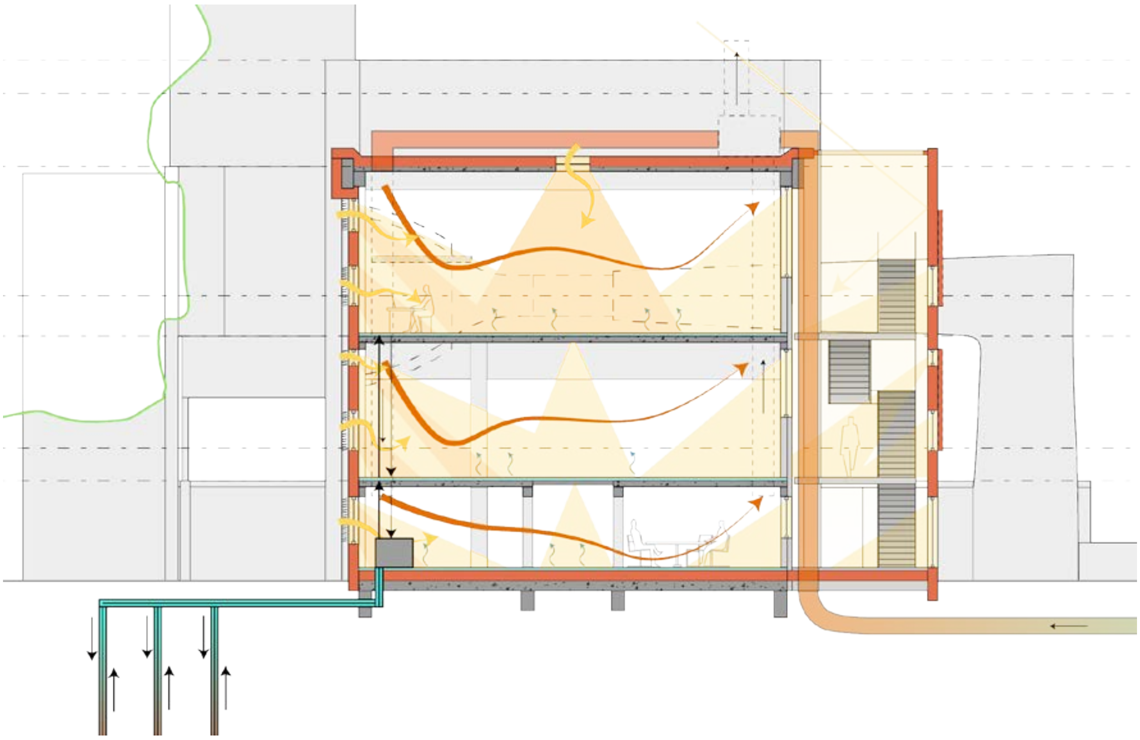


Figure 114: Resulting section of the Low Speed Lab with proposed measures

FUNCTIONAL (PHASE 4)

The add-on on the north side of the building will be the entrance to the building and will have central staircase. Additionally, other functions can added to this space, like:

- Elevator (to all floors)
- Two groups of (accessible) toilets at each floor
- Meeting/lunch tables at each floor
- Storage rooms
- Ducts for installations

Figure 115 shows the proposed division line between shared and private space. Most of the shared space will be built new, but a portion of the east wing will be used too. The above-mentioned functions are placed in the shared space.

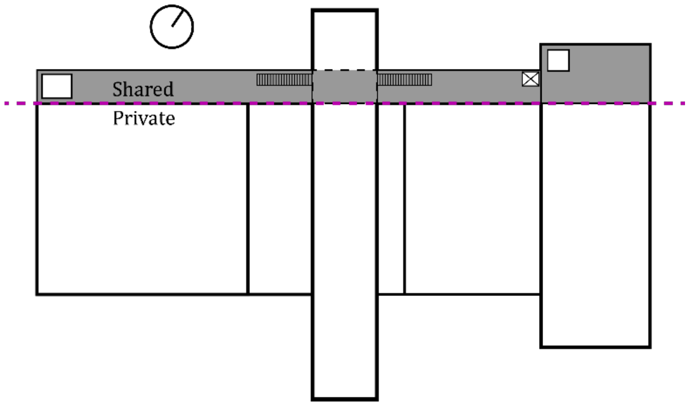


Figure 115: Location of shared and private spaces

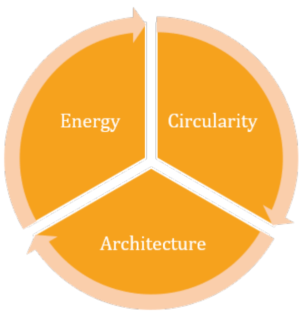
FAÇADE

The design of the addition on the north side involves two important design decisions:

1. Location of thermal insulation
2. Open atrium or addition with closed floors

For both, the design criteria can be listed. First, the location of the thermal insulation will be discussed (Table 23). The location of the thermal insulation influences the usability of the addition. If the insulation is placed on the existing façade, the addition will be a different climatic zone. This saves energy for heating, but decreases the amount of comfortable floor space.

Table 23: Design criteria: location of thermal line in new facade

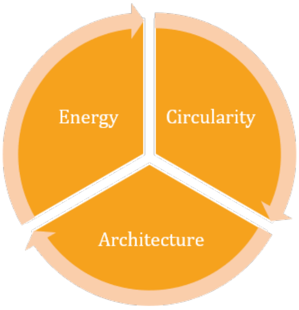


Energy	More volume to heat Easier placement of insulation Smaller risk of overheating
Circularity	-
Architecture	Extra usable floor space Comfortable walking routes More shared space

The benefits of placing the thermal insulation in the new façade weigh up to the disadvantage of increasing the heated zone. Therefore, the insulation will be placed on the exterior.

The second design decision involves the openness of the add-on. Table 33 shows the considerations for making closed floors in the add-on. The main benefit of making closed floors is that the ventilation and heating is more balanced (energy). The main drawback is that the concept and view on the wind tunnel is obstructed (architecture). As the architecture is highly, comprised when the floors are closed, the add-on will be made as an atrium.

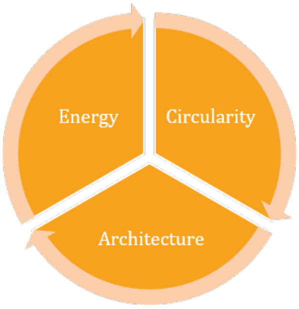
Table 24: Design criteria: closed floors



Energy	More balanced heating and ventilation More energy for lighting as less daylight is let through
Circularity	More material for flooring Less material for railings
Architecture	Lack of view on the wind tunnel More usable floor space

As a new façade is added on exterior of the add-on, it is no longer needed to replace the entire north façade of the current volume. The north façade can remain in place. By this, less materials are consumed and brought into the CDW cycle. The layers in the façade that were added in 1977 are taken of, because the corrugated steel plates limit daylight. The disadvantage is that leaving in the original facade is not a solution to the lack of view.

Table 25: Design criteria: leaving in the original facade



Energy	Single glazing between shared and private space
Circularity	Less materials are taken off the building
Architecture	Preserve original character Lack of view to the atrium from the offices

The total width of the add-on can best be 4500 mm. This width is based on the width of the stairs, opening in the wind tunnel and connection to existing façade. The new façade connects to the columns in volume 4.

FAÇADE OPENINGS

The window concept will also be used in the atrium (add-on). The insulated shutters that are planned on the north move to the new façade. Technically, this results in a simpler system than in the previous section.

A skylight is placed on top of the atrium to let in light, as sunlight hardly reaches the north façade. The top part of the new façade reflects light in to the rooms. Although the R-value of a skylight is significantly lower than the roof, the skylight lets in light and saves on energy for lighting.

FLOORS

To allow light to reach the ground floor as well, the floors in the atrium do not cover the entire surface. The ground floor is heightened by the thermal insulation. This affects the surroundings of the building and the terrain has to be levelled as well.

The height difference between floor 1 and 1+ is 800 mm. As there is not enough length to make a ramp, the elevator will be able to reach both levels. The costs for the elevator will be higher, but the accessibility and flexibility will increase.

HEATING

The ground floor of the add-on will also be equipped with floor heating.

VENTILATION

The ducts that were planned in the add-on are easier to place, because the floors are not closed.

ELECTRICITY GENERATION

The section no longer shows PV-panels, because there are no panels on top of this roof.

8.4. ADAPTATION 4: BUILDING SCALE

In this chapter, the measures presented in section (Figure 114) are applied to the entire building and material choices are made.

Large parts of the façade and the roof are being replaced and a new volume is added to the building. Therefore, new materials and systems have to be chosen. In chapter 3.9, the requirements for buildings with circular building materials have been discussed. Building materials are joint together in components (e.g. façade panel, window, heat recovery unit). To enable circular material use, these components should be adaptable, made of low impact materials and reusable. Moreover, the materials should be able to be taken apart again. In this chapter, some decisions regarding the material choice are discussed in detail.

FUNCTIONAL

Figure 116 shows the floor plans of the LSL in scale 1:500. Each floor is split in a shared and private area. The private area contains four lettable rooms per floor (with exception of the ground floor). All rooms are accessible from the shared space. The location of the doors is based on current façade openings and accessibility.

There are three staircases in the building, of which two are located in the shared space. The main staircase is located in the centre and around the wind tunnel. The building also has two elevators, of which one is located in the add-on. This elevator goes to level 0, 1, 1+ and 2.

The central staircase consists of two mirrored stairs, is 1500 mm wide and follows the shape of the wind tunnel. Making only one set of stairs would save energy, space and material, but lengthens the walking distances and is architecturally less appealing. Therefore, two sets of stairs have been designed.

The entrance is located at the east side of the wind tunnel instead of the west side, because this location is closer to the elevator and the road. The entrance is kept simple, as it might be located elsewhere in the future (flexibility).

The toilets are located at both ends of the add-on. On the west side, there are two normal toilets per floor. And on the east side there is an accessible toilet at level 0, 1+ and 2. For the plumbing, new holes have to be drilled in the concrete floor.

In the north-east corner of the building, where the toilets are located, a large space for shared facilities is made. At level 0 this space is a lunch room and container storage, at level 1+ it is a storage room and at level 2 it is a meeting room. By this, all desired functions of the current users are given a place.

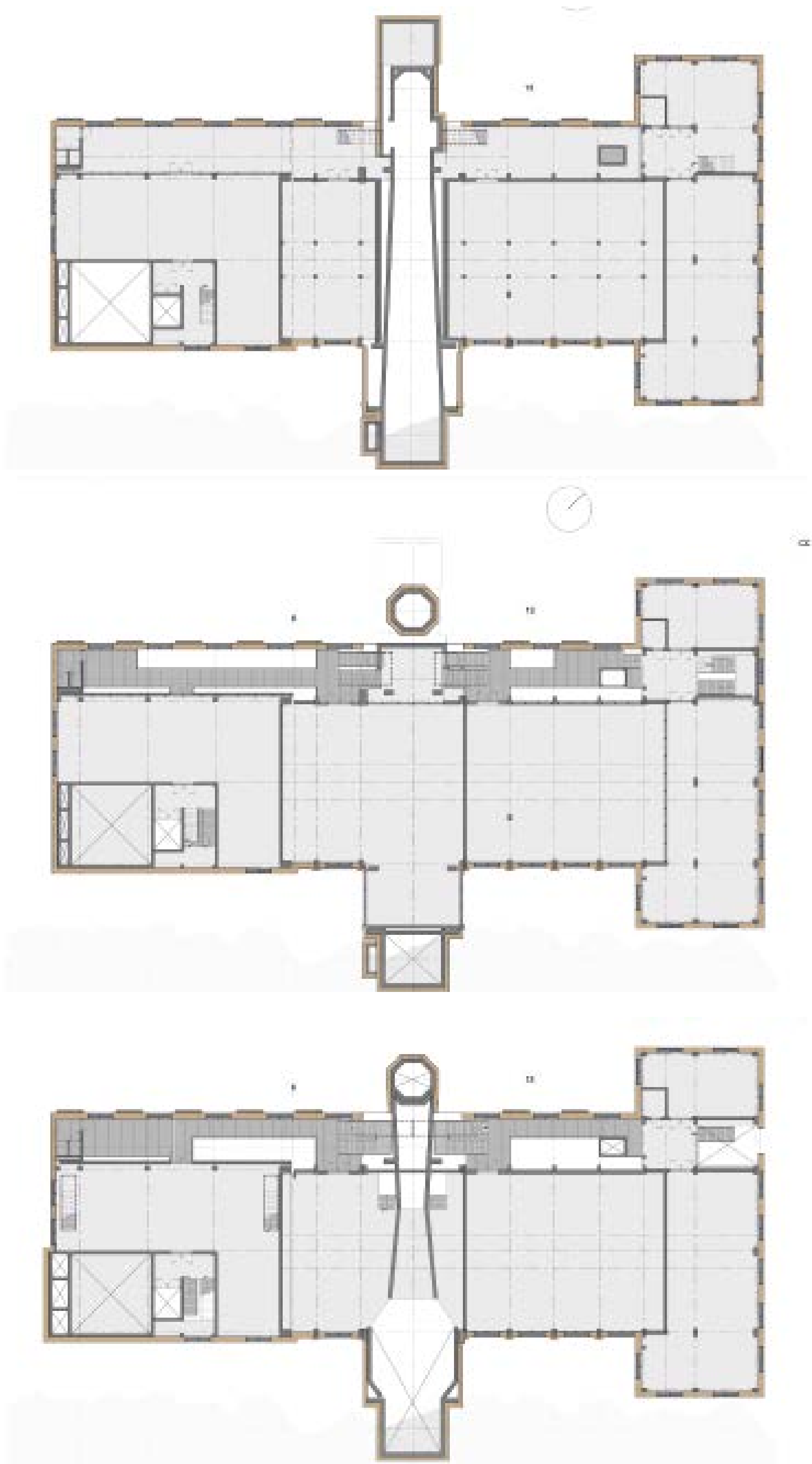


Figure 116: Ground floor, First floor and Second floor in scale 1:500

FAÇADE

Replacing the façade has its advantages and disadvantages. A number of materials are taken out, of which most are not recycled, as was discussed in the material inventory in chapter 6.8. The main materials of the current façade are: common brick, wooden window frames, glass, rockwool insulation, concrete, corrugated steel cladding and wooden panelling. The recycling options of these materials are discussed in chapter 8.5.

The new façade will be placed at the outside of the building and spans floor to floor. As the floor thickness varies from 140 to 200 mm, there is enough material to attach the façade to. The basis of the façade system is shown in Figure 117. It consists of timber studs with flexible insulation, a layer of rigid insulation to limit cold bridges and wooden façade cladding. Some changes have been made to increase the circularity of the pictured system. For instance, the plasterboard has been replaced by plywood sheeting and a water repellent foil is placed on the exterior of the rigid wood fibre insulation. Also, both horizontal and vertical weatherboarding is used in the façade.

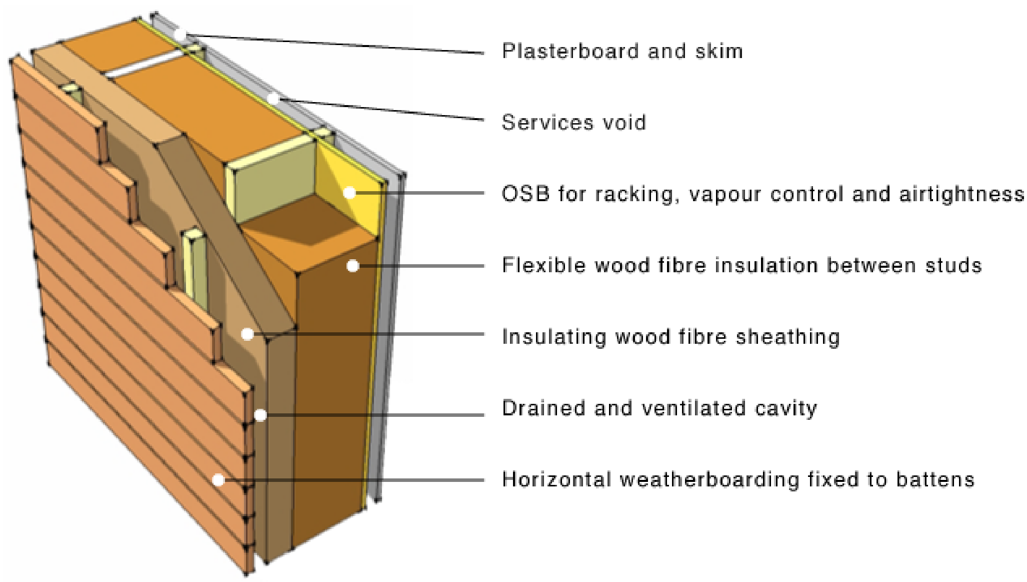


Figure 117: Typical timber frame section showing key components (GreenSpec, 2017)

This timber frame system has been chosen as is follows most rules for designing with circular building materials, as shown in Table 26.

Table 26: Aspects of circular building materials (BAMB, 2016; Crawford, 2011; Rau & Oberhuber, 2016; Verhaar, 2014)

Circular building materials	Explanation
have components for disassembly;	Components are not glued, but screwed.
are adaptable;	The inner and outer layers can be replaced. Additional openings can be made.
consume as little as possible;	The system can be scaled in thickness.
are built of low impact materials;	OSB, spruce, wood fibre insulation and black locust (robinia) are all low-impact materials.
are reusable at the same energy level.	All of the above listed materials are usually incinerated (NIBE, 2017). However, the materials are used in large quantities and simplification of sizes can help to improve the reusability.

The values in the tables are based on product sheets and building product books. These can be found in the Appendix. Table 27 shows that the Rc-value of the timber frame wall is 9,188 m^2.K/W and the total thickness is 448 mm. The Rc-value is slightly higher than desired (9 m^2.K/W), which costs more material. However, the thickness of both insulation types is based on actual products and the combination of these thicknesses (220 and 120 mm) resulted in the closest value to 9 m^2.K/W. Moreover, this thickness is also used in other façade and roof types.

Table 27: Timber frame wall

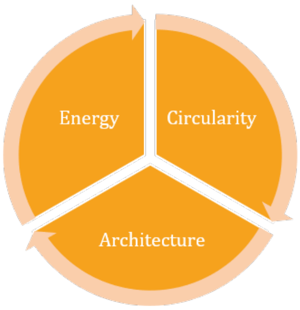
TIMBER FRAME WALL

Layer	Material	Thickness (mm)	Lambda (W/m.K)	Rc (m2.K/W)
Interior plating	Plywood	18	0,130	0,138
Service void	Not ventilated	38		0,180
Battens	Spruce (38 x 50 mm)	38		
Plating for racking, vapour control and airtightness	OSB	12	0,130	0,092
Insulation	Flexible wood fibre insulation	220	0,038	5,789
Timber studs	Spruce (225 x 50 mm)	225	0,130	1,731
Bridging factor (%)	15%			
Insulation	Rigid wood fibre insulation	120	0,043	2,791
Weather-proofing membrane		2		
Cavity	Moderately ventilated	22		0,090
Battens	Spruce (22 x 50 mm)	22		
Cladding	Timber (Black Locust)	16	0,150	0,107
		Rc (m2.K/W)		**9,188**
		U (W/m2.K)		**0,109**
		Total thickness (mm)		**448**

The above-mentioned system can also be combined with other insulation types, but wood fibre insulation seemed most suitable for this building. Information of Nibe and GreenSpec was combined to make a decision. Nibe categorises façade insulation based on shadow costs and environmental impact. Greenspec categorises thermal insulation in origin (natural, mineral or oil based). The main reasons why wood fibre insulation has been chosen is that the product is made of natural materials, is reusable and recyclable, has a relatively low Embodied Energy and is produced for different applications (battens and boards). So, this insulation type can be used for the roof, façade and floor.

It is attempted to use as little different types and thicknesses of wood fibre insulation. This has certain advantages and disadvantages (Table 28). Nonetheless, standardisation of building products (e.g. insulation, windows, timber, beams) is desirable.

Table 28: Design criteria: standardisation of insulation material and thickness



Energy	An option has to be found that suits all purposes, which might result in a lower quality material
Circularity	Higher reusability of material, as the sizes are comparable Oversizing results in more material consumption
Architecture	Higher viability, as the materials are bought in larger amounts

Spruce has been chosen for making studs and battens, because this wood type has a low Embodied Energy and is the most chosen wood type for these purposes. For cladding, black locust (Dutch: robinia) without timber treatment has been chosen. This type of wood has a low Embodied Energy, can be produced in the Netherlands and scores well on environmental impact (NIBE, 2017).

Table 26 listed one of the façade systems in the new façade. In total, there will be four variations. The basis of all types is similar and the main difference is the cladding. Figure 118 shows the main architectural ideas. The building is wrapped in ribbons to bring unity to the facade. These ribbons are horizontally clad. Also, the floors are highlighted by 400 mm high ribbons. These are also horizontally clad.

The façade in between the floors is clad vertically. The windows and doors are all 2000 mm wide and are placed accordingly to the proposed window concept. To show the height of the floors, the windows are placed in vertical surfaces with an alternative arrangement of vertical cladding. However, on the facades with BIPV, this alternative arrangement is partly replaced by coloured photovoltaic panels. As the width of this surface is 2000 mm all around the building, the photovoltaic panels can be unitised.

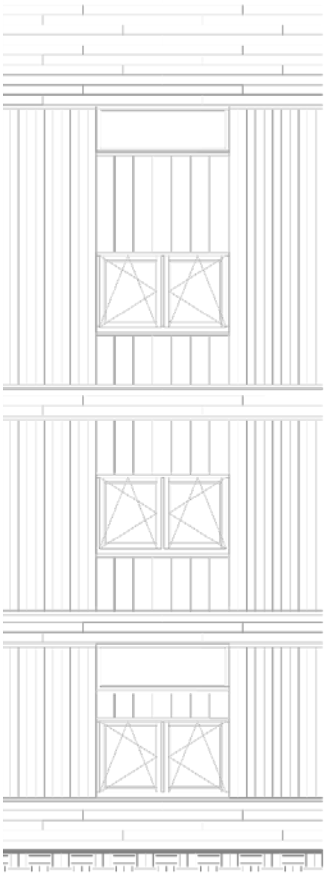


Figure 118: Façade layout

Another variation concerns the façade of the wind tunnel. To highlight the location of this wind tunnel, a different façade material will be used for these surfaces. Table 29 shows the layers in this system. The Rc-value is 8,780 m².K/W and the total added thickness is 362 mm. Although the wind tunnel is not heated, it is still a major thermal bridge for the rest of the building.

Table 29: Rendered wall

RENDERED WALL

Layer	**Material**	**Thickness (mm)**	**Lambda (W/m.K)**	**Rc (m2.K/W)**
Structure	Concrete	350	2,000	0,175
Insulation	Flexible wood fibre insulation	220	0,038	5,789
Timber studs	Spruce (225 x 50 mm)	225	0,130	1,731
Bridging factor	15%			
Insulation	Rigid wood fibre insulation	120	0,043	2,791
Weather-proofing membrane		2		
Cladding	Render (lime)	20	0,800	0,025
		Rc (m2.K/W)		**8,780**
		U (W/m2.K)		**0,114**
		Total thickness (mm)		**362**

The last variation is the new façade on the north side of the building. As this façade also has to be load-bearing, the structure is slightly different. For this, Cross Laminated Timber (CLT) panels are placed. These panels are made of multiple layers of structural lumber boards and can be ordered in various sizes. The downside of choosing these panels is that these panels are not yet produced in The Netherlands and have to be imported.

As these CLT walls are made entirely of wood, the Rc-value of this variation is higher (Table 30).

Table 30: Timber frame wall on CLT

TIMBER FRAME WALL ON CLT

Layer	Material	Thickness (mm)	Lambda (W/m.K)	Rc (m2.K/W)
Structural wall	Cross Laminated Timber	120	0,130	0,923
Insulation	Flexible wood fibre insulation	220	0,038	5,789
Timber studs	Spruce (225 x 50 mm)	225	0,130	1,731
Bridging factor	15%			
Insulation	Rigid wood fibre insulation	120	0,043	2,791
Weather-proofing membrane		2		
Cavity	Moderately ventilated	22		0,090
Battens	Spruce (22 x 50 mm)	22		
Cladding	Timber (Black Locust)	16	0,150	0,107
		Rc (m2.K/W)		**9,700**
		U (W/m2.K)		**0,103**
		Total thickness (mm)		**500**

On the exterior of the new north façade, insulating shutters are placed. These are designed to have the height of a floor and slide in front of the windows. When put in position, these panels increase the thermal resistance of the opaque façade elements. The panels are modelled after an existing building (Figure 119).

Figure 119: Insulating shutters at the Gemeentewerf in Amstelveen by Isoluik B.V. (Isoluik)

FAÇADE OPENINGS

Façade openings are filled with windows and doors. To define the type of window and door, a number of decisions has to be taken including: the gas infill, number of panes and frame material. In the following paragraphs, the decision process is explained.

The tree most commonly used inert gases for window are argon, krypton and xenon. These properties of these gases vary embodied energy, the ideal width for application and the amount of produced greenhouse gases. Table 31 shows the comparison of these three inert gases. The ideal width between two glass panes is 20mm for air, 16mm for argon, 12mm for krypton, and 8mm for a xenon infill (Weir & Muneer, 1998).

Table 31: Comparison of inert gases used in double and triple glazing (Weir & Muneer, 1998)

Gas	Yield volume per hour (hr-1)	Energy consumption rate (kW)	Specific energy consumption (kJ/Litre)
Argon	900000	168	0.672
Krypton	44.43	475.5	38500
Xenon	3.39	475.5	511400

Based on these widths of these gases the embodied energy of a window can be calculated. A double-glazed wooden window frame of 1.2 by 1.2 m results in the values in Table 32.

Table 32: Summary of energy content for raw materials and manufacturing processes (Weir & Muneer, 1998)

	Embodied Energy (MJ)		
	Argon	Krypton	Xenon
Inert infill gas	0.01	508.2	4500
Timber	195.3	195.3	195.3
Aluminium	408.8	408.8	408.8
Glass	289.4	289.4	289.4
Manufacture	137.0	137.0	137.0
Total	1030.51	1538.7	5530.5

Argon seems to be the most suitable inert gas, because the yield volume is the highest, it has the lowest specific energy consumption and lowest Embodied Energy. However, the ideal width is the highest (16mm). Therefore, more material is consumed for spacers and sealing.

The database of NIBE does not contain research on glazing types. Therefore, other literature has been consulted. The main variables in choosing glazing units are the number of glass panes, glass thickness, type of inert gas and the application of coatings (for instance, a low-e coating). Whether double or triple glazing is the best option is influenced by other factors including orientation, thermal insulation and shading measures.

Research shows that triple glazing outperforms double glazing both in energy use (embodied and operational energy) and in cost (Loussos, 2013; Silverstein, 2007). Table 33 shows the comparison of three studies regarding the Embodied Energy of glazing types. The results of these three studies do not match, but glass seems to be the deciding element.

Table 33: Comparison of three glazing studies

Glass type	Specification	U-value (W/m2K)	Embodied Energy (MJ)	Author
Single (current) HR++ Triple glass	4 4 - 4 4 – 4 - 4	5,8 1.2 0.7	0 471.4MJ 627.3MJ	(Loussos, 2013)
Double, air, no coating Double, argon, low-e Triple, argon, low-e	4 – 20Air - 4 4e – 16Ar - 4 4e - 16Ar – 4 – 16Ar – e4	2.76 1.31 0.65	1030.50 1038.93 1192.06	(Weir & Muneer, 1998)
Single Double HR Triple HR	6 3 – 13Ar - 3 6 – 13Ar - 3	5.36 1.60 0.78	unknown 547 837	(Bosschaert, 2009)

The main difference between the number of glazing panes are: the embodied energy (material energy) and the operational energy (building based energy). The investment up front is higher for a triple glazed window, but the operational energy is lower as the thermal resistance is higher.

Figure 120 shows a comparison between glazing types. Loussos (2013) calculated that triple glazing is a better choice than HR++ glass, considering energy use (intersection at 2.2 years) and cost (intersection at 10 years). The calculations are based on an East and West oriented façade, a wooden window frame and a window life span of 35 years. The calculations show that the operational energy is the most influential factor, as this differs 71,4 MJ/m2.year in energy use.

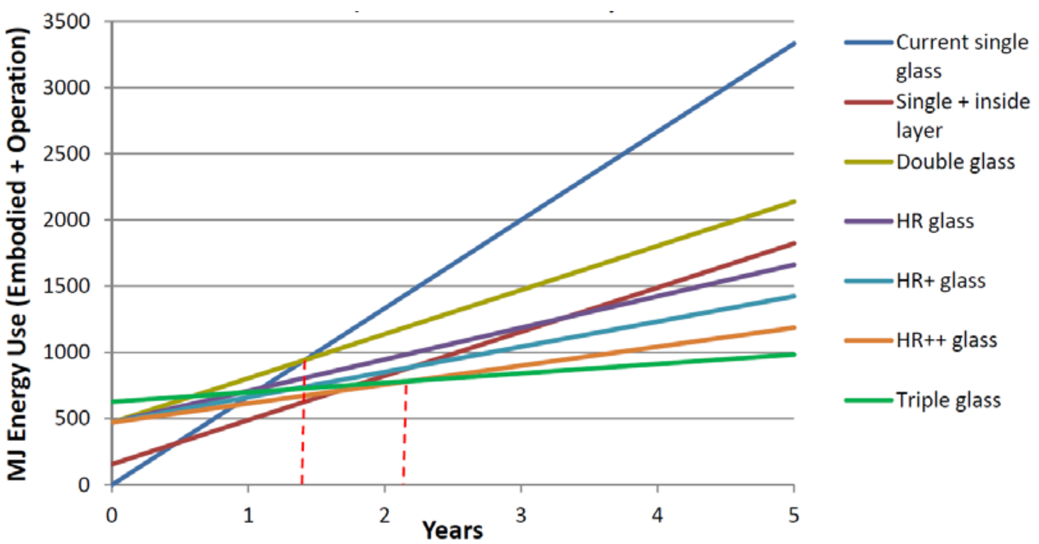


Figure 120: Energy use (Operation + Embodied) for different glass types (Loussos, 2013, fig. 5.2)

Last, the choice of window frame material is important. The Embodied Energy, recyclability and shadow costs of window frames differ much (Jones, 2014). In general, wooden window frames are the best choice based on Embodied Energy and the worst choice based on recyclability as 90-95% of wooden window frames are incinerated (NIBE, 2017a).

European Softwood can best be chosen for the window frames, because it has a low Embodied Energy (2686 MJ/m^3) and is moderately durable. This type of wooden window frames also contains EPDM, primer and paint (Loussos, 2013; NIBE, 2017).

In summary, a window and door type with argon infill, triple glazing and European Softwood has been chosen. Three types of windows and doors of the company HEBO have been chosen. These products belong to the category SYSTEEM 80X114 MM THERMO and the properties are shown in Table 34.

Table 34: Windows and doors (HEBO, 2012)

SYSTEEM 80X114 MM THERMO			
Window frame	80 x 114 mm		
Window frame material	Meranti		
Glazing type	4-14-4-15-4 mm		
Types	Fixed window	0,89 W/m^2.K	700 x 2000 mm
	Side/bottom hung sash window	0,97 W/m^2.K	1200 x 2000 mm
	Side/bottom hung sash door	1,20 W/m^2.K	2200 x 2000 mm

The benefit of choosing this product series is that the products are part of the program used in the energy calculation. The downside of these products is that the window frame is made of Meranti, a wood type that has a high Embodied Energy and does not score well on environmental impact (NIBE, 2017).

FLOORS

The ground floor in insulated with five layers of rigid wood fibre insulation (Table 35). On top of the insulation, a low radiant heating panel is placed. This floor heating system is demountable and reusable.

Table 35: Ground floor

GROUND FLOOR

Layer	**Material**	**Thickness (mm)**	**Lambda (W/m.K)**	**Rc (m2.K/W)**
Structure	Concrete	200	2,000	0,100
Vapour barrier		2		0,001
Insulation	Rigid wood fibre insulation	60	0,046	1,304
Insulation	Rigid wood fibre insulation	60	0,046	1,304
Insulation	Rigid wood fibre insulation	60	0,046	1,304
Insulation	Rigid wood fibre insulation	60	0,046	1,304
Insulation	Rigid wood fibre insulation	60	0,046	1,304

	Low profile radiant heating panel system	30		0,750
Interior plating	Fermacell overlay	10	0,320	0,031
Finish		8		
		Rc (m2.K/W)		**7,404**
		U (W/m2.K)		**0,135**
		Total thickness (mm)		**350**

The floors in the add-on are made of Cross Laminated Timber (CLT) panels and have the same thickness as the walls (120 mm). The majority of the panels have the same dimensions, as the span in the add-on does not vary. In reality, the grid varies along the length of the building, as can be seen in the floor plans. However, simplifying the construction increases the reusability of the elements (floors, beams, walls). Therefore, the distance between beams in the add-on is 3600 mm. The size of these standard CLT panels is 1500 x 3600 mm.

The beams are a vital element of this add-on and keep the CLT facade in place. Therefore, the beams could not be made from I-joists. Instead, normal timber beams are used.

ROOF

There are two roof types for this building: a green roof and a photovoltaic roof. A green roof has been chosen, because it buffers rain water and has a climatizing effect on the building. Both roofs have a similar basis, as shown in Table 36. All layers below the drainage layer are the same for both types. The vapour barrier that has been chosen is made of Polyolefine Copolymerisaat Bitumen (POCB) and will be mechanically fixed with screws of galvanised steel. This type of roof covering scores best on environmental impact and recycling potential. Additionally, mechanically attached POCB is better than glued POCB (NIBE, 2017).

The product that has been chosen is Icopal Universal WS, a roof covering with a built-in root-barrier. Although a root barrier is not necessary for the roof surfaces with photovoltaic panels, it is best to use this material everywhere as this increases reusability and flexibility.

Table 36: Green roof system

GREEN ROOF

Layer	**Material**	**Thickness (mm)**	**Lambda (W/m.K)**	**Rc (m2.K/W)**
Structure	Concrete	150	2,000	0,075
Vapour control layer				0,001
Insulation	Rigid wood fibre insulation	120	0,043	2,791
Insulation	Rigid wood fibre insulation	120	0,043	2,791
Insulation	Rigid wood fibre insulation	120	0,043	2,791
Insulation	Rigid wood fibre insulation	60	0,043	1,395
Vapour barrier and root barrier	POCB	3		0,060
Drainage layer		30		
Filtration layer		10		

Substrate		40	
Finish	Semi-intensive green roof		
		Rc (m2.K/W)	**9,903**
		U (W/m2.K)	**0,101**
		Total thickness (mm)	**503**

HEATING

As described, a floor heating system of the company Jupiter has been chosen. This system consists of recycled wood fibre board and an aluminium diffuser plate. These plates are 30mm thick and have an R-value of 0,75 m^2.K/W. The standard panels measure 1000 x 500 mm and are laid loose on the floor. This floor heating system is demountable and reusable.

The floor heating pipes are connected to a number of installations, including: a circulation pump, climate regulator, temperature sensors and the heat pump. This system also includes electrical heating and cooling elements.

The heat pump type that has been chosen is a vertical closed loop heat pump. The depth of a borehole depends on the amount of energy

VENTILATION

The building will be equipped with mechanical ventilation, because this enables central heat recovery. As the infiltration factor of the façade is very low, displacement ventilation is not working. Therefore, both the inlet and outlet will be mechanical. The system measures the levels of CO_2 in the air and adjusts the rate to those levels.

The installations are located at the installation room on the 3rd floor. Fresh air is led through earth tubes before entering the building with a velocity of 1 m/s. The amount of earth tubes can be calculated with the following formula:

Amount of earth tubes = (amount of people in the building x ventilation capacity per person) / πr^2

The building is designed for 70 people and the minimal ventilation capacity is 6,5 dm^3/s per person according to het Bouwbesluit. The most common earth tube of Heger is an earth tube with a diameter of 200 mm.

Amount of earth tubes = (70 x 0,0065) / π x 0,100^2 = 0,455 / 0,0314 = 14,7

Placing fifteen earth tubes is not efficient, because it requires substantial labour and ground works. The larger the diameter of the tube or the higher the airflow, the less heat is exchanged with the earth. Placing more tubes with smaller diameters is therefore better, but costs more material.

Changing the diameter to 300 mm results in the following calculation:

Amount of earth tubes = (70 x 0,0065) / π x 0,150^2 = 0,455 / 0,071 = 6,4

For now, seven earth tubes are laid. The depth, length, soil quality and inclination are not calculated in this thesis.

ELECTRICITY GENERATION

Electricity is generated with photovoltaic panels on the roof and the façade. Two types of panels are used, as the colour of the façade panels has to match the Black Locust cladding.

The tests of Nibe show that CIGS panels are the best option considering material and energy consumption. These panels are made of Copper, Indium, Gallium and Selenium. However, the yield of these panels is lower than monocrystalline or polycrystalline panels.

Table 37: Photovoltaic panels

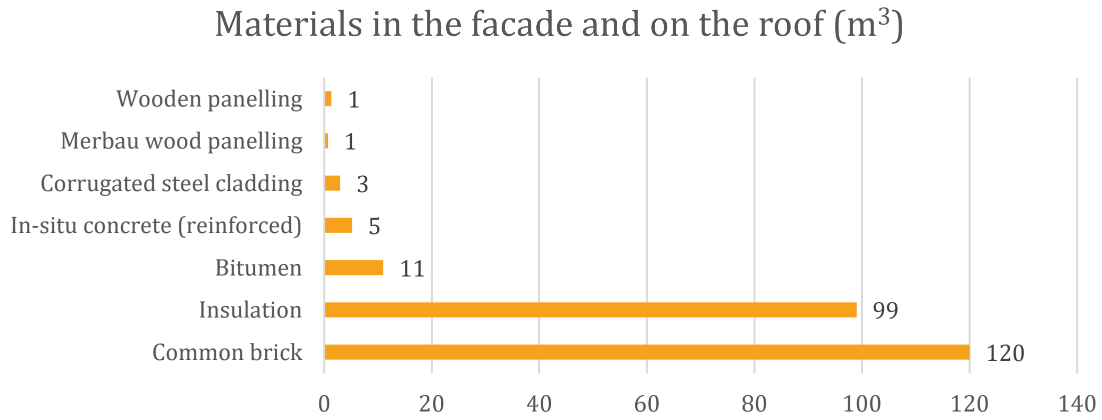
	SOLIBRO SL2-F CIGS THIN-FILM MODULE	SOLIBRO SL2 CIGS THIN-FILM MODULE
Panel type	Thin-film with edge	Thin-film
Application	Roof	Façade
Type	CIGS [Cu (In, Ga) Se2]	CIGS [Cu (In, Ga) Se2]
Colour	Black	Black
Size	1190 x 789.5 mm	1196.6 x 796.1 mm
Performance	125 – 145 Wp	115 – 135 Wp

Changing the colour of a photovoltaic panel from blue or black to another colour can be done by placing a coating. However, the energy yield of coloured panels is lower.

On the roof, the panels are placed at a height of 300 mm above the vapour barrier. By this, the panels can be ventilated. The panels in the façade are less ventilated, as the cavity only measures 38 mm. This will decrease the energy yield of these façade panels.

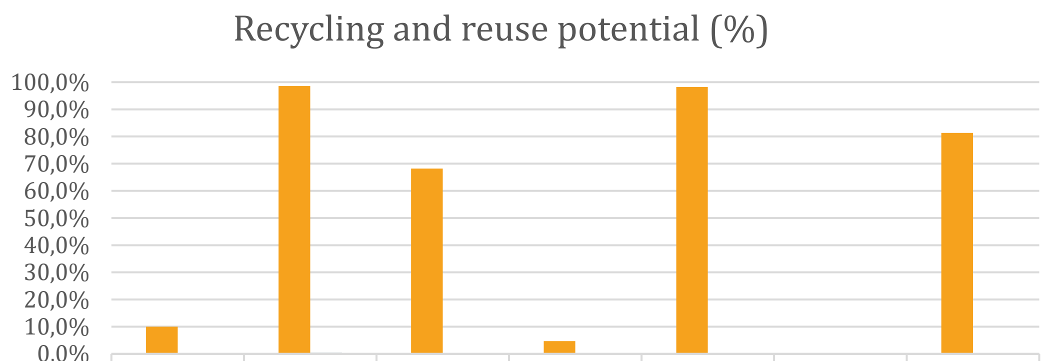
8.5.MATERIAL CHANGES

In chapter 6.8, a material inventory was made of the load-bearing structure, the façade and the roof of the Low Speed Lab. The amount, age, waste scenario and Embodied Energy of these materials were investigated. This resulted in recommendations for the design phase. In this chapter, it will be discussed how these materials that came off the facade and roof are reused and recycled.



Recurrence of Figure 84: Materials in the facade and on the roof (m3)

As the entire façade is replaced for a timber frame wall, the above-mentioned materials are salvaged from the façade and roof (with the exception of common brick in the north façade). Additionally, in the demolition of the 3rd floor and the machine hall another 239,77 m^3 of concrete is taken out of the building. Also, the single glazed wooden window frames are replaced by triple glazing. Based on the reuse and recycling potential listed in Figure 85, the potential as described in the material inventory and the quantities, the recycling options have been chosen.



	Insulation (rockwool)	In-situ (reinforced) concrete	Masonry (splitsteen)	Bitumen	Prefab concrete panels	Single glazed wooden window frames	Corrugated steel plates
Recycling	10,0%	98,6%	68,2%	4,7%	98,2%	0,1%	81,3%
Reuse	0,0%	0,4%	0,0%	0,1%	0,0%	0,0%	0,0%

Recurrence of Figure 85: Recycling and reuse potential of common materials

INSULATION (ROCKWOOL)

There is 99 m^3 of rockwool insulation in the façade and on the roof of the LSL. Most of the insulation is 40 mm thick and the total surface measures 2085 m^2. The material still has a potential service life of 35 years and there is no indication that the insulation values have decreased due to wetting or compaction. The recycling and reuse potential of rockwool insulation is only 10,0% and 85% is landfilled (NIBE, 2017).

Therefore, it is best to reuse the material on site. The aim was to insulate the building in as little as possible different materials and dimensions, but there is one deviating façade: the wind tunnel. The wind tunnel is a non-heated space with a high thermal mass and changing the type and thickness of insulation has a smaller effect in this location than anywhere else in the building. The façade type rendered wall can be changed to enable reuse of the rockwool insulation.

For the wind tunnel, 879 m^2 of 220 mm thick flexible wood fibre insulation is required. This layer can be replaced by two layers of 40 mm thick rockwool insulation. By this, 1758 m^2 can be reused on site. This accounts for 84% of the total volume and does not include the losses during deconstruction and assembly. The Rc-value will hereby decrease from 8,780 to 5,153 m2.K/W. Table 38 shows the new proposal.

Table 38: Rendered wall

RENDERED WALL

Layer	Material	Thickness (mm)	Lambda (W/m.K)	Rc (m2.K/W)
Structure	Concrete	350	2,000	0,175
Insulation	Reused rockwool insulation	40	0,037	1,081
Insulation	Reused rockwool insulation	40	0,037	1,081
Timber studs	Spruce (80 x 50 mm)	80	0,130	0,615
Bridging factor	15%			
Insulation	Rigid wood fibre insulation	120	0,043	2,791
Weather-proofing membrane		2		
Cladding	Render (lime)	20	0,800	0,025
		Rc (m2.K/W)		**5,153**
		U (W/m2.K)		**0,194**
		Total thickness (mm)		**222**

IN-SITU (REINFORCED) CONCRETE

Concrete accounts for the largest amount of material that is taken out of the building during the refurbishment. About 245 m^3 of concrete will be removed, which is 13% of the total concrete volume in the building. After treatment, concrete can be reused as aggregate for new concrete. Therefore, the reuse and recycling potential is 99%.

The concrete is reinforced and can therefore not be taken out in blocks. Often, concrete is demolished on site and crushed elsewhere. It can also be crushed on site. However, there seems to be no purpose for the material in and around the refurbished building. Recycling in new concrete seems to be the best option.

MASONRY (SPLITSTEEN)

Masonry is used for both the inner and outer leaf of the façade and it is likely a cement mortar is used. The potential service life of the masonry walls is another 60 years. Therefore, it is a waste of material to demolish these walls, but this is not possible in combination with the new façade. At the moment, reclamation of the bricks does not seem possible. However, if the mortar type allows it, the bricks could be taken out one by one. Otherwise the bricks can be used as aggregate for new bricks.

BITUMEN

The entire roof of the LSL is covered in bitumen, which accounts for 11 m^3. The age of the bitumen is unknown, but the material seems to be at the end of its service life. According to Nibe, the reuse and recycling potential of bitumen is only 4,8%. However, if taken off carefully, the material can be recycled and added as recycled content.

The new roof will be covered in POCB, a material that requires less maintenance and differs substantially in composition. Replacing the POCB with recycled bitumen therefore does not seem logical.

Reuse of bitumen sheets for interior purposes is not wise either, as there are a number of health issues concerning material in bitumen (NIBE, 2017).

Although the waste scenario of bitumen sheets is not optimistic, careful deconstruction will increase the recycling potential. The bitumen will not be reused on site and is disposed.

PREFAB CONCRETE PANELS

On the ground floor, prefab concrete panels are placed in the façade. These panels are made of two concrete leaves with insulation in between. The total area of these panels is 65 m^2 and 42 m^3 of panels are taken out during the refurbishment. Each panel is unique and custom made for the addition in 1977. The potential service life is 35 years, but the Rc-value is not sufficient.

The waste scenario is optimistic: 98,2% can be recycled. But, the panels are heavy, expensive to transport and are unique. Reusing the panels on site is the preferred scenario. In the new design, the prefab concrete panels are used for both interior and exterior purposes: as furniture and as landscaping objects.

SINGLE GLAZED WOODEN WINDOW FRAMES

In total, the single glazed wooden windows account for 537 m^2. The service life of the windows is about as long as the component age. As the origin of the windows is known, the windows can be taken apart and the float glass can be recycled.

Though, there is a purpose for the windows on site as well. Figure 121 shows the location of new transparent walls on the second floor that divide the floors in four lettable units. These walls are transparent, because this provides a view of the wind tunnel and can be made of the salvaged wooden window frames. In time, the windows can be reused or recycled too. In total, eight walls with a sum of 370 m^2 of new transparent walls are constructed.

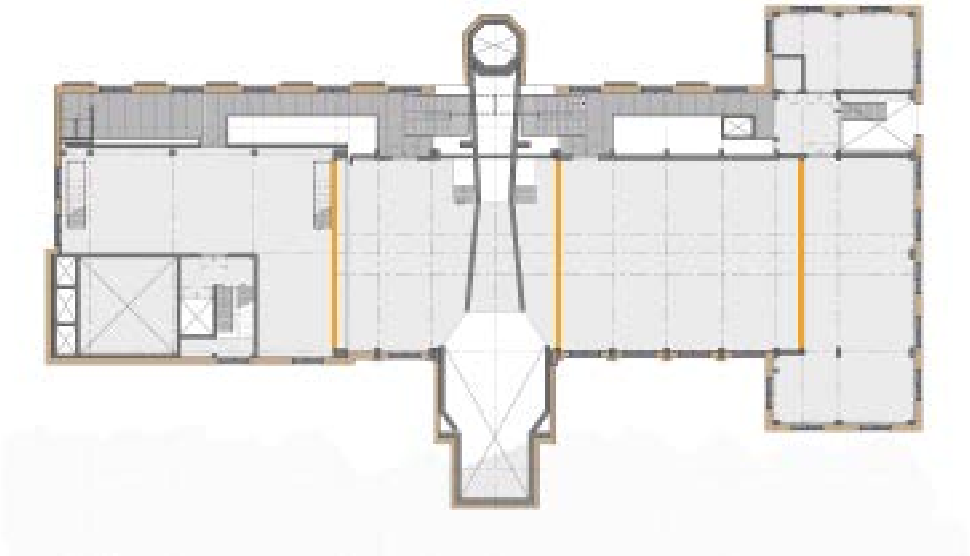


Figure 121: Second floor plan with location of transparent walls in yellow

CORRUGATED STEEL PLATES

The 222 m^2 of blue corrugated steel plates in the façade have a service life of 30 years and are 40 years old. They still fulfil their function, but are taken off the building to let in more daylight. The recycling potential is 81,3% and the reuse potential is 0%, because the plates are often damaged when taken off. No purpose has been found for the plates on site, apart from interior solutions. Therefore, is seems best to dispose the plates and strive for optimal recycling.

CONCLUSION

Three materials can be reused on site, including: prefab concrete panels, windows and insulation. However, the majority of the volume that is taken out of the building is recycled (Table 39).

Table 39: Waste scenario per material

Waste scenario	Material	Purpose
Recycling	In-situ (reinforced) concrete	
	Masonry (splitsteen)	
	Bitumen	
	Corrugated steel plates	
Reuse (other purpose)	Prefab concrete panels	Rendered facade
	Single glazed wooden window frames	Furniture and landscaping
Reuse (same purpose)	Insulation (Rockwool)	Walls

9. VALIDATION

This thesis presents both a method and a refurbishment proposal for the TU Delft. The design pursues to achieve net-zero energy and implements circular use of building materials. A validation of the energy consumption provides an indication of the amount of measures that should be taken to refurbish a building in a portfolio of the TU Delft. In this chapter, it will be explained how the validation was executed.

9.1. EXPECTED ENERGY CONSUMPTION

At the moment, the LSL uses heat from the underground heat distribution network and electricity from the electricity grid. It does not consume natural gas.

Key energy data for 2016 (FMRE Energy, 2013):

Heat (m3 a.e.)	44431	Heat (KWh/m2)	155
Natural gas (m3)	0	Natural gas (KWh/m2)	0
Electricity (MWh)	220	Electricity (KWh/m2)	136
Primary Energy (MWh)	994	Primary Energy (KWh/m2)	288

In the refurbished building heat will no longer be taken from the underground heat distribution network, because it is a non-renewable energy source. Instead, heat is extracted from the ground using a heat pump.

The consumption of Primary Energy is expected to change. The following interventions will likely decrease the energy consumption:

- Thermal insulation: Improving the R-value to Passive house standard
    - Ground floor: from 0,150 m^2K/W to 7,0 m^2K/W
    - Façade: varying from 0,200-2,326 m^2K/W to 9,0 m^2K/W
    - Roof: from 1,657 m^2K/W to 10,0 m^2K/W
- Air infiltration: reducing the infiltration to 0,2 $dm^3/s.m^2$
- Heating: low temperature floor heating instead of radiators
- Lighting: optimisation of window placement for natural daylight
- Installations: for ventilation and circulating energy

And the following interventions will likely increase the energy consumption.

- Solar gains:
    - Decrease of window area
    - Placement of blinds
    - Increase of Solar Heat Gain Coefficient
- Volume: increase in building volume that has to be climatized
    - Current volume 14000 m^3

    - Demolition of (uninsulated) machine hall 1110 m^3
    - Demolition of (uninsulated) top floor 338 m^3
    - New-build of 4,5m wide addition 2740 m^3
- Materials:
    - Replacement of façade and installations
    - Addition of building volume
- Occupation:
    - More users because of better layout and more usable floor area
    - Spread out occupation in accordance to energy generation

At the moment, the building tends to overheat in summer. The only solution in the current building is opening windows (not many can be opened). The night ventilation and blinds are not mentioned as cooling elements, because they do not change the energy consumption of the current building. However, both measures are expected to decrease the energy consumption for cooling in the refurbished building.

9.2. CALCULATION METHOD

To calculate the energy consumption, a program called Uniec^2 was used. This online program can calculate the Energieprestatiecoëfficient (EPC). EPC is a good indicator of the energy neutrality. A calculation will be made for a simplified version of the building with proposed refurbishment measures.

Figure 122: Brand logo of Uniec (www.uniec2.nl)

Although the design is finished, some variations have to be taken into consideration. Besides the energy consumption of the building, the following factors also influence the energy neutrality:

1. Total embodied energy of added components and materials
2. Process energy of the wind tunnel
3. Process energy of Inholland

Whether these will be calculated will be decided later.

9.3. CALCULATION INPUT AND RESULTS

Step-by-step, the required input can be added in the program. All data input used in Uniec is taken from the Revit model. Other requirements can be found in chapter 7.1.

The following input is required:

- Building layout
    - Infiltration
    - Building construction elements
- Building services engineering
    - Heating and warm water heating
    - Ventilation system
    - Cooling system
    - Humidification system
- Electrical installations
    - Solar power
    - Lighting

The EPC calculation in Uniec has a number of limitations that are worth mentioning. First, occupancy schedules are not visible and cannot be changed. This is a disadvantage for this building, as the occupancy varies greatly throughout the day, week and year. By this, energy can be saved. The insulating shutters are not used for input either, as they do not raise the thermal resistance all day, but only at night. And this cannot be modelled.

Also, the atrium cannot be modelled as one open space. At the moment it has been modelled as a 600 m^2 space. As a result, the lighting and ventilation are not correct.

Last, the deciduous trees cannot be added ad shading. There is a variety of options regarding shading, but there is no option in which the light and heat are let through in winter and blocked in summer. Therefore, the shading has been kept simple.

Uniec 2.2

STUDIEBEREKENING

Graduation_LSL - Low Speed Lab
Calculation Rc 10 - 9 - 8

0,14

Algemene gegevens

projectomschrijving	*Low Speed Lab*
variant	*Calculation Rc 10 - 9 - 8*
straat / huisnummer / toevoeging	
postcode / plaats	*Delft*
eigendom	*Combinatie koop/huur*
bouwjaar	*1952*
renovatiejaar	*2017*
categorie	*Energieprestatie Utiliteitsbouw*
datum	*12-10-2017*
opmerkingen	

Indeling gebouw

Eigenschappen rekenzones

type rekenzone	omschrijving	massa vloer	type plafond
verwarmde zone	Building	> 400 kg/m²	geen of open plafond

Interne warmtecapaciteit volgens bijlage H — *nee*

Gebruiksfuncties per rekenzone Building

gebruiksfunctie	A_g [m²]	open verbinding	40% regel	aangesloten op gem. ruimte	$\theta_{int;set;H}$ [°]	$q_{g;spec}$ [dm³/sm²]	EPC eis
kantoorfunctie	3.500,00	nee	nee	ja	20,00	1,11	0,80
gemeenschappelijke ruimte	600,00	nee	nee	n.v.t.	0,00	0,00	0,00

Infiltratie

meetwaarde voor infiltratie $q_{v;10;spec}$	*ja*
lengte van het gebouw	*57,00 m*
breedte van het gebouw	*18,00 m*
hoogte van het gebouw	*15,00 m*

Eigenschappen infiltratie

rekenzone	gebouwtype	$q_{v;10;spec}$ [dm³/s per m²]
Building	grondgebonden gebouw, vrijstaand, plat dak of geen dak	0,20

Open verbrandingstoestellen

Het gebouw bevat geen open verbrandingstoestellen.

Figure 123: Uniec calculation summary page 1 (left)

BUILDING LAYOUT (DUTCH: INDELING GEBOUW)

The building is modelled as one calculation zone (Dutch: type rekenzone), because the building has one climate system. In theory, the wind tunnel and the vertical wind tunnel could be modelled as unheated space (Dutch: Aangrenzende Onverwarmde Ruimte). As these rooms do not have to be heated, less energy would be consumed for heating and the EPC would be lower. Because of the complicated shape of the wind tunnel it is better to model the building as one calculation zone.

Floor mass (Dutch: massa vloer):

- < 100 kg/m^2
- 100-400 kg/m^2
- **>400 kg/m^2**
- Concrete Core Activation (Dutch: betonkernactivering)

Ceiling type options (Dutch: type plafond):

- Closed ceiling (Dutch: gesloten plafond)
- **No ceiling or open ceiling (Dutch: geen of open plafond)**

The calculation zone consists of two usage functions (Dutch: gebruiksfuncties), being office and common space.

INFILTRATION (DUTCH: INFILTRATIE)

The infiltration value for the facades is 0,20 dm^3/s per m^2, as decided in chapter 7.1.

Bouwkundige transmissiegegevens

Transmissiegegevens rekenzone Building							
constructie	A [m²]	R_c [m²K/W]	U [W/m²K]	g_{gl} [-]	zonwering	beschaduwing	toelichting
Ground floor - vloer op/boven mv; boven grond/spouw (z ≤ 0,3) - 1.250,0 m²							
Ground floor	1.250,00	7,40					
Roof 3rd - buitenlucht, HOR, dak - 600,0 m² - 0°							
Roof	600,00	9,90				minimale belem.	
Roof 4th - buitenlucht, HOR, dak - 100,0 m² - 0°							
Roof	100,00	9,90				minimale belem.	
Roof 5th - buitenlucht, HOR, dak - 225,0 m² - 0°							
Roof	225,00	9,90				minimale belem.	
Roof 6th - buitenlucht, HOR, dak - 40,0 m² - 0°							
Roof	40,00	9,90				minimale belem.	
Facade south - buitenlucht, ZO - 850,0 m² - 90°							
Exterior wall	730,40	9,22				constante belem. hb ≥ 1,0	
Exterior wall at columns	30,00	3,02				constante belem. hb ≥ 1,0	
Window 2000 - 1200…	60,00		0,[illegible]7	0,45	auto	constante belem. hb ≥ 1,0	
Window 2000 - 700 …	25,20		[illegible],89	0,45	auto	constante belem. hb ≥ 1,0	
Door (1 stuks)	4,40		[illegible]3	0,00	nee	constante belem. hb ≥ 1,0	
Facade north - buitenlucht, NW - 850,0 m² - [illegible]0°							
Exterior wall with CLT	667,80	9,7[illegible]				minimale belem.	
Window 2000 - 1200…	52,80		0,97	0,45	nee	minimale belem.	
Window 2000 - 700 …	14,[illegible]		0,89	0,45	nee	minimale belem.	
Window 2000 - 2200…	35,20		0,97	0,45	nee	minimale belem.	
Door (8 stuks)	35,2[illegible]		0,93	0,00	nee	minimale belem.	
Curtain wall (45 stuks)	4[illegible],00		1,00	0,45	nee	minimale belem.	
Facade east - buitenlucht, NO - [illegible]60,0 m² - 90°							
Exterior wall	29[illegible],80	9,22				minimale belem.	
Window 2000 - 1200…	[illegible],60		0,97	0,45	auto	minimale belem.	
Window 2000 - 700 …	9,80		0,89	0,45	auto	minimale belem.	
Window 2000 - 2200…	4,40		0,97	0,45	auto	minimale belem.	
Door (1 stuks)	4,40		0,93	0,00	nee	minimale belem.	
Facade east wind tunnel - buitenlucht, NO - 260,0 m² - 90°							
Exterior wall	240,00	9,22				minimale belem.	
Curtain wall (20 stuks)	20,00		1,00	0,45	auto	minimale belem.	
Facade west - buitenlucht, ZW - 315,0 m² - 90°							
Exterior wall	283,60	9,22				minimale belem.	
Window 2000 - 1200…	21,60		0,97	0,45	auto	minimale belem.	

Figure 124: Uniec calculation summary page 2 (left)

BUILDING CONSTRUCTION

Of all surfaces the following is determined:

- Size
- Type of construction
- Presence of shading devices
- Number of transparent construction elements
- Shading

Figure 125 shows the types of building construction elements that are used. There are five types of opaque façade types (e.g. roof, façade, floor), one type of opaque panel construction and five types of transparent construction elements (e.g. windows and doors). The Rc-values correspond to the design.

Definieer dichte constructies (vloeren, gevels, daken) — Ongebruikt verwijderen — Regel toevoegen

constructie	bron	omschrijving	Rc [m²K/W]
Roof	handmatig		9,90
Ground floor	handmatig		7,40
Exterior wall with CLT	handmatig		9,73
Exterior wall	handmatig		9,22
Rendered wall	handmatig		8,78

Definieer paneelconstructies (afwijkende dichte constructies in gevels) — Ongebruikt verwijderen — Regel toevoegen

constructie	bron	omschrijving	Rc [m²K/W]
Exterior wall at columns	handmatig		3,02

Definieer transparante constructies (ramen en deuren) — Zoeken en vervangen — Ongebruikt verw. — Regel toevoegen

constructie	bron	omschrijving	U [W/m²K]	g_{gl} / g_{ps}	A [m²]
Window 2000 - 1200	ramen hout Hebo	Thermo Systeem ε	0,97	0,45	2,40
Window 2000 - 700	ramen hout Hebo	Thermo Systeem ε	0,89	0,45	1,40
Window 2000 - 2200	ramen hout Hebo	Thermo Systeem ε	0,97	0,45	4,40
Door	deuren hout Hebo	Thermo Systeem E	0,93	0,00	4,40
Curtain wall	handmatig		1,00	0,45	1,00

Figure 125: Building construction elements, screenshot of Uniec

Transmissiegegevens rekenzone Building							
constructie	A [m²]	R_c [m²K/W]	U [W/m²K]	g_{gl} [-]	zonwering	beschaduwing	toelichting
Window 2000 - 700 ...	9,80		0,89	0,45	auto	minimale belem.	
Facade west wind tunnel - buitenlucht, ZW - 260,0 m² - 90°							
Exterior wall	240,00	9,22				minimale belem.	
Curtain wall (20 stuks)	20,00		1,00	0,45	auto	minimale belem.	
Facade west 2 - buitenlucht, ZW - 65,0 m² - 90°							
Exterior wall	56,40	9,22				minimale belem.	
Window 2000 - 1200...	7,20		0,97	0,45	auto	minimale belem.	
Window 2000 - 700 ...	1,40		0,89	0,45	auto	minimale belem.	

De lineaire warmteverliezen zijn berekend volgens de forfaitaire methode uit hoofdstuk 1[illegible] van NEN 1068.

Overige kenmerken vloerconstructies (inclusief evt. kruipruimten en onverwarmde kelders)

Ground floor - vloer op/boven mv; boven grond/spouw (z ≤ 0,3)

hoogte bovenkant vloer boven maaiveld (h)	*0,00 m*
omtrek van het vloerveld (P)	*2[illegible]5,00 m*
grootste dikte v.d. gevels/wanden ter hoogte v.d. bk vloer ($d_{bw;v}$)	*0,50 m*

Verwarming- en warmtapwatersystemen

Vertical closed loop heat pump

Opwekking

type opwekker	*combi-warmtepomp*
bron warmtepomp	*bodem*
ontwerpaanvoertemperatuur	*$\theta sup \leq 30°$*
toestel - warmtepomp	*Nibe F1245-8(PC)*
vermogen warmtepomp	*8,43 kW*
β-factor warmtepomp	*0,46*
aantal warmtepompen	*1*
type bijverwarming	*elektrisch element*
bijstooktoestel geïntegreerd	*ja*
transmissieverlies verwarmingssysteem - januari (H_T)	*1.581 W/K*
warmtebehoefte verwarmingssysteem ($Q_{H;nd;an}$)	*72.618 MJ*
hoeveelheid energie t.b.v. verwarming per toestel ($Q_{H;dis;nren;an}$)	*72.618 MJ*
hoeveelheid energie t.b.v. warmtapwater per toestel ($Q_{W;dis;nren;an}$)	*20.500 MJ*
opwekkingsrendement verwarming - warmtepomp ($\eta_{H;gen}$)	*5,400*
opwekkingsrendement warmtapwater - warmtepomp ($\eta_{W;gen}$)	*2,350*
opwekkingsrendement - bijverwarming ($\eta_{H;gen}$)	*1,000*

Kenmerken afgiftesysteem verwarming

Type warmteafgifte					
type warmteafgifte	positie	hoogte	R_c	$\theta_{em;avg}$	$\eta_{H;em}$

Figure 126: Uniec calculation summary page 3 (left)

HEATING AND WATER (DUTCH: VERWARMING- EN WARMWATERSYSTEMEN)

The vertical closed loop heat pump is the source for both floor heating and warm water. Therefore, a heat pump has been chosen that can do both. The design supply temperature is below 30 degrees Celsius.

According to the calculation, the energy consumption for heating is 109.244 MJ and 20.500 for warm water.

vloer- en/of wandverwarming en/of betonkernactivering	binnenvloer of binnenwand	< 8 m	n.v.t.	n.v.t.	1,00

afgifterendement ($\eta_{H;em}$) *1,000*

Kenmerken distributiesysteem verwarming

warmtetransport door *n.v.t. (lokaal systeem)*
koeltransport door *n.v.t. (lokaal systeem of geen koeling)*
geïsoleerde leidingen en kanalen *ja*
distributierendement ($\eta_{H;dis}$) *1,000*

Kenmerken tapwatersysteem

gebruiksoppervlakte aangesloten op systeem *4.100,00 m²*
gemiddelde lengte uittapleidingen *≤ 3 meter*
afgifterendement warmtapwater ($\eta_{W;em}$) *1,000*

Douchewarmteterugwinning

douchewarmteterugwinning *nee*

Zonneboiler

zonneboiler *nee*

Hulpenergie verwarming

hoofdcirculatiepomp aanwezig *ja*
hoofdcirculatiepomp voorzien van pompregeling *ja*
aanvullende circulatiepomp aanwezig *nee*

Aangesloten rekenzones

Building

Ventilatie

Mechanical Ventilation

Ventilatiesysteem

ventilatiesysteem *Dc. mechanische toe- en afvoer - centraal*
systeemvariant *D5a CO2-sturing met 2 of meer zones*
luchtvolumestroomfactor voor warmte- en koudebehoefte (f_{sys}) *1,00*
correctiefactor regelsysteem voor warmte- en koudebehoefte (f_{reg}) *0,67*

Kenmerken ventilatiesysteem

centrale luchtbehandelingskast aanwezig *ja*
verwarmingsbatterij in luchtbehandelingskast *ja*
koelbatterij in luchtbehandelingskast *ja*
werkelijk geïnstalleerde ventilatiecapaciteit bekend *ja*
mechanische toevoer van buiten ($q_{vinst;1c}$ / $q_{ve;sys;mech;e}$ *0 dm³/s*
mechanische toevoer voorbehandeld ($q_{vinst;1d}$ / $q_{ve;sys;mech;pre}$) *455 dm³/s*
terugregeling / recirculatie *geen terugregeling / recirculatie*
luchtdichtheidsklasse ventilatiekanalen *onbekend*

Passieve koeling

max. benutting geïnstal. ventilatiecapaciteit voor koudebehoefte *ja*

Figure 127: Uniec calculation summary page 4 (left)

VENTILATION (DUTCH: VENTILATIE)

Six types of ventilation can be chosen. The options are:

- A. natural ventilation
- B. mechanical supply and natural outlet
- C. natural supply and mechanical outlet
- **Dc. Mechanical supply and outlet – centralized**
- Dd. Mechanical supply and outlet – decentralized
- E. Combined systems

Mechanical ventilation is essential, as the building makes use of earth tubes, heat recovery and post-heating. Additionally, there are six options:

- D1. Standard (no heat recovery)
- D2. Heat recovery without zoning and without control
- D3. CO2-control for the outlet
- D4a. Time-control without zoning
- D4b. Time-control with 2 or more zones
- **D5a CO2-control with 2 or more zones**

The option with CO2-control is the most efficient option and has been chosen in the building.

According to the Dutch building regulations the ventilation capacity has to be 6,5 dm^3/s per person in an office building. As the building will be designed to accommodate 70 people, a ventilation capacity of 455 dm^3/s is required.

Night cooling cannot be added, but vents and openable windows can be chosen to prevent overheating. As the windows will not be opened at night, but the vents can, these are chosen.

max. benutting geïnstal. spuicapaciteit voor koudebehoefte	*ja*
spuivoorziening	*ventilatieroosters*

Kenmerken warmteterugwinning

rendement warmteterugwinning forfaitair	*tegenstroomwarmtewisselaar - aluminium - 75%*
rendement warmteterugwinning inclusief dissipatie	*ja*
fractie lucht via bypass	*1,00*
toevoerkanaal tussen buiten en WTW toestel	*geïsoleerd kanaal*
type isolatie toevoerkanaal tussen buiten en WTW toestel bekend	*nee*
lengte toevoerkanaal tussen buiten en WTW toestel (L_{bu})	*5,0m*

Kenmerken ventilatoren

nominaal vermogen ventilator(en) forfaitair	*ja*
type ventilatoren (vermogen forfaitair)	*gelijkstroom*
extra circulatie op ruimteniveau	*nee*
ventilatoren met constant-volumeregeling	*nee*

Aangesloten rekenzones

Building

Koeling

Vertical closed loop heat pump cooling

Kenmerken opwekker

type opwekker	*koudeopslag / bodemkoeling (zonder inzet koelmachine)*
koudebehoefte koelsysteem ($Q_{C;nd}$)	*79.651 MJ*
opwekkingsrendement ($\eta_{C;gen}$)	*12,000*

Kenmerken koelsysteem

koeltransport ingevoerd bij verwarmingssysteem	*Vertical closed loop heat pump*
distributierendement ($\eta_{C;dis}$)	*1,00*

Hulpenergie koeling

koude direct afgegeven aan binnenunit of LBK	*ja*
koudeopwekker met toerenregeling (ventilatoren en pompen)	*ja*
koudeopwekker opwekkingsrendement inclusief standby hulpenergie	*nee*
koudeopwekker tevens gebruikt voor verwarming	*ja*

Aangesloten rekenzones

Building

Bevochtiging

bevochtiging 1

Opwekking

type bevochtiging	*stoombevochtiging elektrisch*
opwekkingsrendement ($\eta_{C;gen}$)	*1,00*

Figure 128: Uniec calculation summary page 5 (left)

COOLING SYSTEM (DUTCH: KOELING)

For cooling, the heat pump is used as well. According to the calculation 79.651 MJ is used for that. The cold is directly exchanged with the air and floor heating.

HUMIDIFICATION (DUTCH: BEVOCHTIGING)

An electric steam humidifier has been chosen to regulate the air.

VALIDATION

Kenmerken bevochtigingssysteem

vochtterugwinning uit afvoerlucht naar toevoerlucht	*ja*
fractie aangesloten gebruiksoppervlakte met bevochtiging	*1,00*

Aangesloten rekenzones

Building

Zonnestroom

Photovoltaics

type zonnestroompaneel	*CIGS: koper-indium-gallium-diselenide (100 Wp/m2)*

Zonnestroom eigenschappen

ventilatie	A_{PV} [m²]	oriëntatie	helling [°]	beschaduwing
matig geventileerd - op dak/gevel, met spouw	250,00	HOR	0	minimale belemmering
matig geventileerd - op dak/gevel, met spouw	250,00	HOR	0	minimale belemmering
matig geventileerd - op dak/gevel, met spouw	250,00	HOR	0	minimale belemmering
matig geventileerd - op dak/gevel, met spouw	40,00	[illegible]O	90	minimale belemmering
matig geventileerd - op dak/gevel, met spouw	40,00	ZW	90	minimale belemmering
matig geventileerd - op dak/gevel, met spouw	50,00	[illegible]O	90	minimale belemmering

Verlichting

Lighting

Verlichtingssysteem

verlichtingsvermogen forfaitair	*nee*
oppervlakte daglichtsector (A_{dayl}) forfaitair	*ja*

Kenmerken verlichtingssysteem

aanwezigheidsdetectie > 70% van rekenzone	*ja*
armatuurafzuiging > 70% van verlichtingsvermogen	*nee*

Eigenschappen verlichtingssysteem

regeling	$P_{n;spec}$ [W/m²]	A_{zone} [m²]	F_D
veegpulsschakeling i.c.m. daglichtschakeling	5,0	4.100,00	0,67

Figure 129: Uniec calculation summary page 6 (left)

PHOTOVOLTAICS (DUTCH: ZONNESTROOM)

As discussed in previous chapters, the pv-panels are CIGS panels. In Uniec, these correspond to 100 Wp/m^2.

The building has six surfaces with photovoltaics: three on the roof and three in the façade. For each of these surfaces the following has to be decided:

- Ventilation
- Size
- Orientation
- Inclination
- Shading

The photovoltaic panels on the roof are modelled horizontal and those in the façade with a 90-degree inclination. All are minimally shaded.

LIGHTING (DUTCH: VERLCIHTING)

Based on the chosen lighting fixture is was calculated that 5,0 W.m^2 is essential for lighting the building. The system is a sweeping pulse circuit in combination with a daylight system.

Resultaten

Jaarlijkse hoeveelheid primaire energie voor de energiefunctie		
verwarming (excl. hulpenergie)	$E_{H;P}$	47.084 MJ
hulpenergie		42.183 MJ
warmtapwater (excl. hulpenergie)	$E_{W;P}$	22.332 MJ
hulpenergie		0 MJ
koeling (excl. hulpenergie)	$E_{C;P}$	20.3[illegible]1 MJ
hulpenergie		0 MJ
zomercomfort	$E_{SC;P}$	0 MJ
bevochtiging	$E_{hum;P}$	55.06[illegible] MJ
ventilatoren	$E_{V;P}$	17[illegible]7 MJ
verlichting	$E_{L;P}$	382.855 MJ
geëxporteerde elektriciteit	$E_{P;exp;el}$	0 MJ
op eigen perceel opgewekte & verbruikte elektriciteit	$E_{P;pr;us;el}$	585.993 MJ
in het gebied opgewekte elektriciteit	$E_{P;pr;del;el}$	0 MJ

Oppervlakten		
totale gebruiksoppervlakte	$A_{g;tot}$	4.100,00 m²
totale verliesoppervlakte	[illegible]	4.800,00 m²

Elektriciteitsgebruik	
gebouwgebonden installaties	81.231 kWh
niet-gebouwgebonden apparatuur (stelpost)	122.640 kWh
op eigen perceel opgewekte & verbruikte elektriciteit	63.584 kWh
geëxporteerde electriciteit	0 kWh
TOTAAL	140.286 kWh

CO_2-emissie		
CO_2-emissie	m_{co2}	9.967 kg

Energieprestatie		
specifieke energieprestatie	EP	40 MJ/m²
karakteristiek energiegebruik	E_{Ptot}	162.628 MJ
toelaatbaar karakteristiek energiegebruik	$E_{P;adm;tot;nb}$	1.210.440 MJ
E_{ptot} / $E_{P;adm;tot;nb}$ (Bouwbesluit)		0,14 -
E_{ptot} / $E_{P;adm;tot;nb}$ (energielabel)		0,10 -
energielabel nieuwbouw utiliteit		A++++

BENG indicatoren	
energiebehoefte	17,4 kWh/m²
primair energiegebruik	11,0 kWh/m²
aandeel hernieuwbare energie	64 %

Het gebouw voldoet aan de eisen inzake energieprestatie uit het Bouwbesluit 2012.

Figure 130: Uniec calculation summary page 7 (left)

RESULTS (DUTCH: RESULTATEN)

The calculation results in an EPC of 0,14 and an energy label of A++++. The building has the following characteristics (BENG indicators):

- Energy demand of the building 17,4 kWh/m^2
- Primary energy use 11,0 kWh/m^2
- Share of renewable energy 64%

In the current building, the Primary Energy demand was 288 kWh/m^2 in 2016 and the share of renewable energy was 0%.

Figure 131 shows the division of primary energy use per year. The largest amount of energy is used for lighting (382.855 MJ), followed by ventilation (178.717 MJ) and heating (89.277 MJ).

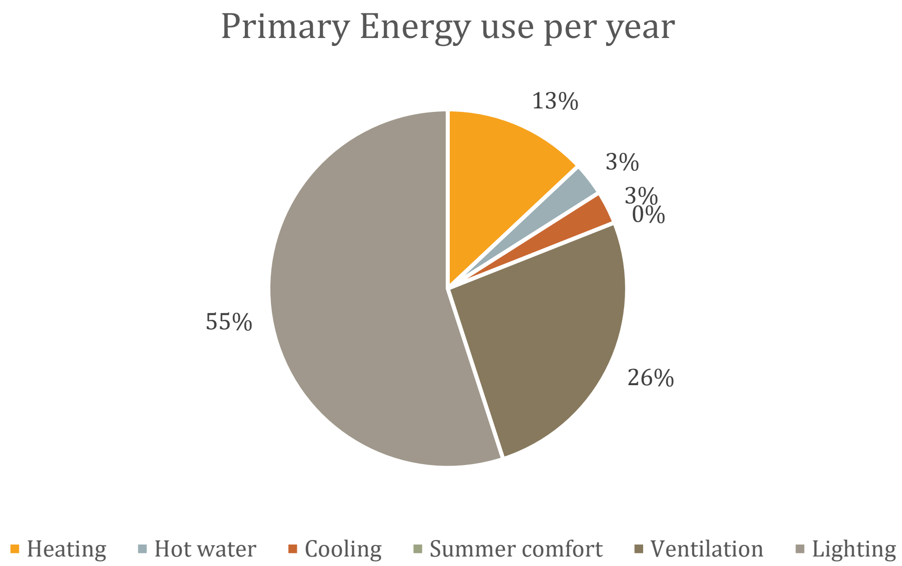


Figure 131: Primary energy use per year

9.4. ALTERNATIVES

It is interesting what happens if the Rc-values are changed. For all, the less material is used, the less embodied energy has to be added. Additionally, it will be investigated how much PV has to be added to make it 100% renewable.

CHANGE OF THERMAL INSULATION

First, the Rc-values and the infiltration will be changed from passive house standard to comfort details (Table 9). The Rc values are lowered. And the infiltration will be changed to 0.3 $dm^3/s.m^2$.

Table 7: Design values for building components (DGMR, 2015; Nieman, 2017; SBRCURnet, 2015)

	Bouwbesluit	**Comfort details**	**Passive house standard**
Ground floor	3,5 m^2K/W	4,0 m^2K/W	7,0 m^2K/W
Facade	4,5 m^2K/W	5,0 m^2K/W	9,0 m^2K/W
Roof	6,0 m^2K/W	6,0 m^2K/W	10,0 m^2K/W
Windows	1,4 W/m^2K SHGC 0.6	-	1,1 W/m^2K SHGC 0.5
Air infiltration	0,6 $dm^3/s.m^2$	0,3 - 0,6 $dm^3/s.m^2$	0,2 $dm^3/s.m^2$

It is expected that the annual energy for heating will increase, as the building has lower thermal resistance. On the contrary, the initial material energy will be lower, as less material is needed to reach the lower thermal resistance. It is interesting to investigate whether the thermal insulation will earn itself back and if so, within which time span.

Therefore, the Embodied Energy of wood fibre insulation and timber will be taken into consideration. These two have the most m^2 that will be decreased. Additionally, decreasing the size of the panels will also save labour and transport energy, but this is difficult to calculate. Table 40.

Table 40: Properties of sawn softwood and wood fibre insulation (Hammond & Jones, 2011)

Material	**Density**	**Embodied Energy in MJ/kg**
Sawn softwood	550 kg/m^3	7,4 MJ/kg
Wood fibre insulation (loose)	55 kg/m^3	10,8 MJ/kg
Wood fibre insulation (board)	140 kg/m^3	20,0 MJ/kg

At the moment the building only has two types of insulation, because this increases the demountability. The two types are:

- 220 mm wood fibre insulation batten
- 120 mm wood fibre insulation board

To change the construction to the lower Rc-values, it is best to change these two types to:

- 100 mm wood fibre insulation batten
- 80 mm wood fibre insulation board

Consequently, the timber studs are also changed to 100 mm, as these are placed in between the battens with a bridging factor of 15%. The total opaque area measures about 4800 m². Table 41 shows the calculation for savings in Embodied Energy.

Table 41: Savings on sawn softwood and wood fibre insulation (Hammond & Jones, 2011)

Material	Savings per m² facade	Embodied Energy per m² facade	Embodied Energy
Sawn softwood	9,9 kg	73,3 MJ	351.648 MJ
Wood fibre insulation (loose)	6,6 kg	71,3 MJ	342.144 MJ
Wood fibre insulation (board)	5,6 kg	112,0 MJ	537.600 MJ
Total			1231.392 MJ

In conclusion, at least 1231.392 MJ would be saved on initial Embodied Energy by decreasing the thermal resistance value Rc. In the following paragraphs it will be investigated whether the annual energy for heating will increase.

The Rc-value and the infiltration factor have been changed in the model (Figure 132).

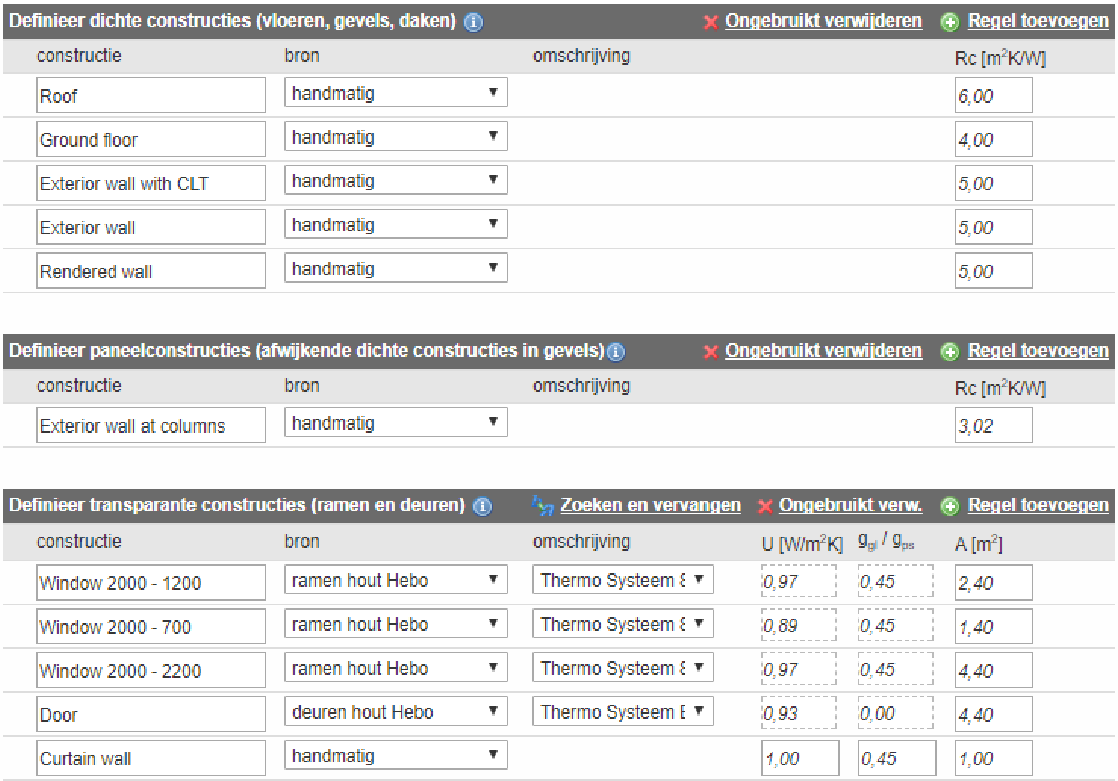


Figure 132: Building construction elements with lower Rc-values, screenshot of Uniec

Resultaten

Jaarlijkse hoeveelheid primaire energie voor de energiefunctie		
verwarming (excl. hulpenergie)	$E_{H;P}$	180.169 MJ
hulpenergie		42.183 MJ
warmtapwater (excl. hulpenergie)	$E_{W;P}$	22.817 MJ
hulpenergie		0 MJ
koeling (excl. hulpenergie)	$E_{C;P}$	16.335 MJ
hulpenergie		0 MJ
zomercomfort	$E_{SC;P}$	0 MJ
bevochtiging	$E_{hum;P}$	55.06[illegible] MJ
ventilatoren	$E_{V;P}$	17[illegible]7 MJ
verlichting	$E_{L;P}$	382.855 MJ
geëxporteerde elektriciteit	$E_{P;exp;el}$	0 MJ
op eigen perceel opgewekte & verbruikte elektriciteit	$E_{P;pr;us;el}$	585.993 MJ
in het gebied opgewekte elektriciteit	$E_{P;pr;del;}$[illegible]	0 MJ

Oppervlakten		
totale gebruiksoppervlakte	$A_{g;tot}$	4.100,00 m²
totale verliesoppervlakte	[illegible]	4.800,00 m²

Elektriciteitsgebruik	
gebouwgebonden installaties	95.284 kWh
niet-gebouwgebonden apparatuur (stelpost)	122.640 kWh
op eigen perceel opgewekte & verbruikte elektriciteit	63.584 kWh
geëxporteerde electriciteit	0 kWh
TOTAAL	154.339 kWh

CO_2-emissie		
CO_2-emissie	m_{co2}	17.905 kg

Energieprestatie		
specifieke energieprestatie	EP	71 MJ/m²
karakteristiek energiegebruik	E_{Ptot}	292.142 MJ
toelaatbaar karakteristiek energiegebruik	$E_{P;adm;tot;nb}$	1.210.440 MJ
E_{ptot} / $E_{P;adm;tot;nb}$ (Bouwbesluit)		0,25 -
E_{ptot} / $E_{P;adm;tot;nb}$ (energielabel)		0,18 -
energielabel nieuwbouw utiliteit		A++++

BENG indicatoren	
energiebehoefte	20,9 kWh/m²
primair energiegebruik	19,8 kWh/m²
aandeel hernieuwbare energie	51 %

Het gebouw voldoet aan de eisen inzake energieprestatie uit het Bouwbesluit 2012.

Figure 133: Uniec calculation summary page 7 (left)

This results in the following summary in Uniec (Figure 133). Table 42 shows the main characteristic changes.

Table 42: Comparison between comfort details and passive house standard

Properties	Comfort details	Passive house standard
Rc-values (floor – façade – roof)	4 – 5 – 6 m^2K/W	8 – 9 – 10 m^2K/W
EPC	0,24	0,14
Energy demand of the building	20,9 kWh/m^2	17,4 kWh/m^2
Primary energy use	19,8 kWh/m^2	11,0 kWh/m^2
Share of renewable energy	51%	64%
Heating	180.169 MJ	47.084 MJ

For heating, an additional 133.085 MJ per year is required. Compared to the Embodied Energy that would be saved (at least 1231.392 MJ) on insulation and timber studs, this results in a payback time of 9 to 10 years (Figure 134). As the facades are expected to have a life span of 25 to 30 years, the additional investment of Embodied Energy is justified.

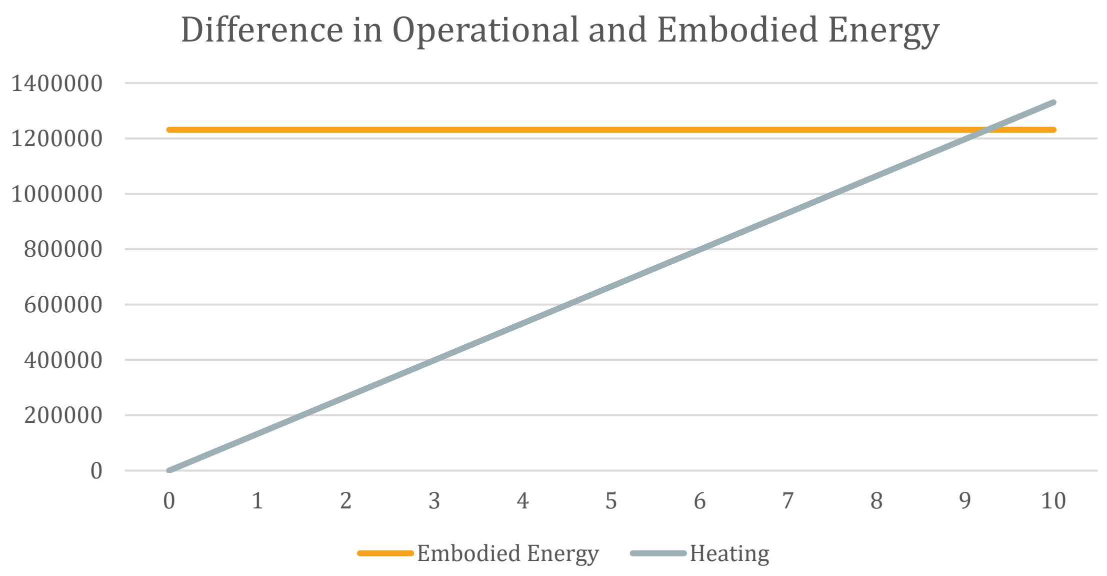


Figure 134: Difference in Operational and Embodied Energy

CHANGE OF RENEWABLE ENERGY GENERATION

In the first calculation, 64% of the energy is renewable. Of this, 64 MWh is electricity and the rest is energy generated by the heat pump. The building already has 750 m^2 of horizontal and 140 m^2 of vertical PV-surfaces.

The aim is to generate 100% of the electricity by renewables. As a solution, the roof of the adjacent parking garage can be used for electricity generation with photovoltaic panels. This parking garage is located 10-15 metres from the Low Speed Lab and will have a roof surface of 3500 m^2.

Not all of this surface has to be used, as can be concluded in Figure 135. Using 250 m^2 of the panels on the parking garage for the Low Speed Lab should be sufficient to make the LSL energy neutral.

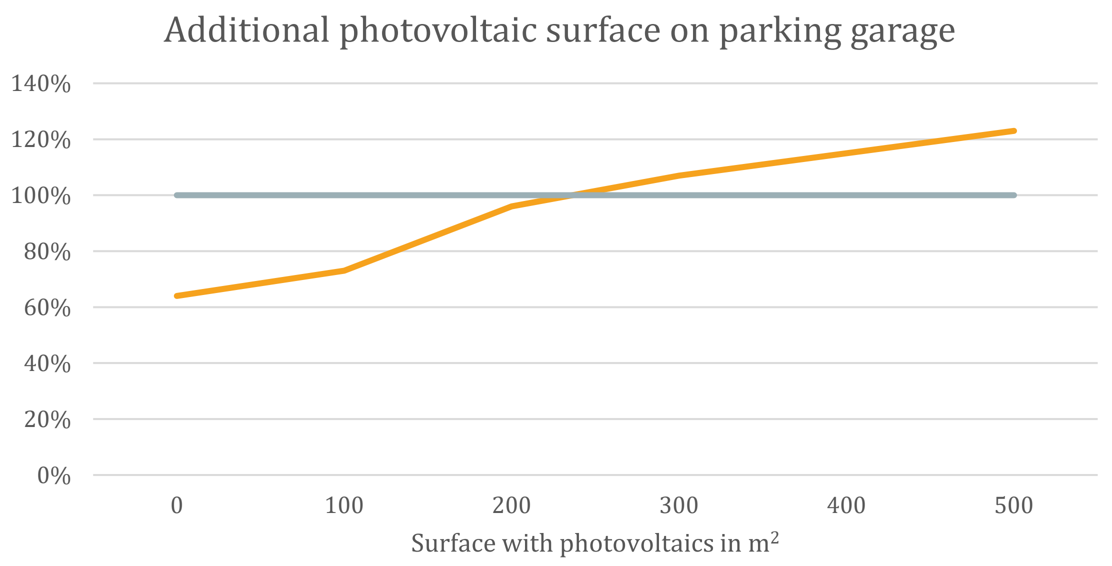


Figure 135: Additional photovoltaic surface on parking garage to generate 100% renewable energy

CONCLUSION

In conclusion, the building can be energy neutral (with an EPC of -0,02). The final results are shown on the following page.

The calculation does not include the following energy:

- Operational energy of the users
  - wind tunnel
  - vertical wind tunnel
  - other machines
- Embodied Energy of added materials and components

Resultaten

Jaarlijkse hoeveelheid primaire energie voor de energiefunctie		
verwarming (excl. hulpenergie)	$E_{H;P}$	47.084 MJ
hulpenergie		42.183 MJ
warmtapwater (excl. hulpenergie)	$E_{W;P}$	22.332 MJ
hulpenergie		0 MJ
koeling (excl. hulpenergie)	$E_{C;P}$	20.3[illegible]1 MJ
hulpenergie		0 MJ
zomercomfort	$E_{SC;P}$	0 MJ
bevochtiging	$E_{hum;P}$	55.06[illegible] MJ
ventilatoren	$E_{V;P}$	17[illegible]7 MJ
verlichting	$E_{L;P}$	382.855 MJ
geëxporteerde elektriciteit	$E_{P;exp;el}$	0 MJ
op eigen perceel opgewekte & verbruikte elektriciteit	$E_{P;pr;us;el}$	772.896 MJ
in het gebied opgewekte elektriciteit	$E_{P;pr;del;}$[illegible]	0 MJ

Oppervlakten		
totale gebruiksoppervlakte	$A_{g;tot}$	4.100,00 m²
totale verliesoppervlakte	A[illegible]	4.800,00 m²

Elektriciteitsgebruik	
gebouwgebonden installaties	81.231 kWh
niet-gebouwgebonden apparatuur (stelpost)	122.640 kWh
op eigen perceel opgewekte & verbruikte elektriciteit	83.865 kWh
geëxporteerde electriciteit	0 kWh
TOTAAL	120.006 kWh

CO_2-emissie		
CO_2-emissie	m_{co2}	-1.488 kg

Energieprestatie		
specifieke energieprestatie	EP	-6 MJ/m²
karakteristiek energiegebruik	E_{Ptot}	-24.274 MJ
toelaatbaar karakteristiek energiegebruik	$E_{P;adm;tot;nb}$	1.210.440 MJ
E_{ptot} / $E_{P;adm;tot;nb}$ (Bouwbesluit)		-0,02 -
E_{ptot} / $E_{P;adm;tot;nb}$ (energielabel)		-0,01 -
energielabel nieuwbouw utiliteit		A++++

BENG indicatoren	
energiebehoefte	17,4 kWh/m²
primair energiegebruik	-0,6 kWh/m²
aandeel hernieuwbare energie	103 %

Het gebouw voldoet aan de eisen inzake energieprestatie uit het Bouwbesluit 2012.

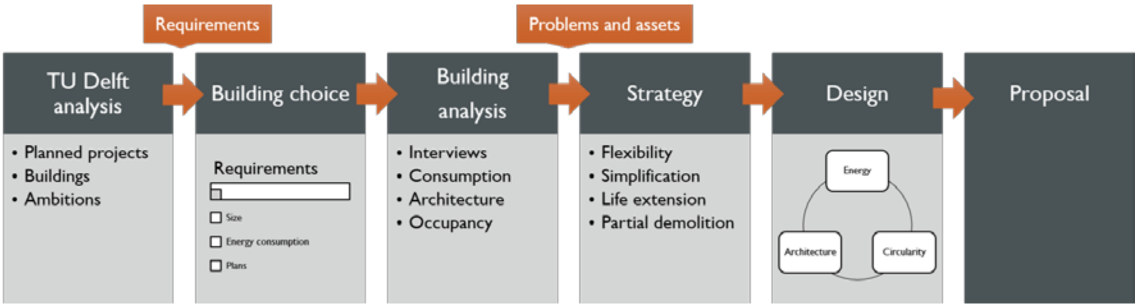
VALIDATION

10. RESULTS

The objective of this graduation project was to design a method by which a building portfolio can be refurbished and to give an example of the method by making a refurbishment proposal. This method was developed for the TU Delft, but can also be used by other building portfolio owners. The results of this graduation project are shown in the following paragraphs.

10.1. METHODOLOGY

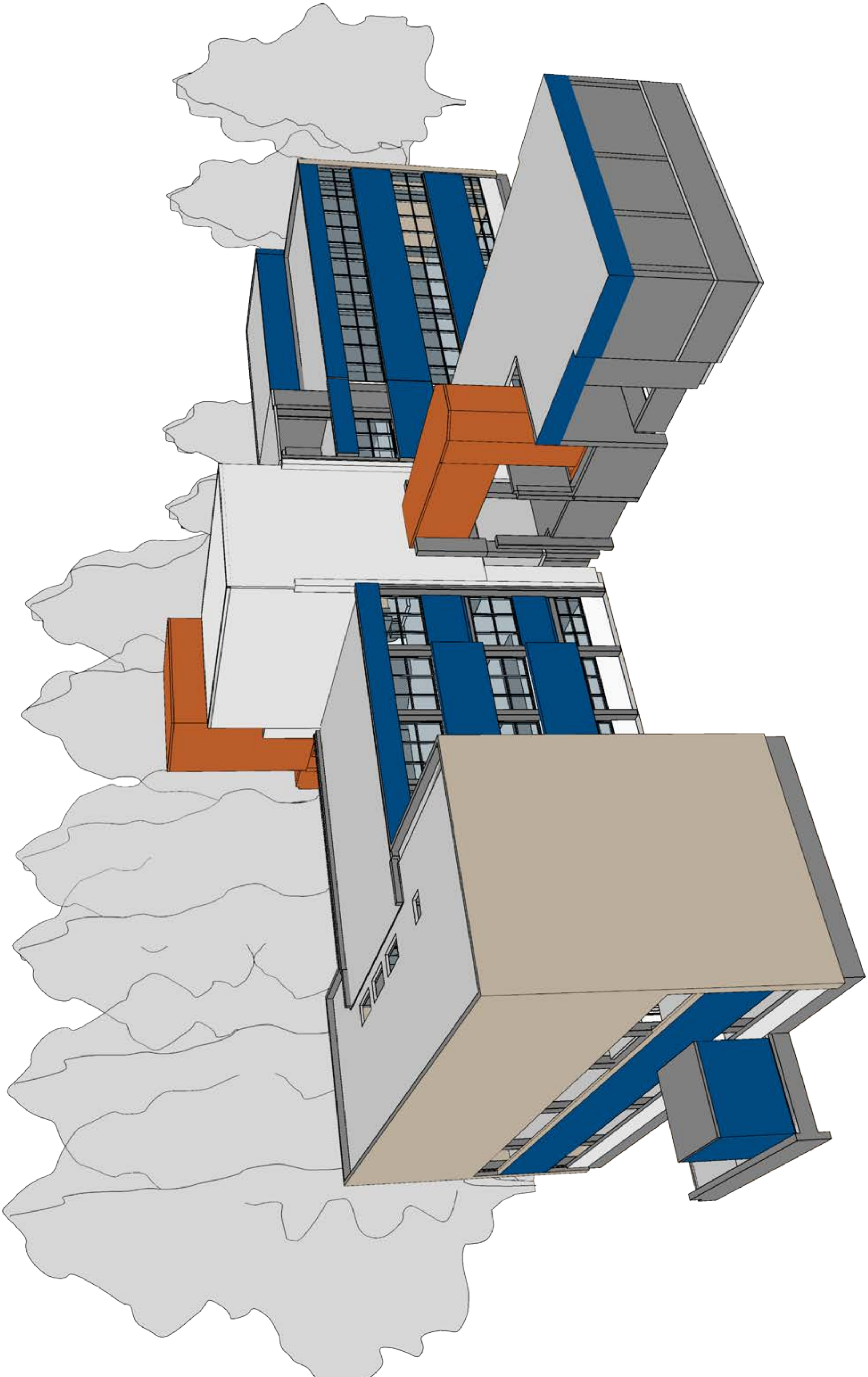
The methodology consists of six phases and results in a building proposal.

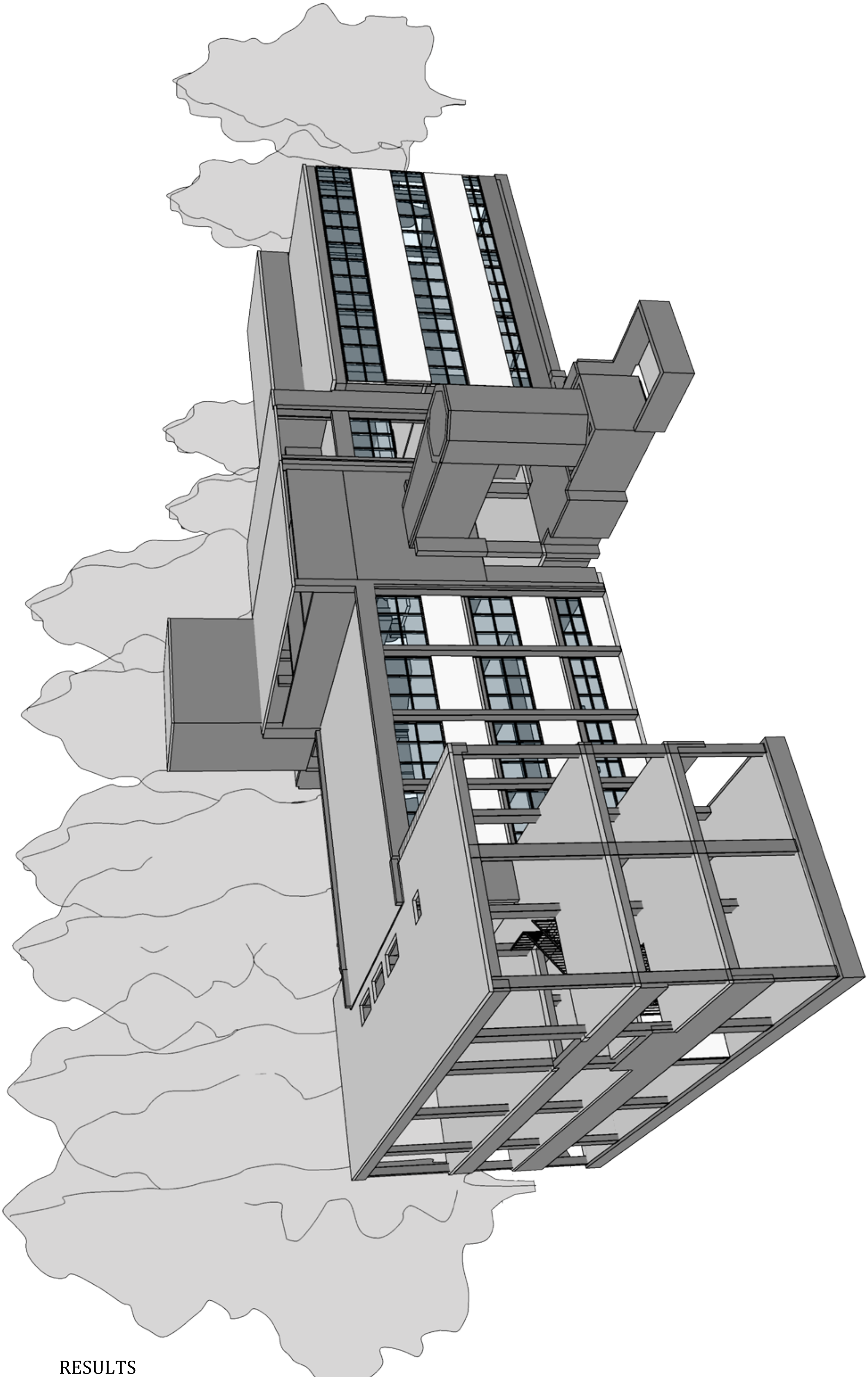


10.2. BUILDING PROPOSAL

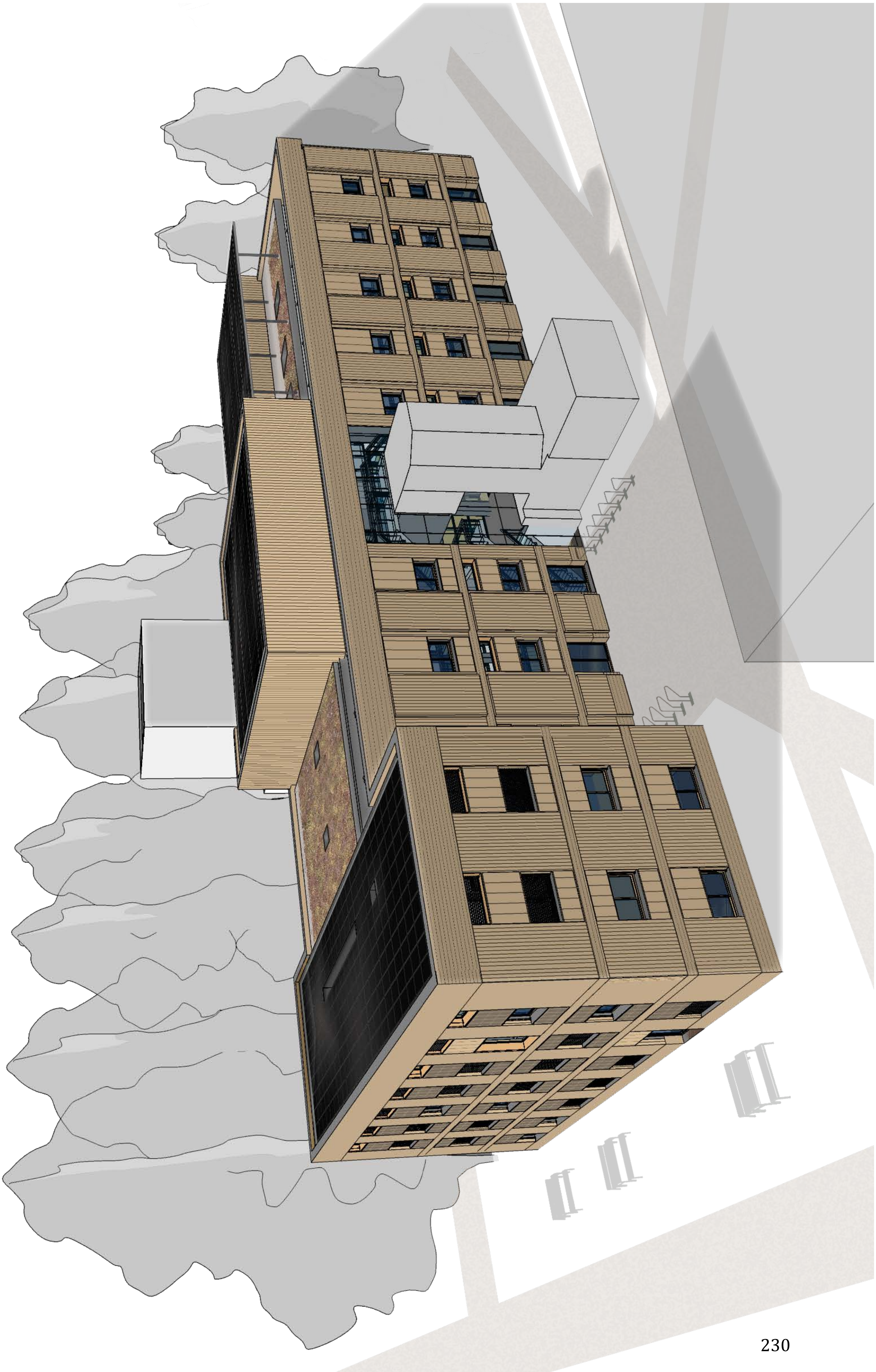
The second result of this graduation project is a building proposal. The proposal is shown on the following pages.

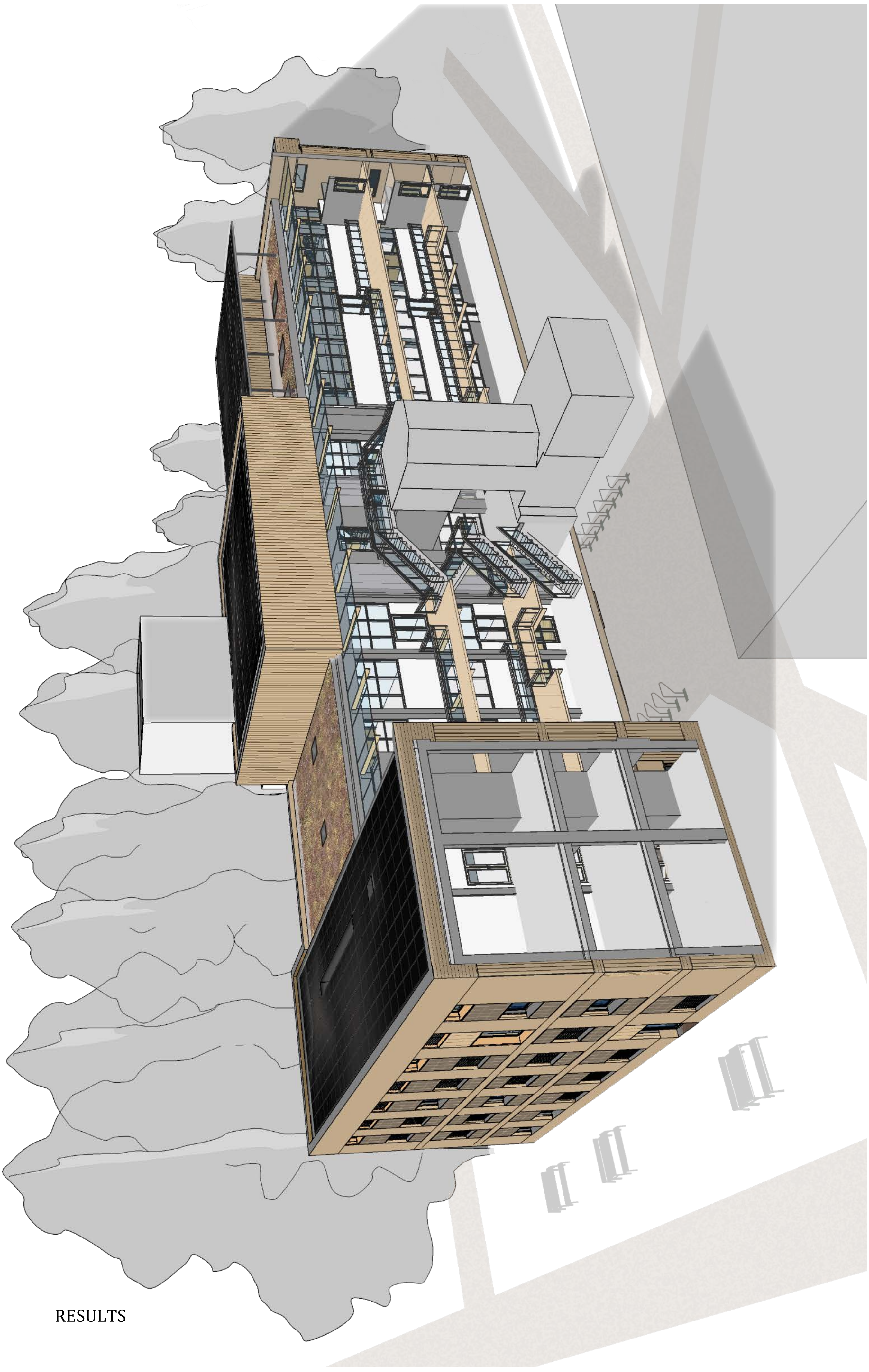
- Current building
- Stripped building
- New building proposal
- New building proposal – transparent façade
- Floor plans – 1:250
- Climate in section
- Façades – 1:250
- Façade detail 1 – 1:50
- Façade detail 2 – 1:50
- Details – 1:5
- Render of the interior





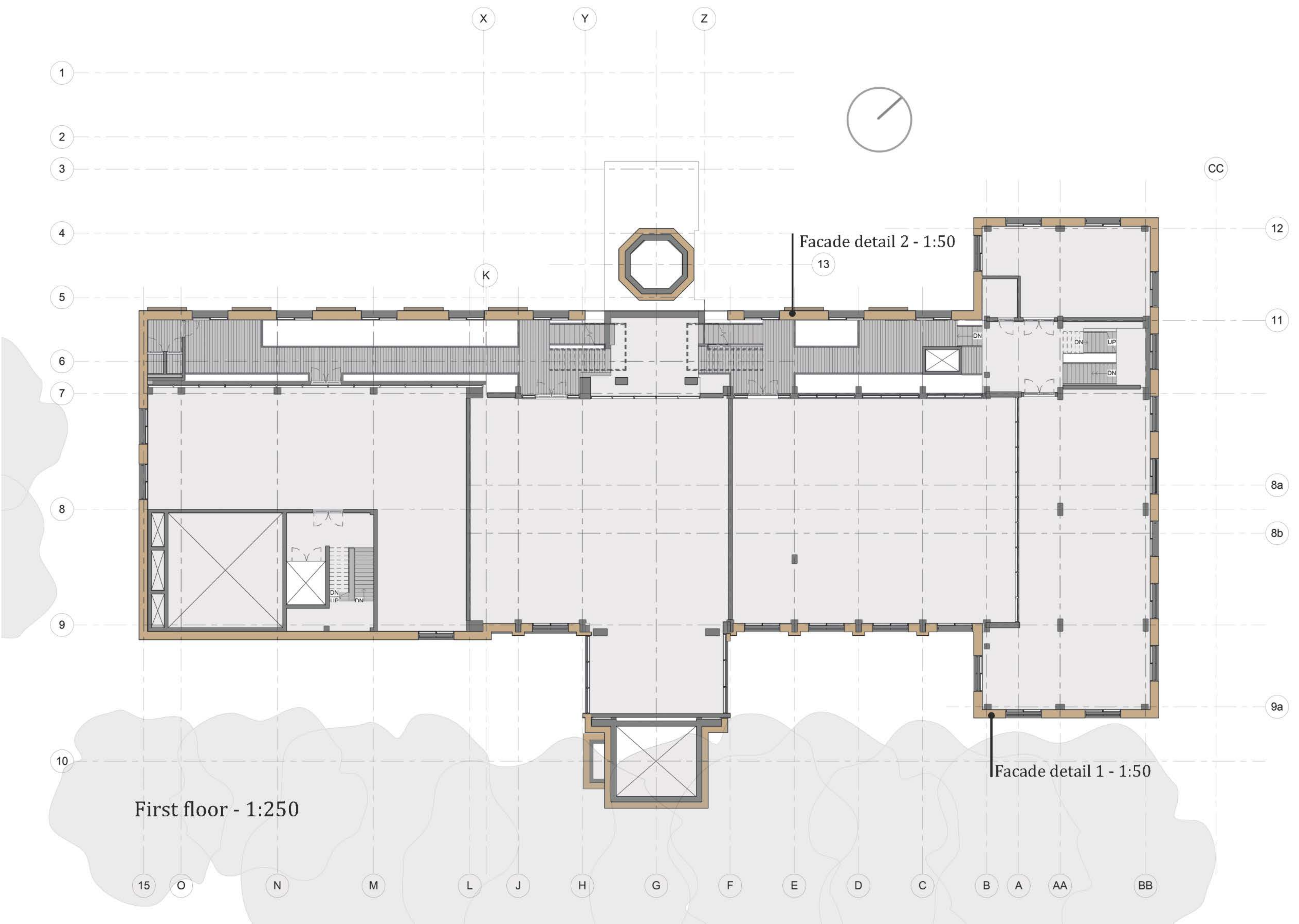
RESULTS



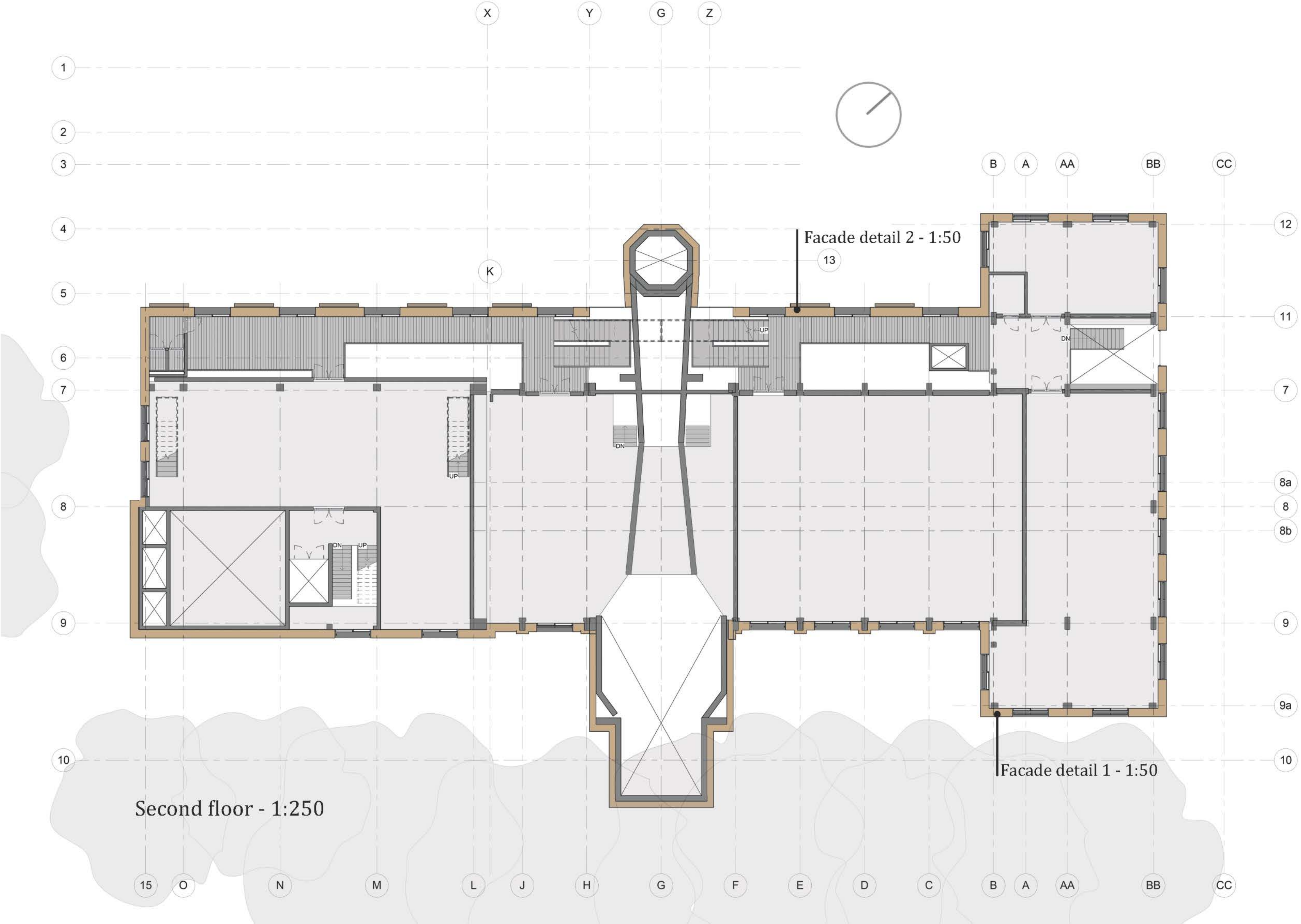


RESULTS

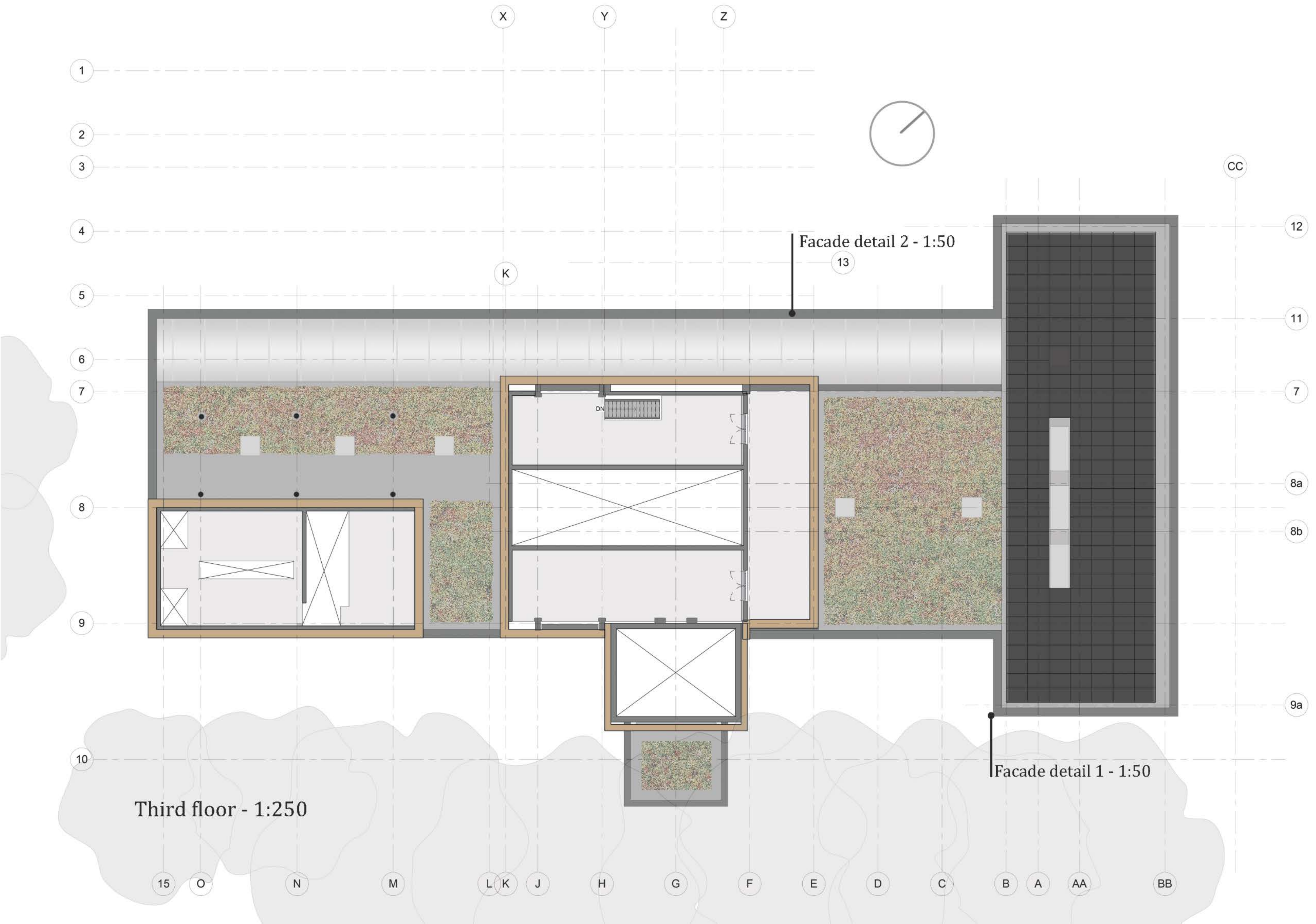
Ground floor - 1:250



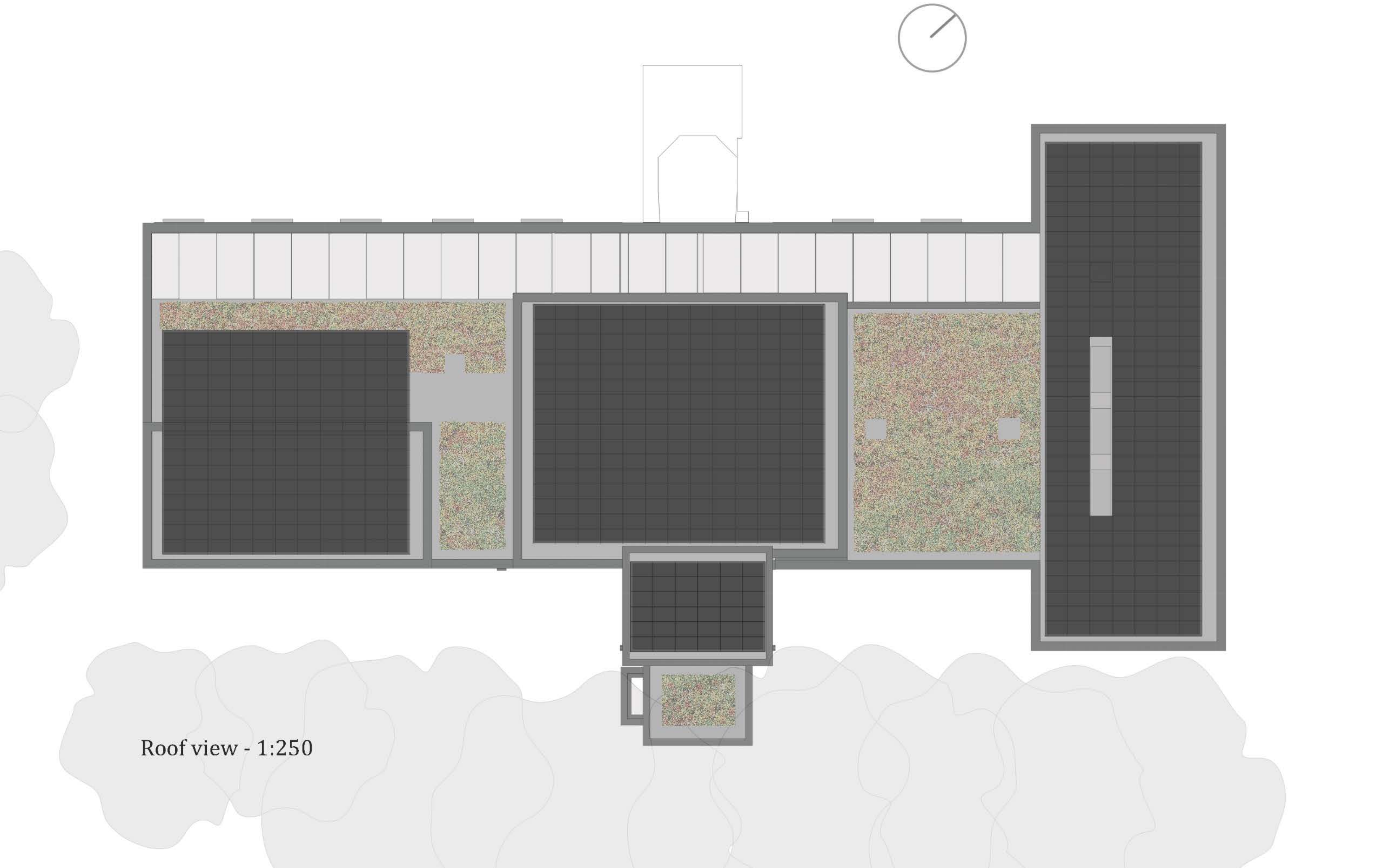
First floor - 1:250



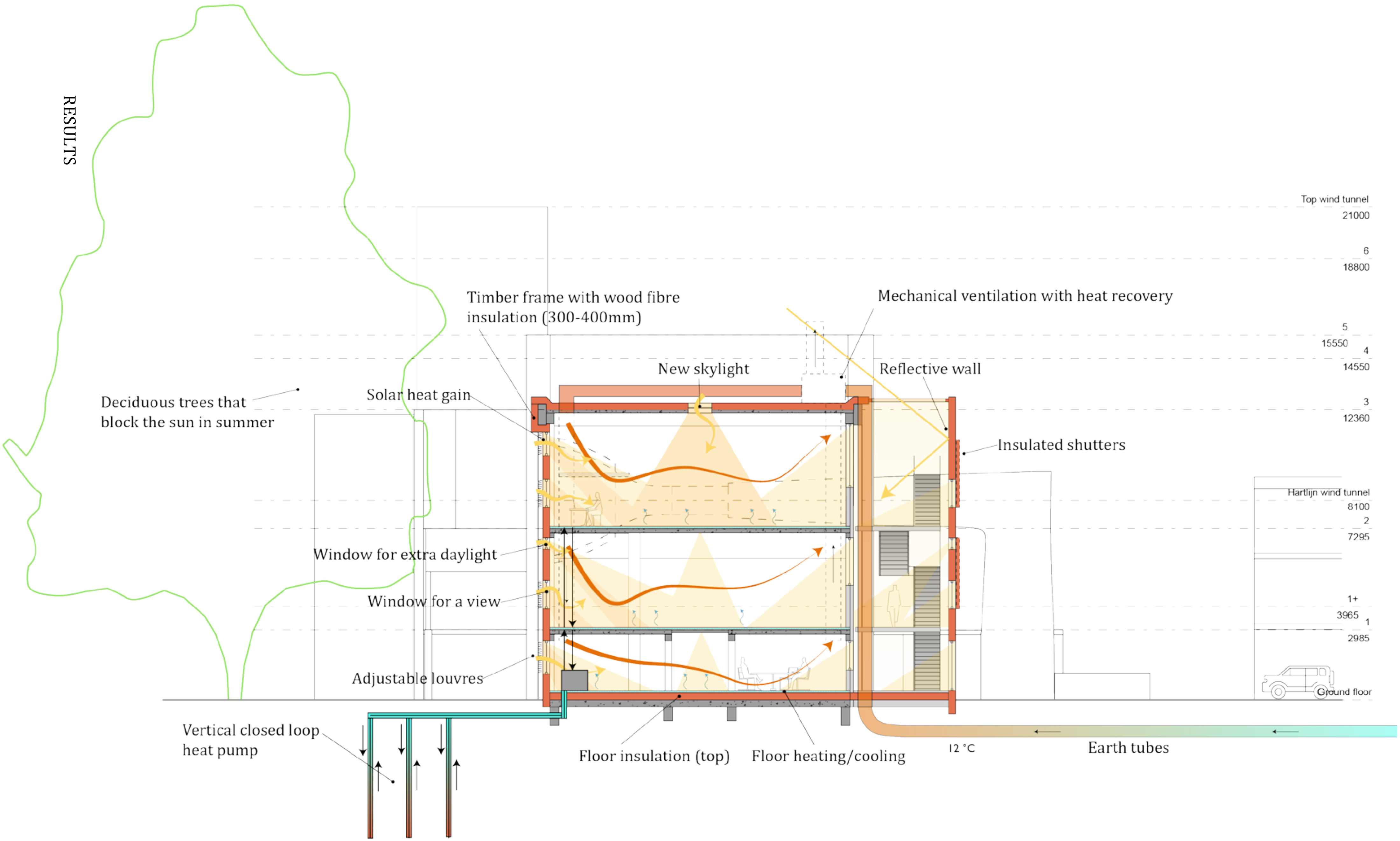
Second floor - 1:250



Third floor - 1:250



Roof view - 1:250

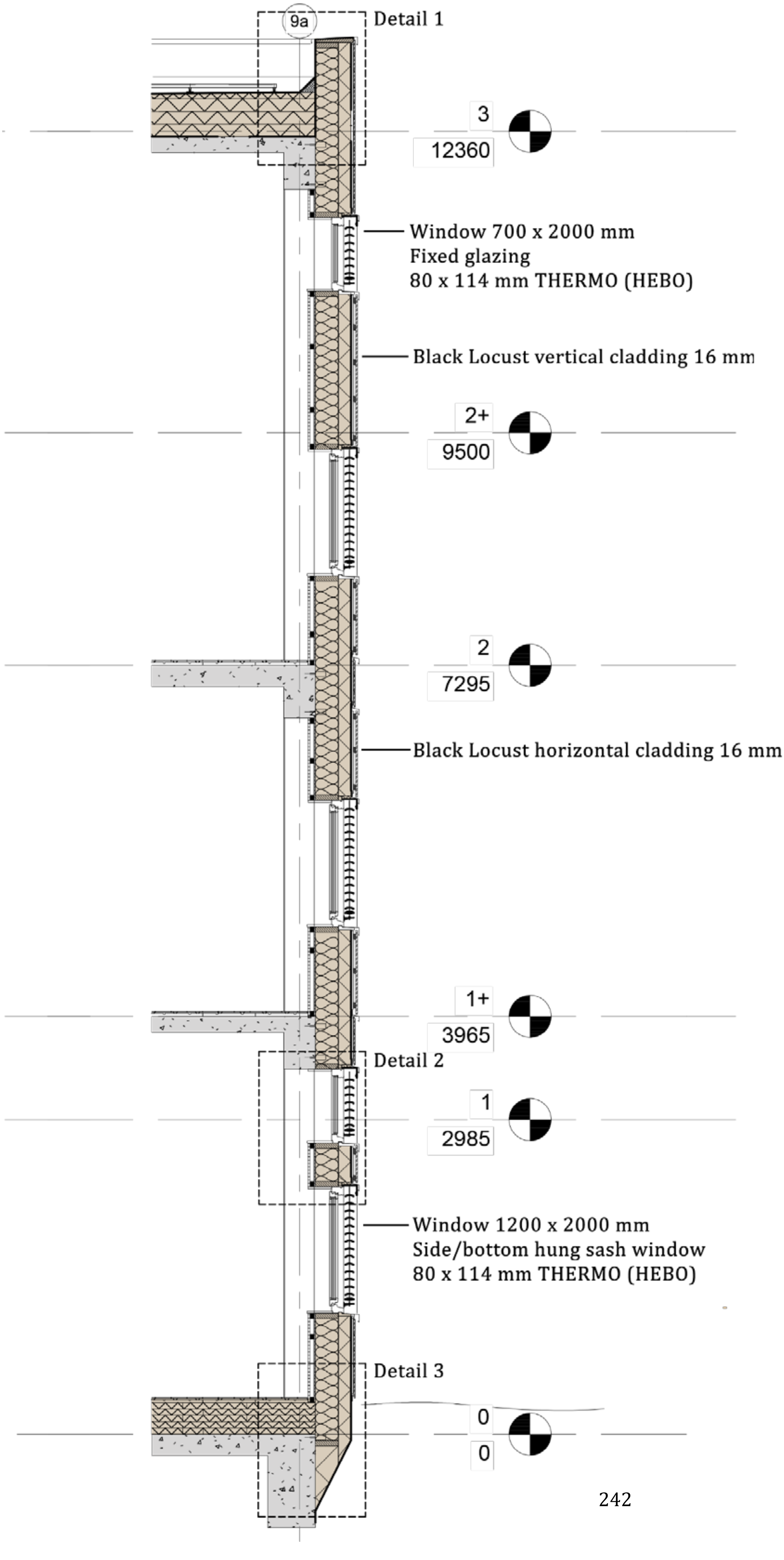

Top wind tunnel
21000
6
18800
5
15550
4
14550
3
12360
Hartlijn wind tunnel
8100
2
7295
1+
3965
1
2985
Ground floor
Timber frame with wood fibre insulation (300-400mm)
Mechanical ventilation with heat recovery
New skylight
Reflective wall
Deciduous trees that block the sun in summer
Solar heat gain
Insulated shutters
Window for extra daylight
Window for a view
Adjustable louvres
Vertical closed loop heat pump
Floor insulation (top)
Floor heating/cooling
12 °C
Earth tubes

East facade - 1:250

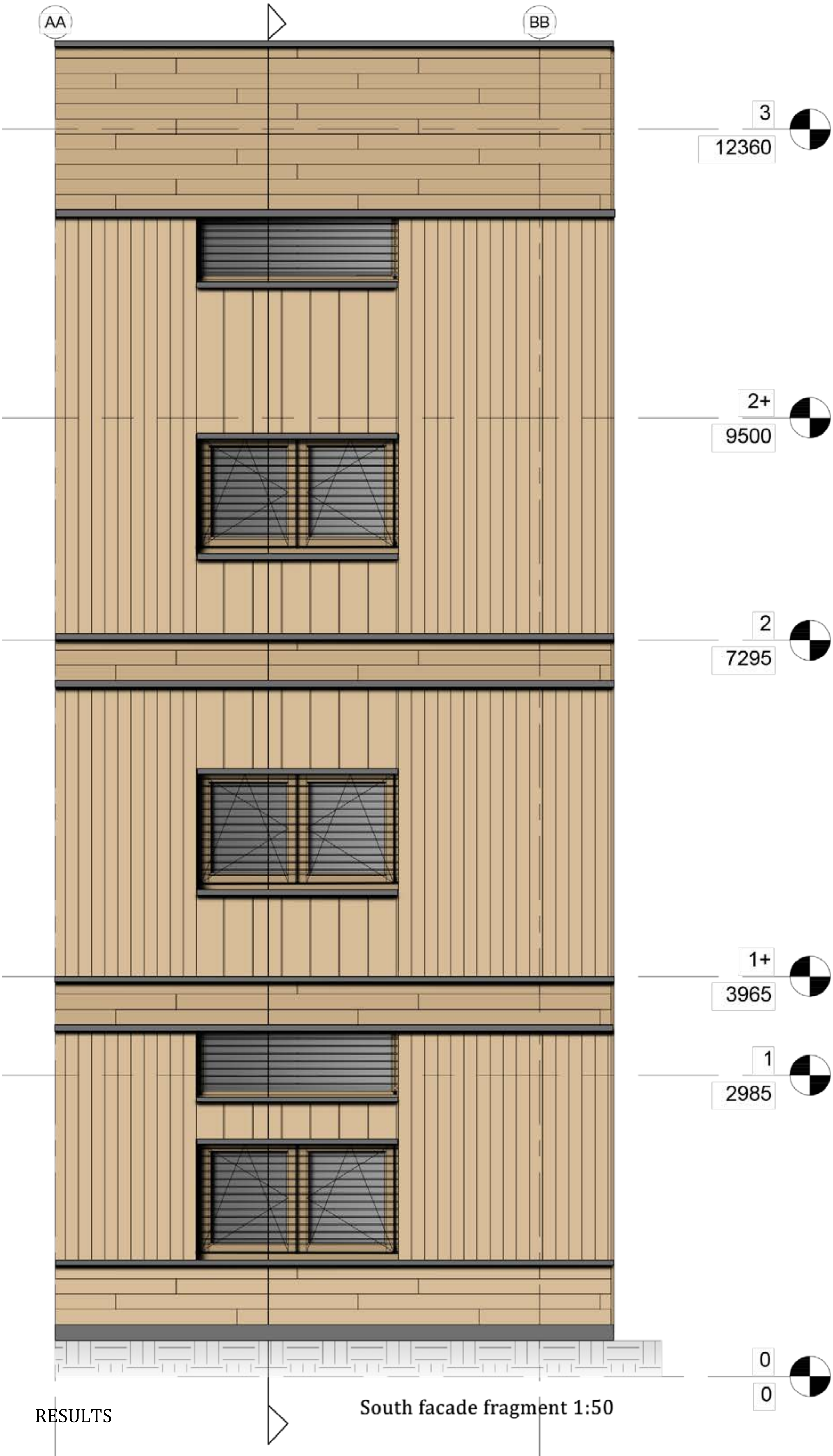
South facade - 1:250

West facade - 1:250

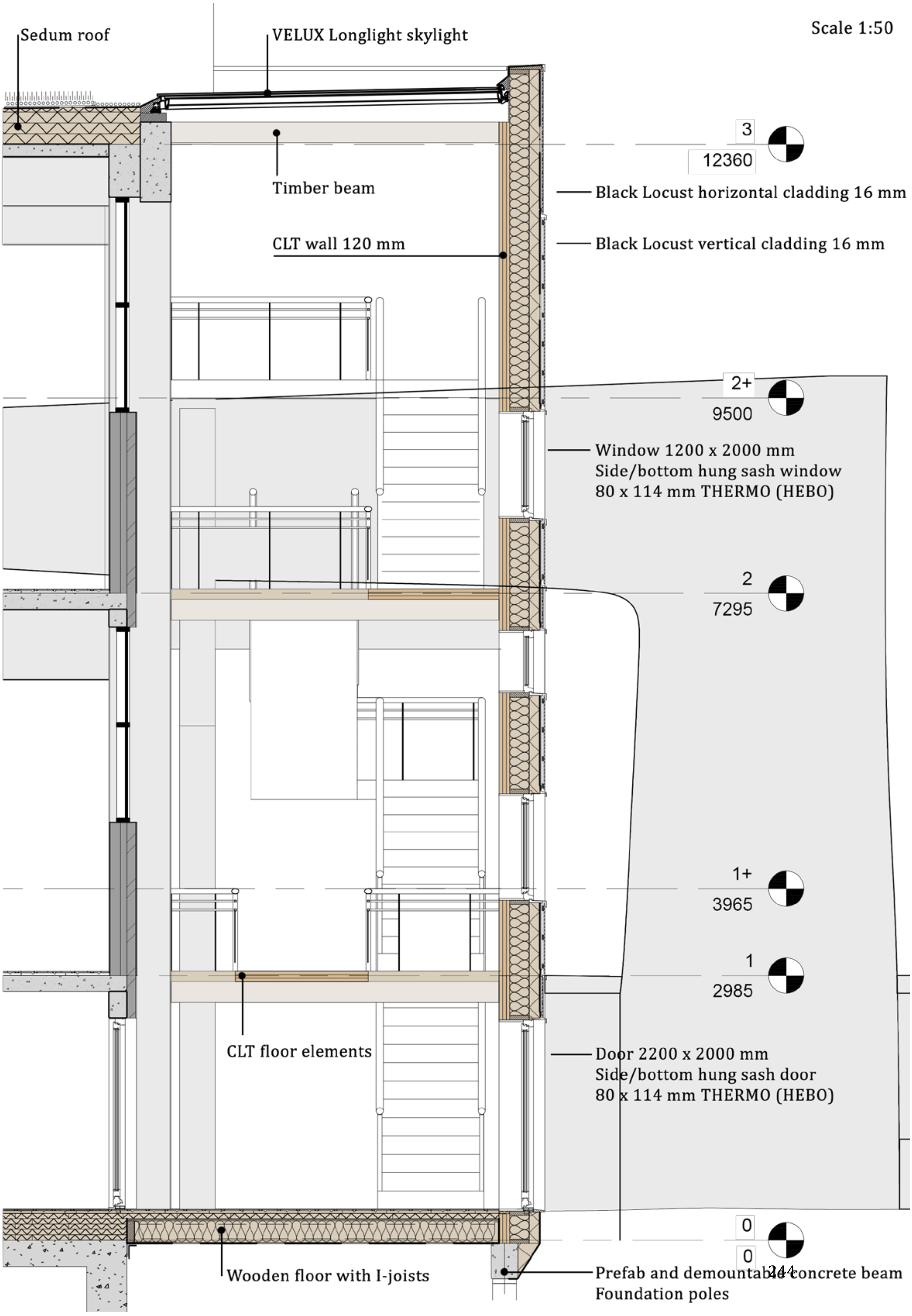
North facade - 1:250



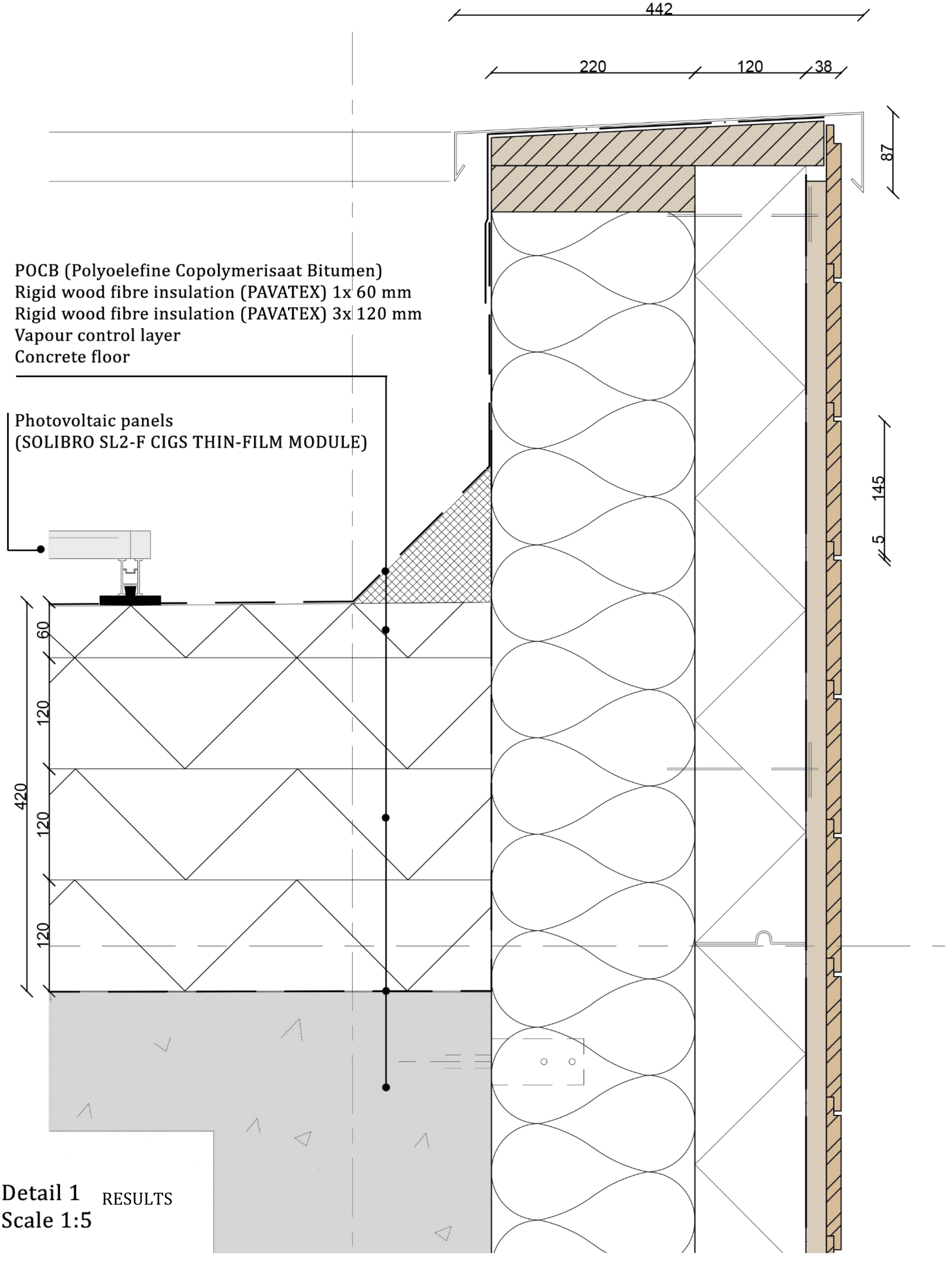
9a
Detail 1
3
12360
Window 700 x 2000 mm
Fixed glazing
80 x 114 mm THERMO (HEBO)
Black Locust vertical cladding 16 mm
2+
9500
2
7295
Black Locust horizontal cladding 16 mm
1+
3965
Detail 2
1
2985
Window 1200 x 2000 mm
Side/bottom hung sash window
80 x 114 mm THERMO (HEBO)
Detail 3
0
0



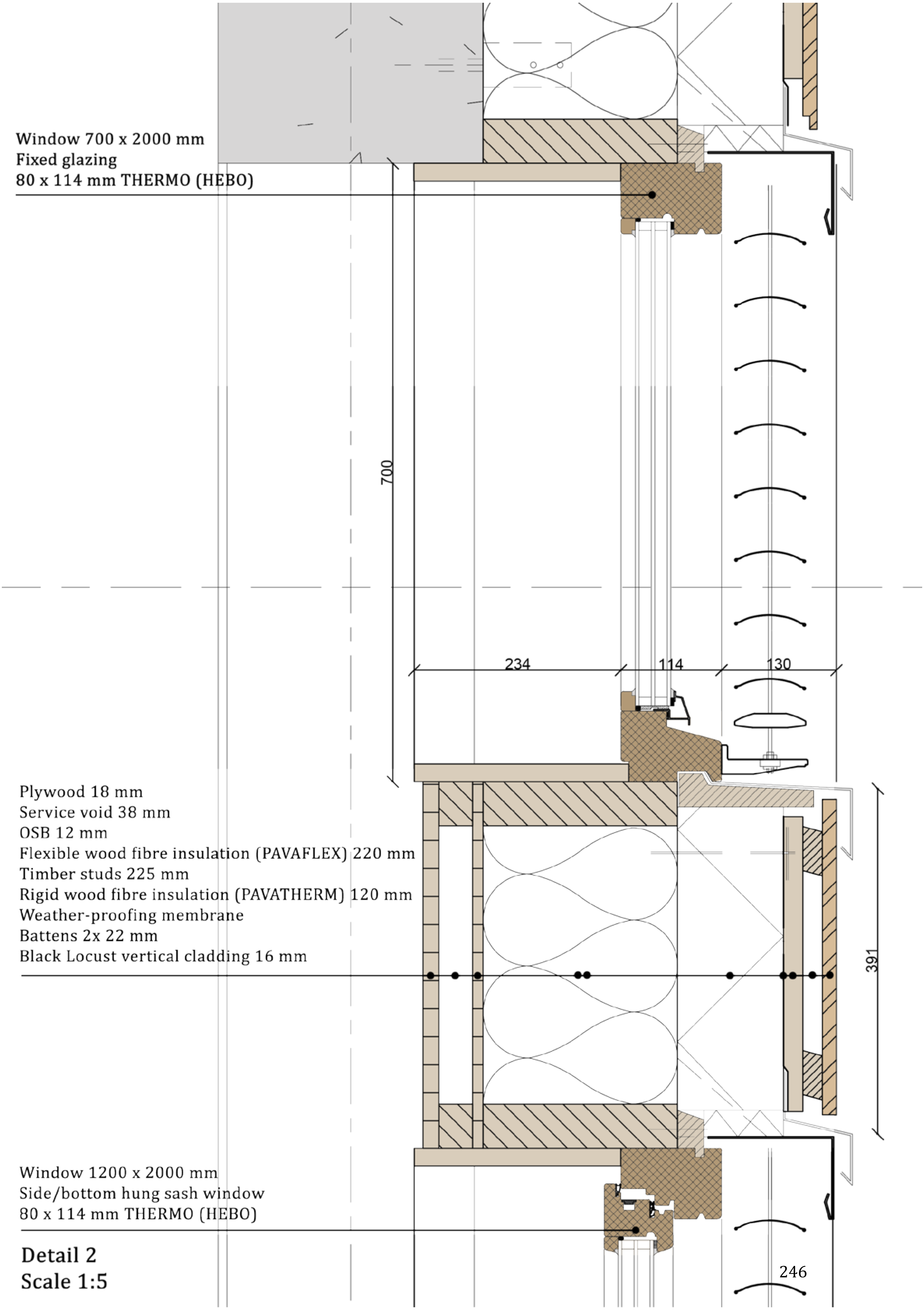
South facade fragment 1:50



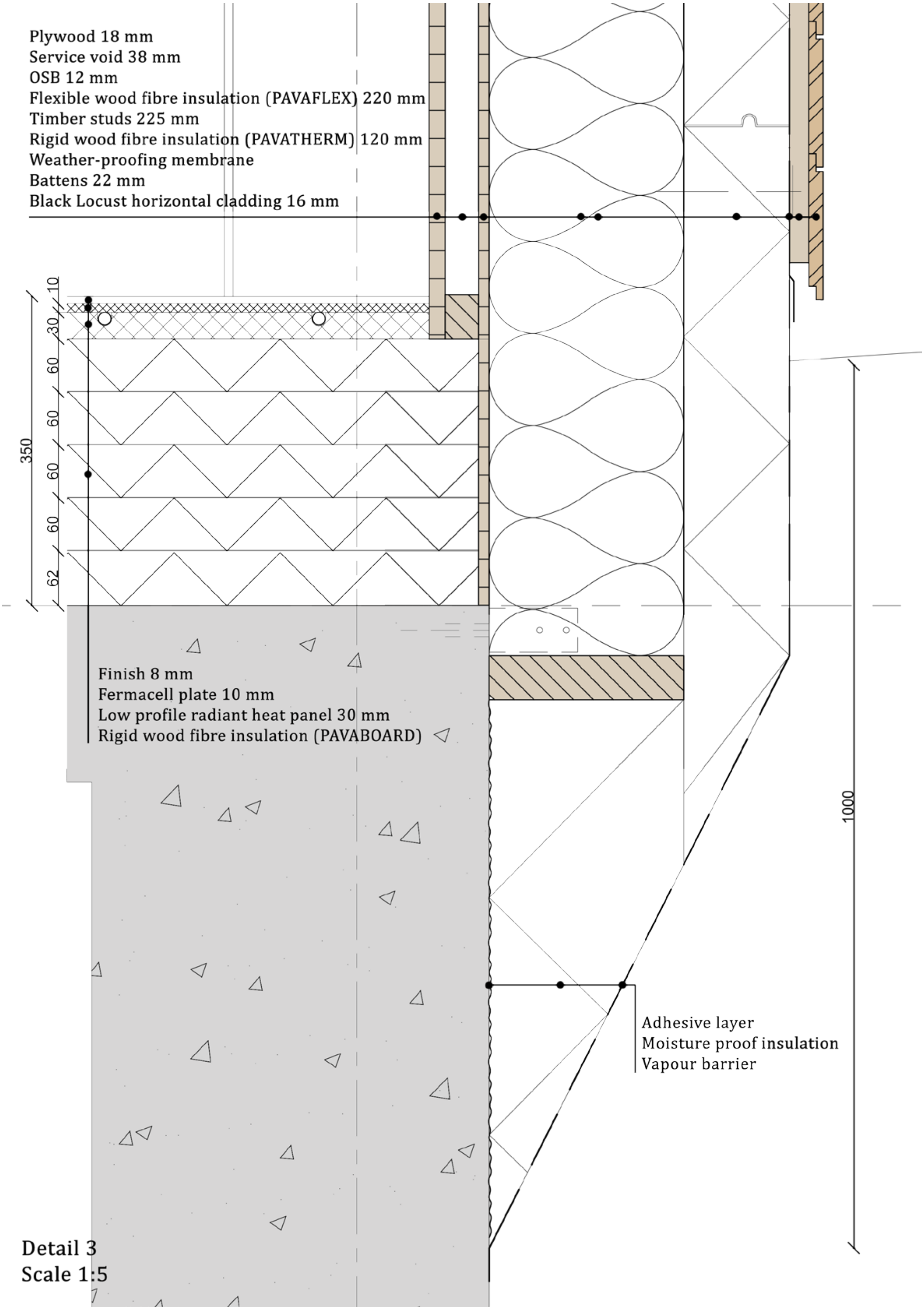
Scale 1:50
Sedum roof
VELUX Longlight skylight
Timber beam
CLT wall 120 mm
Black Locust horizontal cladding 16 mm
Black Locust vertical cladding 16 mm
3
12360
2+
9500
Window 1200 x 2000 mm
Side/bottom hung sash window
80 x 114 mm THERMO (HEBO)
2
7295
1+
3965
1
2985
CLT floor elements
Door 2200 x 2000 mm
Side/bottom hung sash door
80 x 114 mm THERMO (HEBO)
0
0
Wooden floor with I-joists
Prefab and demountable concrete beam
Foundation poles



Detail 1 RESULTS
Scale 1:5



Detail 2
Scale 1:5



Detail 3
Scale 1:5

11. CONCLUSION

What technical (re)design solutions should be used in the refurbishment of a TU Delft building to achieve net-zero energy whilst taking circular use of building materials into consideration?

This study shows how the building portfolio of the TU Delft can be upgraded and presents a method for energy neutral and circular refurbishments. The objective of this research is to decrease the energy and material consumption of the TU Delft, by stimulating refurbishment. TU Delft owns many buildings, of which the majority is in need of refurbishment. Also, the energy consumption is too high and needs to decrease (FMRE, 2013a).

Refurbishments can have a large impact on the energy and resource consumption, as it concerns 99,1% of the building stock (CBS, 2017c). Overall, the Built Environment is a large contributor to worldwide problems, because this sector consumes large amounts of resources, energy and water (UNEP-SBCI, 2017). These problems include global warming, depletion of natural resources and devastation of natural conditions. A large impact can be made by increasing the amount and extent of refurbishments (BPIE, 2013). By designing net-zero buildings that make use of circular building materials, both the energy and material scarcity are addressed.

The result of this thesis, a refurbishment model, offers a step-to-step approach for building portfolio owners. The model, as presented in chapter 10.1, consists of six phases. First, an analysis of the building portfolio of TU Delft has to be made by researching the building stock, plans and ambitions (Chapter 4). This analysis results in a list of requirements which can be used in the building choice (Chapter 5) and includes for instance energy consumption, latest year of refurbishment and planned projects. By this, the building that makes the largest impact on the total building stock is chosen. In the third phase, a building analysis is made (Chapter 6). A thorough building analysis is essential for a feasible refurbishment and should cover several topics (e.g. user comfort, functionality, energy consumption and material quality). With this information a strategy can be set out and the design phase can start (Chapter 7 and 8). To finish with a feasible result, three fields have to be balanced: Energy (e.g. consumption, climate, generation), circularity (e.g. flexibility, recyclability, material consumption) and architecture (e.g. appeal, feasibility, comfort). In reality, the design phase consists of a series of balanced compromises of these three fields. The chosen interventions and measures result in a refurbishment proposal (Chapter 0).

The refurbishment model has been tested on the Low Speed Lab, a multifunctional building on the perimeter of the campus. A refurbishment is essential as the building has a lot of potential, but does not function in the current state. It does not provide a comfortable indoor climate, the energy consumption is above average and the morphology is defect. A flexible and feasible design has been developed by decreasing the energy consumption and adding measures to reuse and generate energy and materials. Hereby, this refurbishment proposal is the first step towards a low consuming and self-sufficient campus.

RECOMMENDATIONS

This study shows how the building portfolio of the TU Delft can be upgraded and presents a method for energy neutral and circular refurbishments. However, further development of this method could increase the feasibility and usability of the method.

First, the viability of the project could be calculated. The costs of the proposed measures have not been calculated, but are important for any building owner. The actual refurbishment costs could be calculated. Additionally, the Embodied Energy of all added and subtracted materials are worth investigating.

Also, the proposed measures and interventions are chosen based on personal knowledge and a brief calculation. It would be of added value if the measures could be quantified. For all, the buildings at campus share many properties and requirements. Further development of a range of feasible measures would contribute to the applicability of the method.

Next, the EPC calculation can be extended or another method for calculating the energy consumption can be used. At the moment, the EPC calculation does not include process energy used in the wind tunnels and machines of other users, because there was no information of the energy consumption of these processes. As mentioned, the usage-based and material-related energy could not be added in this calculation. Changes in, for instance, user occupancy and temperature setpoints cannot be changed in the calculation. Therefore, a number of design decisions could not be tested.

Subsequently, designing with energy balances would significantly contribute to the method. In this thesis, the arrangement of the photovoltaics and windows has been chosen with use of simplified programs. However, calculating (and adjusting) the energy demand, energy production and solar gains simultaneously will result in a lower energy consumption and more balanced generation.

Last, the method can be improved by coming up with a faster method of making a detailed Material Passport. This thesis included an extensive building analysis and the making of a 3D model, which resulted in a material analysis. A faster method for making a Material Passport would significantly contribute to the speed and quality of the process.

DISCUSSION

The main outcomes of this project are a refurbishment method and a building proposal for the TU Delft. The objective of this thesis is to encourage the TU Delft and other large building portfolio owners to refurbish their buildings. This is done by handing these organisations a method and an accompanying example.

As discussed in Chapter 4, the TU Delft and FMRE have the objective to make the campus more sustainable by reducing the energy consumption, decreasing the CO_2 emissions and increasing the share of renewable energy on campus. However, most of their plans and projects do not reflect this ambition. By providing these organisations with this refurbishment method, the focus hopefully shifts from cost management to energy management. For all, the students of TU Delft are taught all about sustainability, but the campus itself is not more than a mere reflection of that ambition.

CONCLUSION

12. REFLECTION

In this chapter, I will reflect on actions related to this graduation project. It aims at making connections between theory and practice, so I can learn from my past actions. I will discuss three subjects regarding my graduation project, being:

- Choice of topic
- Defining the scope
- The process from research to design

P3, June 2017
At that moment, I am at two-third of my graduation project. Most of the desk research has been done and I am now progressing to design and development. About half of the time I have left will be spent on this stage and the other on making presentable results.

P4, September 2017
In the last months, I have spent most of my time designing and documenting the design process. Documenting this process was rather difficult, but the design phase itself was pleasant.

CHOICE OF TOPIC

The topic of this research has four themes: refurbishment, energy neutrality, portfolio management and circular economy. To me, all are relevant for our current building stock, society and my personal learning process. I am least familiar with circular economy and would therefore like to reflect on this choice. Circular economy is an upcoming theme in both society and the Built Environment. Although the principles have been around for quite some time, its significance is now being researched by many people. That is one of the main reasons I came into contact with the circular economy, but also one of the reasons why I find it hard to do my research. In the course of my graduation, I got to know more and more people investigating this topic. Often people that already have a better understanding of the concept and application. This gives me the feeling that my research is not as significant as I would like it to be and I am less original than I thought. Whether that is the case is hard to determine, but fortunately I am still enjoying this research.

P3, June 2017
In the next months and in future projects I plan to focus on what I am achieving rather than what others are, because comparing efforts often does not give a good overview.

P4, September 2017
Solely focusing on the achievements turned out to be a difficult objective, as I lost the tread of my own progress at some point. I've regained focus and am content with all four topics within my graduation.

DEFINING THE SCOPE

Choosing the bandwidth of my research proved to be difficult. As mentioned above, it encompasses four themes combined into one research and answers the following questions: how to determine what building should be refurbished; how to determine how the building functions now; how to make an energy neutral building; how to put the principles of circular building materials into practice. Before starting, I had a basic understanding of these topics. My research is progressing slow and I think this has to do with my scope. The graduation project goes in to too many topics and I made it too detailed. It partially has to do with the way I work. I have always been both thorough and widely focused, which are both time-consuming activities. In the past, the architectural projects were often smaller and the scope was set, which made the projects more comprehendible.

P3, June 2017
In the next months, I plan on making decisions faster and in future projects I plan on consulting (and listening to) others for advice on the width of my scope. Also, focusing on subjects that I already master combined with one new subject might be wiser.

P4, September 2017
In the last months, I have decided to not investigate some parts of the scope of this research or spending less time on them (e.g. quantifying the disassembly potential, studying variants, calculating several packages, calculating initial energy consumption). These were not part of the initial scope of my project, but were added over time. In my opinion, this worked to a certain extend. Fact is that I plan on validating the building design in between P4 and P5, which I would rather have finished before P4 (although it is extra research). Nonetheless, I think validation is possible within the time limit.

THE PROCESS FROM RESEARCH TO DESIGN

This graduation project consists of a literature study, the making of a methodological framework and a design phase. I realise that I am having troubles making the step from research (literature and methodology) to actual designing. I struggle with getting on, because I often have the feeling I do not know enough (yet) to make informed decisions. This causes me to look into the subject more, but also makes is easier to stall a decision. In daily life, I do not struggle with making decisions, but the expected scientific approach of a graduation project somehow makes me even more of a perfectionist.

P3, June 2017
In the next months and in future projects I think I could best alternate between research and designing as often as possible, to avoid having longer periods of one of both. Also, I think I work best in a team. To me, being able to have short discussions with a team member and complementing each other's knowledge sounds ideal.

P4, September 2017
In the last months, I have often switched between documenting, designing and research (material and climate). This helped for making decisions, but slightly made me loose the thread of my project. In the last weeks, I got back this focus back and got an overview of what still has to be done.

OVERALL THOUGHTS

The progress of this research might have been too slow, but I am very satisfied with the result. I am grateful that it was possible to extend the graduation by a quarter, as my concentration was not optimal due to personal circumstances in the first months. Overall, I am very content with my graduation project. The enthusiasm about this field of study has only grown and I would like to use my knowledge in other projects.

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14. APPENDIX

14.1. APPENDIX: CAMPUS BUILDINGS

Provided by FMRE

Overzicht uitgegeven Gebouwnummers Vastgoed

gb nr	vl nr	adres	meest gangbare naam	vl naam	Bouwjaar	PC	jaar opl	opmerkingen
1		geen eigendom meer	voorheen Kanaalweg 2b		1902			gebouwd als Lab. voor Toegepaste Natuurkunde en Electrotechniek
2								Nummer in gebruik voor bewegwijzering gebouw 102
		geen eigendom meer	voorheen Mijnbouwplein 11		1930			gebouwd als Geb. voor Technische Fysica
3		Mijnbouwstraat 120	Science Centre Delft			2628 RX	1912	reno 1961 en 2008; gebouwd als Geb. voor Mijnbouwkunde
	3.1	gesloopt	Science Centre Delft		1966			
	3.2	gesloopt	Science Centre Delft		1912			
	3.3	Mijnbouwstraat 120	Science Centre Delft	Trafostation				
4		Julianalaan 65	Woning Julianalaan 65			2628 BC		
5		Julianalaan 67	TNW - Kluyverlab. voor Biotechnologie			2628 BC		gebouwd als Geb. voor Technische Botanie
	5.1	Julianalaan 67	TNW - Kluyverlab. Voor Biotechnologie		1919-1958			aanb.1988
	5.2	Julianalaan 67	Botanische tuin					
	5.3	gesloopt	voorheen tuinhuis					
6		Poortlandplein 6	TNW - Poortlandplein 6			2628 BM		
7		geen eigendom meer	voorheen de Vries v Heijstplantsoen 2				1923	Voorheen Geb. voor Analytische (en Anorganische) Chemie (GAAC)
8		Julianalaan 132-134	Bouwkunde			2628 BL		Voorheen Hoofdgebouw
	8.1	Julianalaan 132-134	Bouwkunde	vleugel Midden			1945	Voorheen Hoofdgebouw
	8.2	Julianalaan 132-134	Bouwkunde	vleugel Oost			1945	Voorheen Hoofdgebouw
	8.3	Julianalaan 132-134	Bouwkunde	vleugel West			1945	Voorheen Hoofdgebouw
	8.4	Julianalaan 132-134	Bouwkunde	vleugel Zuid			1945	Voorheen Hoofdgebouw
9		Zuidplantsoen 2	voorheen Multi Media Services				1945	reno 2008-2009 (voor BK-city)
10		Zuidplantsoen 6	voorheen Tempel				1945	reno 1990 en 2008-2009 (voor BK-city)
11		gesloopt	voorheen TU Delft Vastgoed				1958	Gesloopt 2006
12		Julianalaan 136	TNW - Delft Chem Tech			2628 BL	1945	autoclavenlab 1988
13		Julianalaan 138	Woning Julianalaan 138			2628 BL	1938	
14		Julianalaan 140	Woning Julianalaan 140			2628 BL	1938	
15		Prins Bernhardlaan 6	TNW - Fysische en Chemische technologie			2628 BW	1950	
	15.1	Prins Bernhardlaan 6	TNW - Fysische en Chemische technologie fabr. 1	Fysische technologie				
	15.2	Prins Bernhardlaan 6	TNW - Fysische en Chemische technologie fabr. 2	Chemische Technologie			1950	
16								Nummer in gebruik voor bewegwijzering gebouw 116
17		gesloopt	voorheen IWEB			2628 CR	2006	voorheen paviljoen Floriade 2002
18								Nummer in gebruik voor bewegwijzering gebouw 97 en 104
19		Mekelweg 3	STUD			2628 CC	1980	
20		Mekelweg 5	Aula Congrescentrum			2628 CC	1966	
21		Prometheusplein 1	TU Delft Library			2628 ZC	1997	
22		Lorentzweg 1	TNW - Technische Natuurkunde			2628 GJ	1963	
	22.0	Lorentzweg 1	TNW - Technische Natuurkunde	vleugel F1 + F2 + F3 + F4	1963			
	22.1	Lorentzweg 1	TNW - Technische Natuurkunde	vleugel A1 + A2	1963			
	22.2	Lorentzweg 1	TNW - Technische Natuurkunde	vleugel B1 + B2	1963			
	22.3	Lorentzweg 1	TNW - Technische Natuurkunde	vleugel C1 + C2	1963			
	22.4	Lorentzweg 1	TNW - Technische Natuurkunde	vleugel D1 + D2	1963			
	22.5	Lorentzweg 1	TNW - Technische Natuurkunde	vleugel E1 + E2	1973			
	22.6	is nu gebouw 97.6	TNO Stieltjesweg	vleugel E3				
	22.7	is nu gebouw 97.7	TNO Stieltjesweg	vleugel N	1998			Gebouwd voor Technisch Physische dienst (TPD) van TNO
	22.8	Lorentzweg 1	TNW - Technische Natuurkunde	vleugel H	1963			Heliumhuisje
	22.9	Lorentzweg 1	TNW - Technische Natuurkunde	vleugel K	2003			voorheen TNO I&T Lithografie
23		Stevinweg 1	Civiele Techniek en Geowetenschappen			2628 CN	1973	
	23.0	Stevinweg 1	CiTG - Hoofdgebouw	Hoofdgebouw				
	23.1	Stevinweg 4	CiTG - Stevin 1	Stevin 1			1956	
	23.2	Stevinweg 3	CiTG - Stevin 2	Stevin 2			1969	
	23.3	Pieter Calandweg 3	CiTG - Stevin 3	Stevin 3			1970	
	23.4	is nu gebouw 96	voorheen CiTG - Stevin 4					
	23.5	NC. Kistweg 4	CiTG - Logistieke strook	Logistieke strook			2006	<- opdrachten nieuwbouw zijn vlgs archief van mei 2006?
	23.6	Stevinweg 1	CiTG - Kopgebouw	Kopgebouw				reno 2007
24		gesloopt na brand 2008	voorheen Bouwkunde Berlageweg 1				1970	13 mei 2008 door brand verwoest; vervolgens gesloopt
	24.0	gesloopt na brand 2008	voorheen Bouwkunde Berlageweg 1	Vleugel 0	1970			
25		Van der Broekweg	Terrein Green Village					gesloopt voorheen Gas - Watermeter station
	25.1	Van der Broekweg	Laagspanningsruimte Green Village					
26		Van den Burghweg 1	Gebouw Van den Burghweg 1		1-2-1984			Voorheen Rijkswegenlab.
	26.1	Van den Burghweg 1	Gebouw Van den Burghweg 1	vleugel A				
	26.2	Van den Burghweg 1	Gebouw Van den Burghweg 1	vleugel B				
	26.3	Van den Burghweg 1	Gebouw Van den Burghweg 1	vleugel C				
	26.4	Van den Burghweg 1	Gebouw Van den Burghweg 1	vleugel D				
27								
28		Van Mourik Broekmanweg 6	TNO Van Mourik Broekmanweg 6			2628 XE	2002	
29								
30		Jaffalaan 9	Gebouw Jaffalaan 9-9a / Landbergstraat 8			2628 BX	1966	reno 1989
	30.1	Jaffalaan 9a	Onderwijs & Studentenzaken	vleugel A	1966			reno 2006
	30.2	Jaffalaan 9	IKC	vleugel B	1966			reno 2005 / reno 2015
	30.3	Jaffalaan 9 / Landbergstraat 8	IKC/FMVG	vleugel C	1966			reno 2005 / reno 2015
	30.4	gesloopt	voorheen fietsenberging	Landbergstraat				
31		Jaffalaan 5	Techniek Bestuur en Management			2628 BX		
	31.1	Jaffalaan 5	Techniek Bestuur en Management	vleugel A1	1992			
	31.2	Jaffalaan 5	Techniek Bestuur en Management	vleugel A2	1992			in 1998 verbouwd tot nieuwe entree en collegezaal
	31.3	Jaffalaan 5	Techniek Bestuur en Management	vleugel B	1998			
	31.4	Jaffalaan 5	Techniek Bestuur en Management	vleugel C	1998			
	31.5	Jaffalaan 5	Techniek Bestuur en Management	vleugel D	1998			
32		Complex Landbergstraat 15	Industrieel Ontwerpen			2628 CE		bd 10 (OUD)
	32.1	Landbergstraat 15	Industrieel Ontwerpen	vleugel A	1972			reno 2001-2002(?)
	32.2	Landbergstraat 15	Industrieel Ontwerpen	vleugel B	1972			reno 2001-2002(?)
	32.3	Landbergstraat 15	Industrieel Ontwerpen	vleugel C	1972			2005 verbouwd, grotendeels t.b.v. (composieten lab van) INHOLLAND
	32.4	Landbergstraat 15	Industrieel Ontwerpen	vleugel D	1972			reno 2001-2002(?)
	32.5	Landbergstraat 19	Industrieel Ontwerpen / Datacenter IO / InHolland	vleugel E	1955			voorheen bouwdeel 9; gesloopt (2008?)
33	33.1	Landbergstraat og	Pulse	vleugel A				
	33.2	Landbergstraat og	Coffee & Bikes	vleugel B				
34		Mekelweg 2	3mE			2628 CD		bd 6 (OUD)
	34.1	Mekelweg 2	3mE	vleugel A	1955			reno 2001-2002(?) voorheen vleugel 0 / BD6
	34.2	Mekelweg 2	3mE	vleugel B	1956			reno 2001-2002(?) voorheen vleugel 2 / BD8B
	34.3	Mekelweg 2	3mE	vleugel C	1956			reno 2001-2002(?) voorheen vleugel 1 / BD8A
	34.4	Mekelweg 2	3mE	vleugel D	1955			reno 2001-2002(?) voorheen vleugel 5 / BD7
	34.5	Mekelweg 2	3mE	vleugel E	1956			reno 2001-2002(?) voorheen vleugel 3 / BD8C
	34.6	Mekelweg 2	3mE	vleugel F	1974			reno 2001-2002(?) voorheen vleugel 6 / BD5
	34.7	Mekelweg 2	3mE	vleugel G	1957			reno 2001-2002(?) voorheen vleugel 7 / BD4
	34.8	Mekelweg 2	3mE	vleugel H	1956			reno 2001-2002(?) voorheen vleugel 4 / BD8D
	34.9	Mekelweg 2	3mE	vleugel J	1960			reno 2001-2002(?) voorheen vleugel 8 / BD3
	34.10	Leeghwaterstraat 39	MSP	vleugel K	2008			
	34.11	Mekelweg 2	3mE	vleugel L	1955		aanb 1990	reno 2001-2002(?) voorheen vleugel 9 / BD2
35		Corn. Drebbelweg 5	Gebouw Cornelis Drebbelweg 5			2628 CM	1955	reno 1986 en (vermoed. 2006 t.b.v. tentamen- en practicumgebouw)
	35.0	Corn. Drebbelweg 5	Gebouw Cornelis Drebbelweg 5					
36		Mekelweg 4	EWI			2628 CD		
	36.1	Mekelweg 4	EWI	hoogbouw + collegezalen			1969	
	36.2	Mekelweg 4	EWI	lage voorbouw			1966	
	36.3	Mekelweg 4	EWI	hallen			1966	reno 2005
	36.4	Mekelweg 4	EWI	ESP lab			1972	
	36.5	Feldmanweg 17	EKL	EKL			1989	Voorheen DIMES
37		Mekelweg 8	Sport			2628 CD	1959-1996	
38		Mekelweg 10	Cultuur			2628 CD	1995	
39								
40		gesloopt	voorheen Technische Materiaalwetensch.				1961	Gesloopt 2007; gebouwd als geb voor Metaalkunde
	40.1	gesloopt	voorheen Technische Materiaalwetensch.	hallen	1957			
	40.2	gesloopt	voorheen Technische Materiaalwetensch.	voorbouw	1961			
41		gesloopt	voorheen Rotterdamseweg 139 DTO				1958	Gesloopt; gebouwd voor TNO Metaalinstituut
42		gesloopt	voorheen Rotterdamseweg 139a ROB				1955	Gesloopt 2006 - 2007; gebouwd als lab voor Warmte- en stoftechniek
43		Leeghwaterstraat 36	Warmte Krachtcentrale			2628 CA	1955	uitbr 1964-1967
	43.1	Leeghwaterstraat 36	Warmte Krachtcentrale		1955			uitbr 1964-1967
	43.2	Leeghwaterstraat	Gasreduceerstation LD / Waterkamer/In holland		?			
44		Rotterdamseweg 145	Gebouw Rotterdamseweg 145			2628 AL	1961	voorheen YES! Delft; gebouwd als lab voor Aero- en hydrodynamica
45		Leeghwaterstraat 42	L&R Lage Snelheden Lab / VSSD			2628 CA	1952	kantooraanbouwen eind jaren 70
46		Leeghwaterstraat 44-44a	TNO Leeghwaterstraat 44 / Hal Leeghwaterstraat 44a			2628 CA	1977	aanbouw 2005
	46.1	Leeghwaterstraat 44	TNO Leeghwaterstraat 44					voorheen kantoor P&E
	46.2	Leeghwaterstraat 44a	Hal Leeghwaterstraat 44a					voorheen hal P&E
47		gesloopt	voorheen woning Cornelis Drebbelweg 3a					Gesloopt 2012
48		geen eigendom meer	voorheen Vijzelgemaal Oudelaanmolensloot				1967	
49								Nummer in gebruik voor bewegwijzering gebouw 92
50		Mekelweg 15	TNW - Reactor Instituut Delft			2629 JB	1963	
	50.0	Mekelweg 15	TNW - Reactor Instituut Delft	vleugel 0				

	50.1	Mekelweg 15	TNW - Reactor Instituut Delft	vleugel 1	2003			
	50.2	Mekelweg 15	TNW - Reactor Instituut Delft	vleugel 2	2003			
	50.3	Mekelweg 15	TNW - Reactor Instituut Delft	vleugel 3	1963			
	50.4	Mekelweg 15	TNW - Reactor Instituut Delft	vleugel 4	1963			
	50.5	Mekelweg 15	TNW - Reactor Instituut Delft	vleugel 5	1998			
	50.6	Mekelweg 15	TNW - Reactor Instituut Delft	vleugel 6	div			
51		gesloopt	voorheen Windenergiegebouw				1987	Gesloopt (2008?)
52		geen eigendom meer	voorheen Geodesie, nu VLS				1975	Vermoed. 2003 verkocht aan NMi
	52.1	geen eigendom meer	voorheen Geodesie, nu VLS	hoogbouw	1975			
	52.2	geen eigendom meer	voorheen Geodesie, nu VLS	laagbouw	1975			
53		Watermanweg 6	Woning Watermanweg 6			2629 HR	1963	
54		gesloopt	voorheen Woning Watermanweg 8			2629 HR	1963	
55		Watermanweg 4	Trafostation 2e 10 kV station			2629 HR	1963	
56		Watermanweg 2	Rioolgemaal RID			2629 HR	1970	
57		Watermanweg	Datacenter RID			2629 HR	2007	
58		Van der Maasweg 9	TNW Zuid (DCT, BT en BioNano)					TNW Zuid (DCT & Biotechnologie)
59								
60		Anthony Fokkerweg 5	Logisitiek & Milieu			2629 HC	1983	
61		Kluyverweg 3	L&R - Vliegtuighal			2629HS	1965	reno 2008
62		Kluyverweg 1	L&R - Hoofdgebouw			2629HS	1965	
	62.0	Kluyverweg 1	L&R - Hoogbouw	vleugel HB/TB		2629HS		
	62.1	Kluyverweg 1	L&R - Laagbouw	vleugel NB	2003	2629HS		
63		Anthony Fokkerweg 1	L&R - Simona				1995	
	63.0	Anthony Fokkerweg 1	L&R - Simona	gebouw	1995			
	63.1	Anthony Fokkerweg 1	L&R - Simona aggregaat	hydraulic unit	1998			
64		Kluyverweg 2	L&R - Hoge Snelheden Lab			2629 HD	1969	uitbreiding meethal 2008
65		gesloopt	Gebouw Kluyverweg 4-6			2629 HD	1985	
	65.1	gesloopt	voorheen gebouw Kluyverweg 4	vleugel A			1985	Gesloopt 2013
	65.2	gesloopt	voorheen gebouw Kluyverweg 6	vleugel B			1985	Gesloopt 2015
	65.3	gesloopt	voorheen gebouw Kluyverweg 6	vleugel C			1985	Gesloopt 2015
	65.4	gesloopt	voorheen gebouw Kluyverweg 6	vleugel D			1985	Gesloopt 2015
	65.5	in opslag	voorheen gebouw Kluyverweg 6				2009	Meetpracticum CiTG
66		Kluyverweg 5	The Fellowship			2629 HS	2009	
67		gesloopt in 2012	voorheen Botenloods Proteus					(gesloopt 2012)
68		Rotterdamseweg 191	Manege Prometheus					(geen eigendom TU)
69		geen eigendom meer	voorheen Gasreduceerstation					Michiel de Ruyterweg
70		Van der Maasweg 11	Parkeergebouw TNW Zuid				2015	
71								
72								
73								
74								
75								
76		Rotterdamseweg 155	Woning Hammenboerderij		herbouwd 1927	2628 AL		kelder en toegangspoort uit 1608; stal 19e eeuws
77								
78								
79		Heertjeslaan 9	Nutsgebouw Technopolis				2015	
80		Julianalaan 67	Trafostation Botanische tuin			2628 BC	1960	
81		Michiel de Ruyterweg	Trafostation B DCT			2628 BA		
82		Julianalaan 136	Trafostation C DCT			2628 BL		
83		is nu gebouw 12	voorheen trafostation DCT			2628 BL		
84		Anthony Fokkerweg	L&R trafostation 1 en NSA			2629 HS		
	84.0	Anthony Fokkerweg	L&R trafostation 1					
	84.1	Anthony Fokkerweg	Noodstroomaggregaat					
85		Kluyverweg	Gasreduceerstation LD					
86		Kluyverweg	L&R trafostation 2 / Nissenhut			2629 HT		
	86.0		L&R trafostation 2					
	86.1		Nissenhut groendienst					
87		Leeghwaterstraat	Gasreduceerstation HD				1957	
88		gesloopt	voorheen Trafostation Materiaalwetenschappen					
89		Leeghwaterstraat 44	Trafostation gebouw Leeghwaterstraat 44			2628 CA		
90		Landbergstraat	Trafostation 1e 10 kV station					
91		Van der Waalsweg	Trafostation TU Delft Library			2628 CH		
92		Leeghwaterstraat 46	TNO Leeghwaterstraat 46			2628 CA		
93		gesloopt	voorheen Satelietwaarnemingstation Kootwijk					L&R Kootwijk zendmast (station gesloopt winter 2005-2006; trafo/weg 2009)
94			L&R Westerbork					gehuurd door TU
95		geen eigendom TU	voorheen Techniek Museum			2611 RV	1911	Ezelveldlaan 61
96		Keverling Buismanweg 5	voorheen CiTG - Stevin 4				1970	
97		Stieltjesweg 1	TNO Stieltjesweg 1			2628 CK		
	97.6	Stieltjesweg 1	TNO Stieltjesweg 1	vleugel E3	1973			
	97.7	Stieltjesweg 1	TNO Stieltjesweg 1	vleugel N	1998			
	97.9	gesloopt	voorheen meethal TNO Stieltjesweg		1963			
98		geen eigendom TU	voorheen Zusterhuis Bethel					Reinier de Graafweg 3
99		gesloopt	voorheen Composteerinrichting					Rond 2008 gesloopt
100								
101		Mekelweg 1	voorheen Postkantoor; nu Döner Company				1980	(geen eigendom TU)
102		Korte Geer 1	voorheen Legermuseum			2611 CA		(geen eigendom TU)
103		Van der Waalsweg	Voorheen TNO I&T Lithografie					Verkocht aan TU (is TNW 22-09 geworden)
104		Van der Waalsweg 16	TNO Van der Waalsweg 16					(geen eigendom TU; voor nieuwbouw is TU Meethal (1963) gesloopt)
105		Keverling Buismanweg 8	TNO Keverling Buismanweg - CMC - Hal / Schokbank					Centrum Mechanische en Maritieme Constructie
106								
107								
108								
109								
110		gesloopt	voorheen Shell Expres station					Cornelis Drebbelweg 11; gesloopt (2008?)
111								
112								
113								
114								
115								
116		deels gesloopt / nieuwbouw	Deltares Stieltjesweg 2		1955?			(geen eigendom TU)
117								
118								
119								
120								
121								
122								
123								
124								
125								
126								Voorheen Rijkswegenlab. NU GEBOUW 26
127								
128								
129								
130								
131								
132								
133								
134								
135								
136								
137								
138								
139								
140		Rotterdamseweg 137	Haagse Hogeschool					(geen eigendom TU)
141		Rotterdamseweg 139	DUWO					(geen eigendom TU)
142		Rotterdamseweg 141	InHolland					(geen eigendom TU)
143								
144								
145								
146								
147								
148		Balthasar v.d. Polweg	Vijzelgemaal Oudelaanmolensloot				1967	(geen eigendom TU)
149								
150		gereserveerd	Technopolis Fase 3, kavel 16					
151		gereserveerd	Technopolis Fase 3, kavel 25					
152		Thijssenweg 11	VLS				1975	(geen eigendom TU)
153		gereserveerd	PTC Holland					

154		gereserveerd	Technopolis Fase 4, kavel 12					
155		gereserveerd	Technopolis Fase 3, kavel 15					
156		gereserveerd	Technopolis Fase 3, kavel 17					
157		gereserveerd	Technopolis Fase 3, kavel 24					
158		gereserveerd	Technopolis Fase 3, kavel 14					
159		gereserveerd	Technopolis Fase 3, kavel 21					
160		gereserveerd	Technopolis Fase 1, cluster 1					
161		Molengraaffsingel 10	Yes! Delft Labs					(eigendom TU)
162		gereserveerd	Technopolis Fase 1, cluster 2					
163		gereserveerd	Technopolis Fase 1, cluster 2					
164		gereserveerd	Technopolis Fase 1, cluster 2					
165		gereserveerd	Technopolis Fase 1, cluster 2					
166		gereserveerd	Technopolis Fase 1, cluster 3					
167		gereserveerd	Technopolis Fase 1, cluster 3					
168		gereserveerd	Technopolis Fase 1, cluster 3					
169		gereserveerd	Technopolis Fase 1, cluster 3					
170		gereserveerd	Technopolis Fase 2, cluster 4					
171		gereserveerd	Technopolis Fase 2, cluster 4					
172		gereserveerd	Technopolis Fase 2, cluster 4					
173		gereserveerd	Technopolis Fase 2, cluster 4					
174		gereserveerd	Technopolis Fase 2, cluster 5					
175		gereserveerd	Technopolis Fase 2, cluster 5					
176		gereserveerd	Technopolis Fase 2, cluster 5					
177		gereserveerd	Technopolis Fase 2, cluster 5					
178		gereserveerd	Technopolis Fase 2, kavel 23					
179		gereserveerd	Technopolis Fase 2, kavel 23					
180		geresreveerd	Technopolis Fase 1					voorheen gebouw Rotterdamseweg 380
181		Molengraaffsingel 12-14	Yes! Delft		2009-2010	2629 JD	2010	(eigendom TU)
182		gereserveerd	Technopolis Fase 1, kavel 2					
183		gereserveerd	Technopolis Fase 1, kavel 5					
184		Molengraaffsingel 29	3M Hoofdkantoor					(geen eigendom TU)
185		gereserveerd	Technopolis Fase 1, kavel 8					
186		Molengraaffsingel 33	Exact		2009-2010	2629 JD	2010	(geen eigendom TU)
187		gereserveerd	Technopolis Fase 2, kavel 20					
188		gereserveerd	Technopolis Fase 2, kavel 20					
189		geresreveerd	Technopolis Fase 2					
190		gereserveerd	Technopolis Fase 1, kavel 11A					
191		gereserveerd	Technopolis Fase 1, kavel 11C					
192		gereserveerd	Technopolis Fase 1, kavel 11B					
193		Heertjeslaan 2	Applikon Biotechnology B.V		2012			
194		gereserveerd	Technopolis Fase 1, kavel 10					
195		gereserveerd	Technopolis Fase 1, kavel 10					
196		Heertjeslaan 1	Datacenter Group Delft Property BV		2012			(geen eigendom TU)
197		Rotterdamseweg 183	Radex					(geen eigendom TU)
198		gereserveerd	Technopolis Fase 1, kavel 9					
199		Rotterdamseweg 185	Deltares Rotterdamseweg					(geen eigendom TU)
200		Balthasar v.d. Polweg	wooncomplex Balthasar v.d. Polweg					(geen eigendom TU)
201		Krakeelhof	wooncomplex Krakeelhof					(geen eigendom TU)
202		Korvezeestraat	wooncomplex Korvezeestraat					(geen eigendom TU)
203		Voorhof 1	wooncomplex Voorhof 1					(geen eigendom TU)
204		Voorhof 2	wooncomplex Voorhof 2					(geen eigendom TU)
205		Buitenhof	wooncomplex Buitenhof					(geen eigendom TU)
206		Westplantsoen	wooncomplex Belastingkantoor					(geen eigendom TU)
207		Troelstralaan	wooncomplex Troelstraflat					(geen eigendom TU)
208		Oudraadtweg	wooncomplex Oudraadtweg					(geen eigendom TU)
209		Bagijnhof	wooncomplex Bagijnhof					(geen eigendom TU)
210		Mina Krusemanstraat	wooncomplex Mina Krusemanstraat					(geen eigendom TU)
211		Oost Indieplaats	wooncomplex Oost Indieplaats					(geen eigendom TU)
212		Zusterlaan	wooncomplex Sebastiaansbrug					(geen eigendom TU)
213		Leeghwaterstraat	wooncomplex Container					(geen eigendom TU)
214		Leeghwaterstraat	wooncomplex Leeghwaterstraat					(geen eigendom TU)
215		Balthasar v.d. Polweg	wooncomplex Balthasar v.d. Polweg					(geen eigendom TU)
216		Balthasar v.d. Polweg	nieuwbouw wooncomplex Balthasar v.d. Polweg					(geen eigendom TU)
217								
218								
219								
220		Watermanweg 10	Trafostation 23 kV Watermanweg					(geen eigendom TU)
221		Kanaalweg 2a, 2b en 2c	Gebouw Kanaalweg 2a, 2b en 2c					(geen eigendom TU)
222		Mijnbouwplein 11	Gebouw Mijnbouwplein 11					(geen eigendom TU)
223								
224								
225								
226								
227		deels gesloopt / nieuwbouw	Gebouw De Vries van Heystplantsoen 2					(geen eigendom TU)
228								
229		gesloopt / nieuwbouw	voorheen Dish Hotel Delft Kanaalweg 3					(geen eigendom TU)
230		Kanaalweg 4	Gebouw Kanaalweg 4					(geen eigendom TU)
231								
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249								
250		Apothekersweg	wooncomplex Apothekersweg					(geen eigendom TU)
251			wooncomplex Renswoudehuis					(geen eigendom TU)
252		Ricardishof	wooncomplex Ricardishof					(geen eigendom TU)
253		gesloopt	voorheen wooncomplex Gimmie Shelter					(geen eigendom TU)
254								
255								
256								

Building name	Criteria 1. Gross Floor Area 2.500-25.000 m2 GFA in m2	2. Energy Consumption Primary Energy in 2016 (KWh/m2)	Heating (KWh/m2)	*Heating as % of Primary Energy*	3. Recent developments Executed (since 2010)	Plans (until 2025)	4. Is in need of renovation between 2017-2025 year+ 25 years	5. Can sufficient information be found on	6. In use by TU Delft Usage	Outcome Qualify for all criteria
3. Science Centre Delft	12996	167	96	*58%*	Partially renovated		Maybe			
5. TNW - Kluyverlab. voor Biotechnologie	13460	529	209	*40%*		Dispose of property	Yes			
6. TNW - Poortlandplein 6	365	no data	no data	*no data*			no data			
8. Bouwkunde	46421	168	61	*36%*	Renovated					
12. TNW - Delft Chem Tech	22650	645	457	*71%*		Dispose of property	Yes			
13. Woning Julianalaan 138	100	no data	no data	*no data*			no data	Not enough		
14. Woning Julianalaan 140	100	no data	no data	*no data*			no data	Not enough		
15. TNW - Fysische en Chemische technologie	4958	no data	no data	*no data*		Dispose of property	Yes			
19. STUD	222	no data	no data	*no data*		Renovation	no data		No	
20. Aula Congrescentrum	13987	355	141	*40%*			Yes			20. Aula Congrescentrum
21. TU Delft Library	15158	374	158	*42%*			Yes			21. TU Delft Library
22. TNW - Technische Natuurkunde	53083	232	119	*51%*		Demolition	Yes			
23. Civiele Techniek en Geowetenschappen	67779	369	156	*42%*		Demolition	Yes			
25. Terrein Green Village	11800	no data	no data	*no data*	New	New		Not enough		
26. Gebouw Van den Burghweg 1	13183	no data	no data	*no data*	Partially renovated		no data	Not enough		
28. TNO Van Mourik Broekmanweg 6	10827	no data	no data	*no data*		Renovation	no data			
30. Gebouw Jaffalaan 9-9a / Landbergstraat 8	9377	205	62	*30%*						
31. Techniek Bestuur en Management	13293	233	106	*45%*			Yes			
32. Industrieel Ontwerpen	35046	202	74	*37%*			Yes			
33. Pulse	4700	no data	no data	*no data*		New		Not enough		
34. 3mE	46122	291	150	*51%*						
35. Gebouw Cornelis Drebbelweg 5	5547	154	106	*69%*	Partially renovated					
36. EWI	67220	245	116	*47%*		Demolition	Yes			
37. Sport	7130	470	134	*29%*		Renovation	Yes			
38. Cultuur	3564	199	94	*47%*			no data			
43. Warmte Krachtcentrale	3486	no data	no data	*no data*			Yes			43. Warmte Krachtcentrale
45. L&R Lage Snelheden Lab / VSSD	3458	288	155	*54%*			Yes			45. L&R Lage Snelheden Lab / VSSD
46. TNO Leeghwaterstraat 44	5675	254	169	*67%*			Yes		No	
50. TNW - Reactor Instituut Delft	15500	673	186	*28%*						
53. Woning Watermanweg 6	100	no data	no data	*no data*			no data	Not enough		
55. Trafostation 2e 10 kV station	100	no data	no data	*no data*			no data			
56. Rioolgemaal RID	100	no data	no data	*no data*			no data			
57. Datacenter RID	706	no data	no data	*no data*	New		no data			
58. TNW Zuid	30000	no data	no data	*no data*	New					
60. Logisitiek & Milieu	2763	398	240	*60%*			no data			60. Logisitiek & Milieu
61. L&R - Vliegtuighal	5077	957	225	*23%*			no data			61. L&R - Vliegtuighal
62. L&R - Hoofdgebouw	20972	164	92	*56%*			Yes			
63. L&R - Simona	941	220	0	*0%*			no data			
64. L&R - Hoge Snelheden Lab	2962	514	193	*37%*			no data			64. L&R - Hoge Snelheden Lab
66. The Fellowship	6000	236	97	*41%*	Partially renovated					
70. Parkeergebouw TNW Zuid	8400	no data	no data	*no data*	New		no data			
76. Woning Hammenboerderij	0	no data	no data	*no data*				Not enough	No	
79. Nutsgebouw Technopolis	100	no data	no data	*no data*			no data			
80. Trafostation Botanische tuin	100	no data	no data	*no data*			no data	Not enough		
87. Gasreduceerstation HD	100	no data	no data	*no data*			no data	Not enough		
89. Trafostation gebouw Leeghwaterstraat 44	100	no data	no data	*no data*			no data	Not enough		
97. TNO Stieltjesweg 1	0	no data	no data	*no data*			no data	Not enough	No	
161. Yes! Delft Labs	5528	no data	no data	*no data*	New		no data		No	
181. Yes! Delft	0	no data	no data	*no data*			no data		No	
19[illegible]. Applikon Biotechnology B.V	0	no data	no data	*no data*	New		no data		No	

14.2. APPENDIX: DATASHEETS

Name of building	45. L&R - Low Speed Laboratory/VSSD				
Address	Leeghwaterstraat 42, Delft				
Date of inventory	14-3-2017				
Contacts	**Company**	**Contact person**	**Phone**		
Client	FMRE				
Building user					
Facility Management	FMRE	Thijn Forrer, asset manager	n.a.		
Architect	Multiple	n.a.			
HVAC planner					
Structural engineer					
Fire Protection Engineer					
Facade expert					
Building history	**Year**	**Architect**	**Action / Comment**		
Construction	1952	Ir. A. vd Steur	Rijksgebouwendienst		
Refurbishment 1	1977	Drexhage, Sterkenburg, Bodon & Venstra (DSBV)			
Refurbishment 2					
Refurbishment 3					
General facts			**Comment**	**Photo**	
Form of use (if multiple, relation in %)		research facility, office, educational and laboratory			office / laboratory / retail / storage / residential
Orientation of the main entrance		east			north / west / south / east
Building shape		open city block			high-rise / atrium / ... /
Urban setting		solitaire			solitaire / block / .../
Number of floors above ground		five			
number of floors below ground		zero			
Floor height		2050-4865 mm	yes, different floor heights		Different floor heights?
Building height		18800 mm excl. wind tunnel			
Building dimension		60,19 * 41,28 m			length / width
GFA		3458 m2			above ground / below
NFA		3088 m2			DIN 277
Facade area		≈ 3000 m2	excl. Roof		
Gross volume		≈ 15000 m3			
Persons in the building		40-45 FTE	60-70 in total		
Documentation					
Floor plans	yes	Sections / Elevations	yes		
Facade details	yes	Structural details	yes		
HVAC concept		Energy invoices	no		
Structural expertise	no	Expertise toxic material	no		
Fire expertise	yes	(...)			
Owner interview					
Motivation for refurbishment					
Qualities of the building					
Users' complaints					
Desires for the refurbished building					
Worries					
Organisational restrictions					
Time restrictions					
Financial frame					
<u>**Building**</u>					
Architectural design			**Comment**	**Photo**	
Monumental protection		no			yes / no
Image / Reputation		lack of reputation			building as an icon / proactive tenants / famous architecture / long rental contracts
Quality of location		good access, quiet street, good amount of green			public transport / car access / green / complaints
Emissions		Construction noise			noise / pollutant
Structure					
Construction principle		massive concrete wind tunnel and skeleton building			massive / skeleton
Structural grid		two main grids, three secondary grids			
Load bearing columns		concrete, varying dimensions			material / dimension
Load bearing walls		concrete, varying dimensions			material / dimension
Floor structure		concrete, varying dimensions			material / dimension
Technical installation			**Comment**	**Photo**	
Heat generation		district heating	from adjacent CHP		gas / oil / district heating / others
Cooling		n.a.			machine / state of maintenance
Heat / Cold distribution		water			water / air
Ventilation		de-central			central / de-central
Heat recovery		n.a.			central / de-central / efficiency / age
Fire safety			**Comment**	**Photo**	
Fire compartments					position / size / flash over barrier
Fire exits					number of staircases / lengths of emergency routes
Evacuation route on balconies					
Structural fire safety					load bearing elements / dividing elements
Facade connections					connection / flash over
Sprinkler					position / technology / state of maintenance

Toxic material	Location	Need for action	Expertise	Photo	
Asbestos					
PCB					
PAK					
PCP					
MMMF					

Operational cost	kWh/a	Euro/a	primary energy factor	Year
Final energy heating	155 kWH/m2			2015
Final energy cooling				
Final energy electricity	136 kWh/m2			2015
Maintenance cost facade				

Zone 1

Description / location	Office wind tunnel research group	2nd floor (1e etage)		
Interior		**Comment**	**Photo**	
Floor plan layout	open plan office and one cell			open plan / cells / position of corridor / ... /
Workstations / room	desks at facade, walking path at inner core			
Room size	6,5 * 18 m			depth / width
Room height	4110 mm			between top floor and ceiling
Construction of inner walls	solid concrete and glass cabin walls			material / quality
Top floor	200 mm reinforced concrete	phase 1977		height / material / quality
Accessibility floor				
Suspended ceiling	yes			height / material / quality
Accessibility ceiling				
Artificial lighting		**Comment**	**Photo**	
Type of lamps	pendant luminaire			type / number
Installed capacity				(W/m2)
Size of illumination zone				(m2)
Individual switch	no			yes / no
Presence control	no			yes / no
Electrical installation		**Comment**	**Photo**	
Electrical installation				state / flexibility
IT installation				state / flexibility
Facade 1		**Comment**	**Photo**	
Facade construction principle				according to typology
Facade material				
Facade colour				
Facade grid				
Offset to structural grid				
Dimension of facade columns				
Tasks in the facade				
Type of glass				single / insulated / solar
Year of glass				printed on thermal edge bond
Insulation of opaque parts				material / dimension / quality
U-value / g-value window				
U-value opaque part				
Thermal bridges				
Vapour seals				all sides of facade
Sun protection				form / position / control / quality
Glare protection				form / position / control / quality
Connection to load bearing elements				form / quality / photo
Connection to dividing walls				form / quality / photo
Connection to floor / ceiling				form / quality / photo
HVAC		**Comment**	**Photo**	
Heating device				radiator / induction / floor / ceiling / electro / ... /
Individual control				valve / thermostat / central / ... /
Location of ducts				floor / ceiling / facade / ... /
Cooling device				AC / induction / floor / ceiling / electro / ... /
Means of ventilation				window / exhaust /full
Position of inlet / outlet				
Distribution of air				central / decentralised

14.3. APPENDIX: USER INTERVIEWS

Owner:	**Henk-Jan Siemer, L&R Low Speed**
Location:	**724 m2 GLA. Half of the ground floor and most of the 2nd, 3rd and 4th.**
Date:	**10-04-2017**

1. Motivation for refurbishment

The wind tunnel will be in use for a long time, that can no longer be denied. It makes a lot of money for the TU Delft. Therefore, it is necessary to bring the building to acceptable working standard.

2. Qualities of the building

There is much daylight, the ceilings are high and the wind tunnel is very good.

3. Users' complaints

Too little office space and windows without a view. Also, the climate is bad. The entire building still has single glass, it becomes too hot in summer and the demolition of the adjacent building caused much noise. They are afraid the construction of the new parking garage will lead to excessive noise too. In summer, the building first warms up, which takes about a week, before it becomes and stays very hot inside.

4. Desires for the refurbished building

Extra space to prepare wind tunnel research, more comfortable offices and an extra entrance at the Drebbelweg. They have already presented plans to FMRE for a new entrance, as they think the current one gives a bad impression, but FMRE has not yet agreed on the plans.

5. Worries

They know the building has a large quantity of asbestos, PCB and other hazardous materials.

6. Organisational restrictions

The L&R Low Speed research group is more likely to grow than decrease over the next decades.

7. Time restrictions

This question has not been asked

8. Financial frame

This question has not been asked

9. What is your occupation schedule? (extra question)

The occupation varies, but in general there are 2 full-time technicians, 5 scientists and 6 students. They have their own or a flexible workspace. The wind tunnel research takes place about 50 hours a week, all year round.

10. Is your location flexible within the campus of TU Delft? (extra question)

No, because the wind tunnel is necessary for our research.

11. Is the renting price acceptable? (extra question)

No, they think they pay too much for an outdated and uncomfortable building. However, they cannot move. A few years ago, L&R Low Speed also occupied the first floor, but because of financial reasons they left.

Reasons to reconsider an existing building			
Building immanent factors	Urban design	Desired improvement of the urban quality	
		Prevent vacancy as a cause for social problems in a neighbourhood	
	Architectural design	Outdated appearance	X
		Exterior impression bad for social problems in a neighbourhood	
		Decay of valuable architectural heritage	X
	Function	Transformation of the building	
		Change / optimising of office concept	
	User comfort	Unpleasant indoor conditions – users' complaints	
		Hygienic problems	
		Sick building syndrome (SBS)	
		Building related illness (BRI)	
	Technical installations	High operational energy demand	X
	Hazardous material	Asbestos	X
		PCB	X
		PAK	X
		MMMF	X
	Building physics	Lack of insulation	X
		Wind leaks – draft	
		Water leaks	X
		Fire protection deficiencies	
		Planning for climate change	
	Building owner/user	Tenant considers relocation	
		Owner user initiates renovation	X
Legal reasons	Fire regulation	Compulsory fire safety improvements	
	Safety	Danger of damage to third party	
	Energy consumption	Compulsory energy consumption certificate (energy passport) for resale or rental contracts	
Economic reasons	Operational cost	High energy demand	X
		High maintenance cost	
	Lettability	Bring an empty building back to the market	
		Tenant considers relocation	
	Marketing	Users' representation need	X
	Financial market	Institutional investors are bound to invest	

User:	**Thijn Forrer, Asset manager FMRE**
Location:	**-**
Date:	**13-04-2017**

1. Motivation for refurbishment

No, at the moment there is no motivation for full renovation. At the moment, there are plans for painting the facades and replacing the roof finishing. Until 2026 FMRE wants to maintain the building and what will happen then has not yet been decided.

2. Qualities of the building

It is a functional building. The wind tunnel performs well and is booked 1,5 years in advance.

3. Users' complaints

Acoustic problems with regard to the wind tunnel and autoclave of Inholland. An acoustic report has been made for VSSD. Overheating in summer at the second floor.

4. Desires for the refurbished building

Users of the building have asked for a bicycle and container storage. Also, Inholland and L&R would like a representative entrance at the backside of the building.

5. Worries

This question has not been asked

6. Organisational restrictions

This question has not been asked

7. Time restrictions

This question has not been asked

8. Financial frame

This question has not been asked

9. Is the amount and type of users going to change in the next years? (extra question)

Yes, it is probably going to change. Over the years many users have occupied the building. For instance, there was a print shop at the ground floor. Also, the first floor has been unused for a few years, before Inholland moved here last year. And there are some organisations that can move anywhere on campus. The L&R research group is located here because of the wind tunnel and Inholland because it is close to the main building of Inholland.

Reasons to reconsider an existing building			
Building immanent factors	Urban design	Desired improvement of the urban quality	
		Prevent vacancy as a cause for social problems in a neighbourhood	
	Architectural design	Outdated appearance	
		Exterior impression bad for social problems in a neighbourhood	
		Decay of valuable architectural heritage	
	Function	Transformation of the building	
		Change / optimising of office concept	
	User comfort	Unpleasant indoor conditions – users' complaints	
		Hygienic problems	
		Sick building syndrome (SBS)	
		Building related illness (BRI)	
	Technical installations	High operational energy demand	
	Hazardous material	Asbestos	
		PCB	
		PAK	
		MMMF	
	Building physics	Lack of insulation	
		Wind leaks – draft	
		Water leaks	
		Fire protection deficiencies	
		Planning for climate change	
	Building owner/user	Tenant considers relocation	
		Owner user initiates renovation	
Legal reasons	Fire regulation	Compulsory fire safety improvements	
	Safety	Danger of damage to third party	
	Energy consumption	Compulsory energy consumption certificate (energy passport) for resale or rental contracts	
Economic reasons	Operational cost	High energy demand	
		High maintenance cost	
	Lettability	Bring an empty building back to the market	
		Tenant considers relocation	
	Marketing	Users' representation need	X
	Financial market	Institutional investors are bound to invest	

User:	**Jorik van Koppen, OWee Bestuur 2015-2016**
Location:	**91 m2 GLA. Room on the ground floor and a shared meeting room on the 1st floor.**
Date:	**18-04-2017**

1. Motivation for refurbishment

The OWee Bestuur thinks a renovation is not necessary. They have been using this building for a few years now and are quite satisfied with the room and location.

2. Qualities of the building

The room the board occupies is located at the ground floor, on the north side. It is large enough and stays cool all year round.

3. Users' complaints

The building is outdated, but that is not important for the OWee Bestuur. Complaints are: There is no women's toilet on the ground floor, large deliveries are hard to receive, the meeting room is often occupied because it is shared with the other student organisations and the board doesn't have a storage room in the building (there is one in building 35. Drebbelweg).

4. Desires for the refurbished building

An extra toilet, an easier entrance for deliveries, a private meeting room and a storage room in the building.

5. Worries

No.

6. Organisational restrictions

This question has not been asked

7. Time restrictions

This question has not been asked

8. Financial frame

This question has not been asked

9. What is your occupation schedule? (extra question)

The OWee Bestuur, consisting of 8 people, uses the room fulltime from February until August. And one of them is there part-time the rest of the year. They have 24/7 access to their room and make use of that. The OWee Bestuur is usually there from 9 a.m. to 5 p.m., but in summer this becomes 9 a.m. to 10 p.m.

10. Is your location flexible within the campus of TU Delft? (extra question)

Yes, the location is flexible. A few years ago, the board was located in building 36. EWI. And rumours go they might move to 03. Science Center.

11. Is the renting price acceptable? (extra question)

The renting price is paid by the TU Delft, as the OWee Bestuur is an organisation of TU Delft. Therefore, Jorik van Koppen does not know. The shared meeting room is paid for by the OWEE Bestuur and all student organisations on the first floor. This has the advantage that all can make use, but the OWee Bestuur rather has a private one.

Reasons to reconsider an existing building			
Building immanent factors	Urban design	Desired improvement of the urban quality	
		Prevent vacancy as a cause for social problems in a neighbourhood	
	Architectural design	Outdated appearance	
		Exterior impression bad for social problems in a neighbourhood	
		Decay of valuable architectural heritage	
	Function	Transformation of the building	
		Change / optimising of office concept	X
	User comfort	Unpleasant indoor conditions – users' complaints	
		Hygienic problems	
		Sick building syndrome (SBS)	
		Building related illness (BRI)	
	Technical installations	High operational energy demand	
	Hazardous material	Asbestos	
		PCB	
		PAK	
		MMMF	
	Building physics	Lack of insulation	
		Wind leaks – draft	
		Water leaks	
		Fire protection deficiencies	
		Planning for climate change	
	Building owner/user	Tenant considers relocation	X
		Owner user initiates renovation	
Legal reasons	Fire regulation	Compulsory fire safety improvements	
	Safety	Danger of damage to third party	
	Energy consumption	Compulsory energy consumption certificate (energy passport) for resale or rental contracts	
Economic reasons	Operational cost	High energy demand	
		High maintenance cost	
	Lettability	Bring an empty building back to the market	
		Tenant considers relocation	
	Marketing	Users' representation need	
	Financial market	Institutional investors are bound to invest	

User:	**Nanny Marks, VSSD**
Location:	**253 m2 GLA. Half of the ground floor.**
Date:	**19-04-2017**

1. Motivation for refurbishment

The VSSD has enough space and the location is good. However, it is always cold on the ground floor and the building looks very outdated.

2. Qualities of the building

The building stays cool in summer.

3. Users' complaints

The ground floor is always cold and the heating needs to be on all year round. Also, the rooms are dark and grim. Many maintenance/service mechanics come by. And the noise of the demolition of the adjacent building and the construction works at the first floor for Inholland were very disturbing. Small number of toilets. Burglary.

4. Desires for the refurbished building

That the presence of this wind tunnel is clearer and more visible. It is an interesting building, but everyone knows it for the VSSD. To still have their own entrance to the shop. A parking place for parcel deliveries. More bicycle places.

5. Worries

No.

6. Organisational restrictions

This question has not been asked

7. Time restrictions

This question has not been asked

8. Financial frame

This question has not been asked

9. What is your occupation schedule? (extra question)

9 a.m. until 5 p.m. The VSSD shop is run by four people with an equivalent of 3 FTE. Then there is the VSSD Bestuur and they are with 5 people and 5 FTE.

10. Is your location flexible within the campus of TU Delft? (extra question)

Yes, the VSSD is flexible, but FMRE is not. The prior location was in building 08. Bouwkunde. And in 2002/2003 they moved here.

Before the student organisations were located in the building, the print shop of TU Delft had its place in this building. It was located in the room of the OWee and made use of the entire first floor.

11. Is the renting price acceptable? (extra question)

No, the renting price is too high. In 2013 the price increased a lot. The commercial part of VSSD pays full price, but the board does not pay full price. A monthly energy bill is sent and apparently there is a ratio for the users of the building.

Reasons to reconsider an existing building			
Building immanent factors	Urban design	Desired improvement of the urban quality	
		Prevent vacancy as a cause for social problems in a neighbourhood	
	Architectural design	Outdated appearance	X
		Exterior impression bad for social problems in a neighbourhood	
		Decay of valuable architectural heritage	X
	Function	Transformation of the building	
		Change / optimising of office concept	
	User comfort	Unpleasant indoor conditions – users' complaints	X
		Hygienic problems	
		Sick building syndrome (SBS)	
		Building related illness (BRI)	
	Technical installations	High operational energy demand	
	Hazardous material	Asbestos	
		PCB	
		PAK	
		MMMF	
	Building physics	Lack of insulation	X
		Wind leaks – draft	X
		Water leaks	
		Fire protection deficiencies	
		Planning for climate change	
	Building owner/user	Tenant considers relocation	
		Owner user initiates renovation	
Legal reasons	Fire regulation	Compulsory fire safety improvements	
	Safety	Danger of damage to third party	
	Energy consumption	Compulsory energy consumption certificate (energy passport) for resale or rental contracts	
Economic reasons	Operational cost	High energy demand	X
		High maintenance cost	
	Lettability	Bring an empty building back to the market	
		Tenant considers relocation	
	Marketing	Users' representation need	
	Financial market	Institutional investors are bound to invest	

User:	**Antoine Gerritse, Inholland**
Location:	**? m2 GLA. First floor.**
Date:	**25-04-2017**

1. Motivation for refurbishment

Inholland moved to the first floor of this building about a year ago, after being located in building 32. Industrieel Ontwerpen for 10 years. Moving to this building was their only option and it is close to the main building of Hogeschool Inholland.

A renovation is desired, mainly to get better office spaces. Inholland already proposed a façade renovation, including enlarging the windows so you would have a view from your desk and double glazing could be placed.

2. Qualities of the building

The building has an industrial floor (the print shop was located here), which is useful for the machines of Inholland. Also, they had the opportunity to completely adjust the layout of the first floor to their wishes. The building is easy to reach by car and is close to Inholland.

3. Users' complaints

High windows, lack of outdoor space, thermal- and windleaks. The indoor climate is not comfortable and feels artificial.

4. Desires for the refurbished building

An extra entrance on the Drebbelweg.

5. Worries

Asbestos.

6. Organisational restrictions

This question has not been asked

7. Time restrictions

This question has not been asked

8. Financial frame

This question has not been asked

9. What is your occupation schedule? (extra question)

8 a.m. until 6 p.m. They are here all year round. The lab has 6 to 7 employees and an extra 5 students are working here, which adds up to 12 FTE.

10. Is your location flexible within the campus of TU Delft? (extra question)

No, not anymore. Inholland has spent a large sum of money to change the interior and adjust it to their wishes.

11. Is the renting price acceptable? (extra question)

He does not know.

Reasons to reconsider an existing building			
Building immanent factors	Urban design	Desired improvement of the urban quality	
		Prevent vacancy as a cause for social problems in a neighbourhood	
	Architectural design	Outdated appearance	
		Exterior impression bad for social problems in a neighbourhood	X
		Decay of valuable architectural heritage	
	Function	Transformation of the building	
		Change / optimising of office concept	X
	User comfort	Unpleasant indoor conditions – users' complaints	
		Hygienic problems	
		Sick building syndrome (SBS)	
		Building related illness (BRI)	
	Technical installations	High operational energy demand	
	Hazardous material	Asbestos	X
		PCB	
		PAK	
		MMMF	
	Building physics	Lack of insulation	X
		Wind leaks – draft	X
		Water leaks	
		Fire protection deficiencies	
		Planning for climate change	
	Building owner/user	Tenant considers relocation	
		Owner user initiates renovation	
Legal reasons	Fire regulation	Compulsory fire safety improvements	
	Safety	Danger of damage to third party	
	Energy consumption	Compulsory energy consumption certificate (energy passport) for resale or rental contracts	
Economic reasons	Operational cost	High energy demand	
		High maintenance cost	
	Lettability	Bring an empty building back to the market	
		Tenant considers relocation	
	Marketing	Users' representation need	
	Financial market	Institutional investors are bound to invest	

Summary: Reasons to reconsider an existing building			U	O	U	U	U	T
Building immanent factors	Urban design	Desired improvement of the urban quality						
		Prevent vacancy as a cause for social problems in a neighbourhood						
	Architectural design	Outdated appearance	X			X		X
		Exterior impression bad for social problems in a neighbourhood						
		Decay of valuable architectural heritage	X		X	X		X
	Function	Transformation of the building						
		Change / optimising of office concept			X	X	X	X
	User comfort	Unpleasant indoor conditions – users' complaints					X	X
		Hygienic problems						
		Sick building syndrome (SBS)						
		Building related illness (BRI)						
	Technical installations	High operational energy demand	X					X
	Hazardous material	Asbestos	X				X	X
		PCB	X					X
		PAK	X					X
		MMMF	X					X
	Building physics	Lack of insulation	X			X	X	X
		Wind leaks – draft				X	X	X
		Water leaks	X					X
		Fire protection deficiencies	X					X
		Planning for climate change						
	Building owner/user	Tenant considers relocation			X			X
		Owner user initiates renovation	X					X
Legal reasons	Fire regulation	Compulsory fire safety improvements						
	Safety	Danger of damage to third party						
	Energy consumption	Compulsory energy consumption certificate (energy passport) for resale or rental contracts						
Economic reasons	Operational cost	High energy demand	X			X		X
		High maintenance cost						
	Lettability	Bring an empty building back to the market						
		Tenant considers relocation						
	Marketing	Users' representation need	X	X			X	X
	Financial market	Institutional investors are bound to invest						

14.4. APPENDIX: FAÇADE VALUES

FAÇADE 1

Layer	Material	Width (mm)	Lambda (W/m.K)	R-value (m2.K/W)
Inner leaf	Brick	100	1,000	0,100
Insulation	Lapinus Rockwool 405	50	0,040	1,250
Cavity	Ventilated (medium)	50		0,090
Outer leaf	Brick	100	1,000	0,100
			Rc (m2.K/W)	**1,540**
			U (W/m2.K)	**0,649**
			∑ width (mm)	**300**

FACADE 2

Layer	Material	Width (mm)	Lambda (W/m.K)	R-value (m2.K/W)
Inner leaf	Concrete	300	2,000	0,150
Insulation	Lapinus Rockwool 405	50	0,040	1,250
Cavity	Ventilated (medium)	50		0,090
Outer leaf	Brick	100	1,000	0,100
			Rc (m2.K/W)	**1,590**
			U (W/m2.K)	**0,629**
			∑ width (mm)	**500**

FACADE 3

Layer	Material	Width (mm)	Lambda (W/m.K)	R-value (m2.K/W)
Inner leaf	Concrete	300	2,000	0,150
Insulation	Lapinus Rockwool 405	50	0,040	1,250
Cavity	Ventilated (medium)	70		0,090
Post and beam	Metal posts	40		0,000
Outer leaf	Corrugated metal cladding	40		0,000
			Rc (m2.K/W)	**1,490**
			U (W/m2.K)	**0,671**
			∑ width (mm)	**500**

FACADE 4

Layer	Material	Width (mm)	Lambda (W/m.K)	R-value (m2.K/W)
Inner leaf	*unknown*	300	1,000	0,300
Cavity	Ventilated (very)	100		0,000
Cavity	Ventilated (very)	285		0,000
Insulation	-	0		0,000
Cavity	Ventilated (very)	180		0,000
Post and beam	Metal posts	40		0,000
Outer leaf	Corrugated metal cladding	40		0,000
			Rc (m2.K/W)	**0,300**
			U (W/m2.K)	**3,333**

			∑ width (mm)	**945**

FACADE 5

Layer	Material	Width (mm)	Lambda (W/m.K)	R-value (m2.K/W)
Inner leaf	Concrete	200	2,000	0,100
Insulation	Lapinus Rockwool 405	50	0,040	1,250
Outer leaf	Corrugated metal cladding (5mm)	40	58,000	0,001
			Rc (m2.K/W)	**1,351**
			U (W/m2.K)	**0,740**
			∑ width (mm)	**290**

FACADE 6

Layer	Material	Width (mm)	Lambda (W/m.K)	R-value (m2.K/W)
Inner leaf	Concrete	300	2,000	0,150
Insulation	Lapinus Rockwool 405	50	0,040	1,250
Layer	Plywood	10	0,130	0,077
Timber studs	Timber (15% bridging factor)	120	0,130	0,138
Outer leaf	Plywood cladding	20	0,130	0,154
			Rc (m2.K/W)	**1,769**
			U (W/m2.K)	**0,565**
			∑ width (mm)	**500**

FACADE 7

Layer	Material	Width (mm)	Lambda (W/m.K)	R-value (m2.K/W)
Inner leaf	Concrete	340	2,000	0,170
Inner leaf	Concrete	340	2,000	0,170
Insulation	-	0	0,040	0,000
Cavity	Ventilated (medium)	240		0,090
Timber studs	Timber (15% bridging factor)	240	0,130	0,277
Outer leaf	Plywood cladding	20	0,130	0,154
			Rc (m2.K/W)	**0,861**
			U (W/m2.K)	**1,162**
			∑ width (mm)	**940**

FACADE 8

Layer	Material	Width (mm)	Lambda (W/m.K)	R-value (m2.K/W)
Inner leaf	Concrete	30	2,000	0,015
Insulation	*unknown*	80	0,035	2,286
Outer leaf	Concrete	50	2,000	0,025
			Rc (m2.K/W)	**2,326**
			U (W/m2.K)	**0,430**
			∑ width (mm)	**160**

FACADE 9	-			
Layer	**Material**	**Width (mm)**	**Lambda (W/m.K)**	**R-value (m2.K/W)**
Inner leaf	Concrete	350	2,000	0,175
Insulation	-	0	0,040	0,000
Outer leaf	Render (gypsum)	20	0,800	0,025
			Rc (m2.K/W)	**0,200**
			U (W/m2.K)	**5,000**
			Total width (mm)	**370**

FACADE 10				
Layer	**Material**	**Width (mm)**	**Lambda (W/m.K)**	**R-value (m2.K/W)**
Inner leaf	Concrete	350	2,000	0,175
Insulation	Lapinus Rockwool 405	50	0,040	1,250
Cavity	Ventilated (medium)	60		0,090
Outer leaf	Merbau paneling	19	0,150	0,127
			Rc (m2.K/W)	**1,642**
			U (W/m2.K)	**0,609**
			∑ width (mm)	**479**

ROOF 1				
Layer	**Material**	**Width (mm)**	**Lambda (W/m.K)**	**R-value (m2.K/W)**
Floor	Concrete	140	2,000	0,070
Slant	Foamed concrete	20	0,091	0,220
Insulation	Vapotherm P.U.	40	0,026	1,538
Outer leaf	Mastic asphalt	5	0,200	0,025
Outer leaf	Gravel	50	0,000	0,000
			Rc (m2.K/W)	**1,853**
			U (W/m2.K)	**0,540**
			∑ width (mm)	**255**

ROOF 2				
Layer	**Material**	**Width (mm)**	**Lambda (W/m.K)**	**R-value (m2.K/W)**
Floor	Wooden beams (11%)	160	0,130	0,135
Layer	Plywood	19	0,130	0,146
Insulation	Vapotherm P.U.	30	0,026	1,154
Outer leaf	Mastic asphalt	5	0,200	0,025
			Rc (m2.K/W)	**1,460**
			U (W/m2.K)	**0,685**
			∑ width (mm)	**214**

14.5. APPENDIX: MATERIAL INVENTORY

Phase	Category	No. of items	Material: Area (m^2)	Material: Description	Material: Volume (m^3)	Type
Wind tunnel	Monolithic structure	1		In-situ concrete (reinforced)	281,37	
1952	Walls and beams	82	1157,61	In-situ concrete (reinforced)	339,47	
1952	Walls	22	116,20	Brick cavity wall	11,57	
1952	Columns	41		In-situ concrete (reinforced)	54,46	
1952	Floors and roofs	16	2253,39	In-situ concrete (reinforced)	418,92	
1952	Floors and roofs	2	287,10	Insulation	11,48	
1952	Floors and roofs	4	571,25	Bitumen	5,71	
1952	Windows	50	251,33	Wooden window frames, single glazed		
1977	Walls	13	825,04	Common brick	82,52	Type 1 and 2: Masonry wall
1977	Walls	13	825,04	Insulation	41,27	Type 1 and 2: Masonry wall
1977	Walls	21	342,52	Common brick	34,23	Type 1 and 2: Masonry wall
1977	Walls	3	9,21	Common brick	2,76	Type 1 and 2: Masonry wall
1977	Walls	1	18,06	Insulation	0,90	Type 10: Opaque window elements
1977	Walls	1	18,06	Merbau wood panelling	0,69	Type 10: Opaque window elements
1977	Walls	7	222,39	Insulation	11,11	Type 3: Corrugated metal cladding
1977	Walls	7	222,39	Steel		Type 3: Corrugated metal cladding
1977	Walls	4	243,35	Steel		Type 4: Corrugated metal classing without insulation
1977	Walls	2	73,46	0	11,02	Type 4: Corrugated metal classing without insulation
1977	Walls	6	123,16	Insulation	6,16	Type 5: Corrugated metal cladding (vertical)
1977	Walls	6	123,16	Steel		Type 5: Corrugated metal cladding (vertical)
1977	Walls	3	35,04	Plywood, sheathing grade	0,70	Type 6: Wooden panelling
1977	Walls	3	35,04	Insulation	2,11	Type 6: Wooden panelling
1977	Walls	2	32,25	Plywood, sheathing grade	0,64	Type 7: Wooden panelling without insulation
1977	Walls	3	65,04	Insulation	5,19	Type 8: Prefab concrete panels
1977	Walls	3	65,04	In-situ concrete (reinforced)	5,19	Type 8: Prefab concrete panels
1977	Walls and beams	96	1228,41	In-situ concrete (reinforced)	335,67	
1977	Columns	26		In-situ concrete (reinforced)	56,55	
1977	Floors and roofs	19	2049,48	In-situ concrete (reinforced)	407,41	
1977	Floors and roofs	3	509,33	Insulation	20,37	
1977	Floors and roofs	3	509,33	Bitumen	5,09	
1977	Windows	47	285,61	Wooden window frames, single glazed		
1977	Stairs	7		In-situ concrete (reinforced)	4,74	

14.6. APPENDIX: FAÇADE SYSTEM CALCULATIONS

TIMBER FRAME WALL

Layer	**Material**	**Thickness (mm)**	**Lambda (W/m.K)**	**Rc (m2.K/ W)**
Interior plating	Plywood	18	0,130	0,138
Service void	Not ventilated	38		0,180
Battens	Spruce (38 x 50 mm)	38		
Plating for racking, vapour control and airtightness	OSB	12	0,130	0,092
Insulation	Flexible wood fibre insulation	220	0,038	5,789
Timber studs	Spruce (225 x 50 mm)	225	0,130	1,731
Bridging factor (%)	15%			
Insulation	Rigid wood fibre insulation	120	0,043	2,791
Weather-proofing membrane		2		
Cavity	Moderately ventilated	22		0,090
Battens	Spruce (22 x 50 mm)	22		
Cladding	Timber (Black Locust)	16	0,150	0,107
		Rc (m2.K/W)		**9,188**
		U (W/m2.K)		**0,109**
		Total thickness (mm)		**448**

TIMBER FRAME WALL ON CLT

Layer	**Material**	**Thickness (mm)**	**Lambda (W/m.K)**	**Rc (m2.K/ W)**
Structural wall	Cross Laminated Timber	120	0,130	0,923
Insulation	Flexible wood fibre insulation	220	0,038	5,789
Timber studs	Spruce (225 x 50 mm)	225	0,130	1,731
Bridging factor	15%			
Insulation	Rigid wood fibre insulation	120	0,043	2,791
Weather-proofing membrane		2		
Cavity	Moderately ventilated	22		0,090
Battens	Spruce (22 x 50 mm)	22		
Cladding	Timber (Black Locust)	16	0,150	0,107
		Rc (m2.K/W)		**9,700**
		U (W/m2.K)		**0,103**
		Total thickness (mm)		**500**

TIMBER FRAME WALL COLUMNS (THERMAL BRIDGES)

Layer	**Material**	**Thickness (mm)**	**Lambda (W/m.K)**	**Rc (m2.K/W)**
Insulation	Rigid wood fibre insulation	120	0,043	2,791
Cavity	Moderately ventilated	22		0,090
Battens	Spruce (38 x 50 mm)	22		
Cladding	Timber (Black Locust)	16	0,150	0,107
		Rc (m2.K/W)		**2,987**
		U (W/m2.K)		**0,335**
		Total thickness (mm)		**158**

RENDERED WALL

Layer	**Material**	**Thickness (mm)**	**Lambda (W/m.K)**	**Rc (m2.K/W)**
Structure	Concrete	350	2,000	0,175
Insulation	Rockwool insulation	40 + 40	0,037	2,182
Timber studs	Spruce (80 x 50 mm)	80	0,130	0,615
Bridging factor	15%			
Insulation	Rigid wood fibre insulation	120	0,043	2,791
Weather-proofing membrane		2		
Cladding	Render (lime)	20	0,800	0,025
		Rc (m2.K/W)		**5,153**
		U (W/m2.K)		**0,194**
		Total thickness (mm)		**222**

GREEN ROOF

Layer	**Material**	**Thickness (mm)**	**Lambda (W/m.K)**	**Rc (m2.K/W)**
Structure	Concrete	150	2,000	0,075
Vapour control layer				0,001
Insulation	Rigid wood fibre insulation	120	0,043	2,791
Insulation	Rigid wood fibre insulation	120	0,043	2,791
Insulation	Rigid wood fibre insulation	120	0,043	2,791
Insulation	Rigid wood fibre insulation	60	0,043	1,395
Vapour barrier and root barrier	POCB	3		0,060
Drainage layer		30		
Filtration layer		10		
Substrate		40		
Finish	Semi-intensive green roof			
		Rc (m2.K/W)		**9,903**

		U (W/m2.K)		**0,101**
		Total thickness (mm)		**503**

GROUND FLOOR				
Layer	**Material**	**Thickness (mm)**	**Lambda (W/m.K)**	**Rc (m2.K/ W)**
Structure	Concrete	200	2,000	0,100
Vapour barrier		2		0,001
Insulation	Rigid wood fibre insulation	60	0,046	1,304
Insulation	Rigid wood fibre insulation	60	0,046	1,304
Insulation	Rigid wood fibre insulation	60	0,046	1,304
Insulation	Rigid wood fibre insulation	60	0,046	1,304
Insulation	Rigid wood fibre insulation	60	0,046	1,304
	Low profile radiant heating panel system	30		0,750
Interior plating	Fermacell overlay	10	0,320	0,031
Finish		8		
		Rc (m2.K/W)		**7,404**
		U (W/m2.K)		**0,135**
		Total thickness (mm)		**350**

14.7. APPENDIX: PRODUCT DATASHEETS

pavatex

PAVABOARD *Highly compression-resistant woodfibre insulation boards for flooring systems*

- Compression-resistant woodfibre board with high loading capacity
- Versatile application under liquid screeds, dry screeds and mastic asphalt
- Proven flooring structures with specified loading capacity and sound reduction index

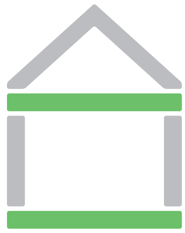
WOOD

Delivery form

Thickn. [mm]	Weight [kg/sqm]	Format [cm]	Number of boards	per pallet [sqm]	per pallet [kg]	Edge profile
20	4.5	110 x 60	224	147.8	685	Flat
40	9.0	110 x 60	112	73.9	685	Flat
60	13.5	110 x 60	72	47.5	662	Flat

Production plant: Cham, Switzerland

Field of application



Technical data

Bulk density ρ [kg/m^3]	220
Thermal conductivity (EN 13171) λ_D [W/(mK)]	0.046
Specific heat capacity c [J/(kgK)]	2100
Vapour diffusion resistance coefficient μ	5
Fire behaviour (EN 13501–1)	Class E
Compressive stress at 10% compressive deformation [kPa]	150
Tensile strength perpendicular to plane of board [kPa]	10
Waste code according to The European Waste Catalogue (EWC)	030105; 170201; 170604
Identification code	WF–EN13171–T5–CS(10\Y)150–TR10–WS2,0–MU5–AFr100

Product description

PAVABOARD is particularly suitable for use under all kinds of liquid screed, dry screed, ready-made parquet and laminate floors. The high compression resistance of PAVABOARD is ideally suited to applications where stresses are high.

Full declaration

For further information see MSDS on www.pavatex.com

Storage

Store dry and protected from damage. Only install when dry. Stack no more than 4 pallets on top of each other.

PAVATEX proven values

The load capacities available for floor constructions have been tested. The various structures, and the data for both point and surface loads, can be found in the relevant country-specific technical documentation.

Version 01/2017
Subject to technical changes

pavatex

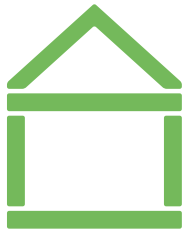
PAVAFLEX *Flexible woodfibre insulation material*

- Natural, flexible, woodfibre insulation material
- Simple to work, outstanding slump resistance
- Mat width specially adapted to the standard grid size in timber-frame construction

Delivery form

Thickn. [mm]	Weight [kg/sqm]	Format [cm]	Board dim. [cm]	Number of boards	Boards per package	per pallet [sqm]	per pallet [kg]	Edge profile
30	1.65	57.5 x 135	57.5 x 135	144	12	111.78	201	Flat
40	2.20	57.5 x 135	57.5 x 135	112	8	86.94	208	Flat
50	2.75	57.5 x 135	57.5 x 135	90	9	69.86	209	Flat
60	3.30	57.5 x 135	57.5 x 135	72	6	55.89	201	Flat
80	4.40	57.5 x 135	57.5 x 135	56	4	43.47	208	Flat
100	5.50	57.5 x 135	57.5 x 135	42	3	32.60	196	Flat
120	6.60	57.5 x 135	57.5 x 135	36	3	27.95	201	Flat
140	7.70	57.5 x 135	57.5 x 135	32	2	24.84	208	Flat
160	8.80	57.5 x 135	57.5 x 135	28	2	21.74	211	Flat
180	9.90	57.5 x 135	57.5 x 135	24	2	18.63	201	Flat
200	11.00	57.5 x 135	57.5 x 135	20	2	15.53	188	Flat
220	12.10	57.5 x 135	57.5 x 135	20	2	15.53	205	Flat
240	13.20	57.5 x 135	57.5 x 135	16	2	12.42	181	Flat

Field of application



Technical data

Bulk density ρ [kg/m³]	55
Thermal conductivity (EN 13171) λ_D [W/(mK)]	0.038
Specific heat capacity c [J/(kgK)]	2100
Vapour diffusion resistance coefficient μ	2
Fire behaviour (EN 13501–1)	Class E
Compressive stress at 10% compressive deformation [kPa]	–
Tensile strength perpendicular to plane of board [kPa]	–
Waste code according to The European Waste Catalogue (EWC)	030105; 170201; 170604
Identification code	WF–EN13171–T3–MU2–AFr5

Product description

PAVAFLEX is a flexible woodfibre insulation material, with outstanding thermal insulation and storage properties for permeable construction methods. The harmless insulation material can be processed using simple cutting tools. Thanks to its flexibility and slump resistance, PAVAFLEX can be installed quickly, easily and with an accurate fit.

Full declaration

For further information see MSDS on www.pavatex.com

Storage

Store dry and protected from damage. Only install when dry. Pallets must not be stacked.

PAVATEX system guarantee

The high-performance adhesion and gluing components used in the PAVATEX system solutions ensure long-lasting, reliable system sealing in modern, multifunctional building envelopes - now also guaranteed by the new PAVATEX warranty. It offers comprehensive service if damage occurs, and therefore once again increases security for designers, installers and builders.

Version 01/2017
Subject to technical changes

pavatex

PAVATHERM-PLUS *Permeable insulation with sarking board*

- Sarking with high-performance additional insulation, anti-slip surface
- Withstands weather for 3 months as protection during construction or temporary roofing
- Highly insulating thanks to added insulation, easy to work thanks to low board weight

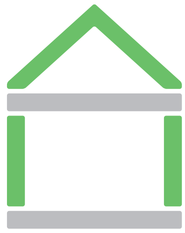
WOOD

Delivery form

Thickn. [mm]	Weight [kg/sqm]	Format [cm]	Board dim. [cm]	Number of boards	per pallet [sqm]	per pallet [kg]	Edge profile
60	12.00	180 x 58	178 x 56	36	37.6	476	Tongue & Groove
80	11.68	180 x 58	178 x 56	28	29.2	481	Tongue & Groove
100	14.00	180 x 58	178 x 56	22	23.0	466	Tongue & Groove
120	16.32	180 x 58	178 x 56	18	18.8	453	Tongue & Groove
140	18.62	180 x 58	178 x 56	16	16.7	467	Tongue & Groove
160	20.96	180 x 58	178 x 56	14	14.6	465	Tongue & Groove

In two stacks on a separable pallet
Production plant: Cham, Switzerland

Field of application



Technical data

Bulk density ρ [kg/m³]	190
Thermal conductivity (EN 13171) lD [W/(mK)]	0.043
Specific heat capacity c [J/(kgK)]	2100
Vapour diffusion resistance coefficient μ	5
Fire behaviour (EN 13501–1)	Class E
Compressive stress at 10% compressive deformation [kPa]	100
Tensile strength perpendicular to plane of board [kPa]	4
Waste code according to The European Waste Catalogue (EWC)	030105; 170201; 170604
Identification code	WF–EN13171–T5–CS(10\Y)90–TR2,5–WS1,0–MU5–AFr100
Sarking board (EN 14964)	EN 622-4 Typ SB.E
KEYMARK	011-7D018

Product description

Combination of PAVATHERM/dry process and ISOLAIR/wet process.

Roof insulation applications: As roof insulation with integrated sarking board, PAVATHERM-PLUS is either laid over the full area as the outer layer of a PAVATEX over-rafter insulation, or is fitted directly on the rafters as a supplement to between-rafter insulation. For use as a sarking board, please observe the country-specific application codes according to the regulations and standards in the technical documentation.

External wall insulation applications: In the external wall area, PAVATHERM-PLUS is suitable as an insulating element for insulation in both solid and timber constructions with clad walls.

Full declaration

For further information see MSDS on www.pavatex.com.

Storage

Store dry and protected from damage. Only install when dry. Stack no more than 4 pallets on top of each other.

PAVATEX System accessories

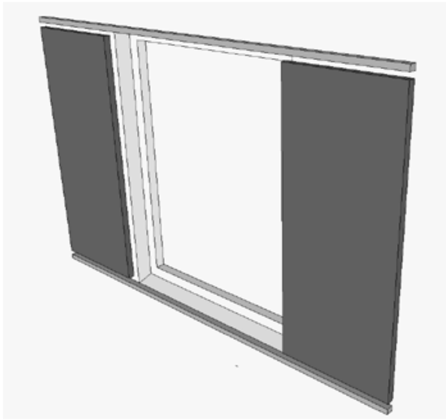
For priming when gluing joints: PAVABASE or PAVAPRIM
Adhesive tapes for joints: PAVATAPE 75/150, PAVAFIX and PAVATAPE FLEX / **for wet bases:** Use PAVACOLL 310 / 600 on PAVATAPE as adhesive medium
For joint gluing: PAVACOLL 310/600
You will find details on usage and installation guidelines in the sealing brochure.

Version 01/2017
Subject to technical changes

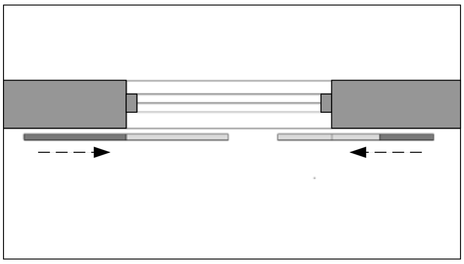
Schuifluiken en gevelschermen 05-SL-AL




PRODUCTOMSCHRIJVING Het trekt de aandacht en houdt nieuwsgierige blikken buiten: een gevel met schuifluiken en gevelschermen passen perfect bij het hedendaagse leven. Het biedt het beste van twee werelden – binnen en buiten – door gefilterd licht binnen te laten waar men wil. De dynamiek van schuifluiken en gevelschermen geven een gebouw flair en spanning. De perfecte aankleding voor een pand dat in de belangstelling mag staan. Schuifluiken zijn niet alleen mooi maar ook heel praktisch. Schuifluiken en gevelschermen onttrekken grote glasoppervlakken in een handomdraai aan inkijk en felle zon. De verschuifbare luiken en schermen zijn daarom een veel gekozen oplossing voor grote gebouwen zoals kantoren en appartementencomplexen. Het energieverbruik voor verwarming en koeling wordt nu nog meer gereduceerd: kostenbesparend en milieuvriendelijker.



MODELLEN De modellen die toegepast kunnen worden als schuifluik kunnen variëren van louvre luiken uit hout of aluminium, geperforeerde aluminium plaat, textielweefsel doek in een aluminium kader tot vele andere combinaties en/of materialen.



RAILSYSTEEM Met het railsysteem boven en onder de raampartij of deur, zijn de panelen eenvoudig te verplaatsen, handmatig of elektrisch bediend. Het aluminium (blank geanodiseerde) railsysteem is onderhoudsarm en kan met behulp van montagebeugels of consoles eenvoudig tegen de gevel worden gemonteerd. In sommige situaties is het mogelijk om de bovenrail aan de onderkant van de overstek te monteren. Isoluik levert het schuifsysteem met een enkel, dubbel of zelfs drievoudig uitgevoerd railsysteem. In de ruststand zijn de schuifluiken ,door een in de rail geïntegreerde klikstop, geblokkeerd.

BEDIENING Door de soepele werking van de loopwielen zijn de schuifluiken en gevelschermen eenvoudig met de hand te bedienen. De handbediende uitvoeringen kunnen, naar wens, onderling verbonden worden waardoor een symmetrische of telescopische schuifbeweging ontstaat. Alle schuifluiken en gevelschermen kunnen ook uitgevoerd worden met een elektrische bediening. Met een druk op de knop zullen de luiken en schermen zich geluidloos naar de gewenste plek verplaatsen.

TECHNISCHE GEGEVENS

Type	05-SL-AL
Fabrikant	Isoluik B.V.
Omschrijving	Schuifluik railsysteem
Materiaal	Aluminium
Behandeling	Blank geanodiseerd
Maximale belasting	60 kg per schuiluik
Minimale luikbreedte	350 mm
Toepassing	Schuifluik

OPTIES

Kappen	Afdekkappen voor afwerken bovenrail

Zeilschip 30, 3991 CT Houten
T (030) 603 55 22 | **F** (030) 604 36 37
www.isoluik.nl | info@isoluik.nl

System IDEAL ECO

JUPITER

PJL | (014) | Rev 2
Mar 2017

30mm acoustic wood fibre system

Low profile radiant heating panel system

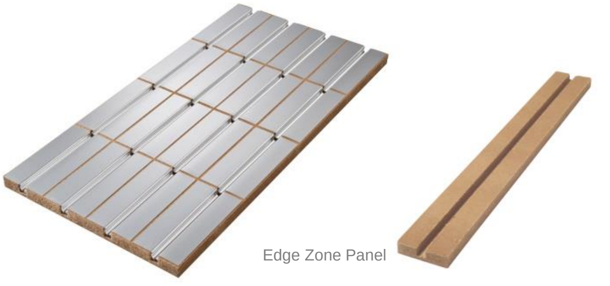
The JUPITER IDEAL ECO system is an engineered underfloor heating system manufactured from 180kPa recycled wood fibre. The system is 30mm thick providing a thermal R value of 0.75m²K/W and is designed to accept the 16mm JUPITER multi-layer PE/RT pipe. The raw woodfibre material has a density of 260 kg/m³ and can provide an acoustic improvement of 24dB when used in conjunction with a dry screed replacement board of minimum mass 21 kg/m².

The heating system consists of two panel types: 'Central zone' panels offer pipe centres of 250mm and 'Edge Zone' panels offer 125mm centres. Both of these panel types are manufactured with pre-affixed 0.5mm thick aluminium diffuser plates to optimise heat output and ensure an even spread of heat where possible. The channel within the aluminium diffuser plates is shaped like the Greek letter Omega (Ω) but upside-down to provide better encapsulation the of pipe.

Central Zone panels are made up of 8 segments and Edge Zone panels are made up of 16 individual segments. Panels can easily be cut to required dimensions with either a jigsaw or hand held circular saw.

Both panel types measure 1000mm x 500mm.

Central Zone Panel



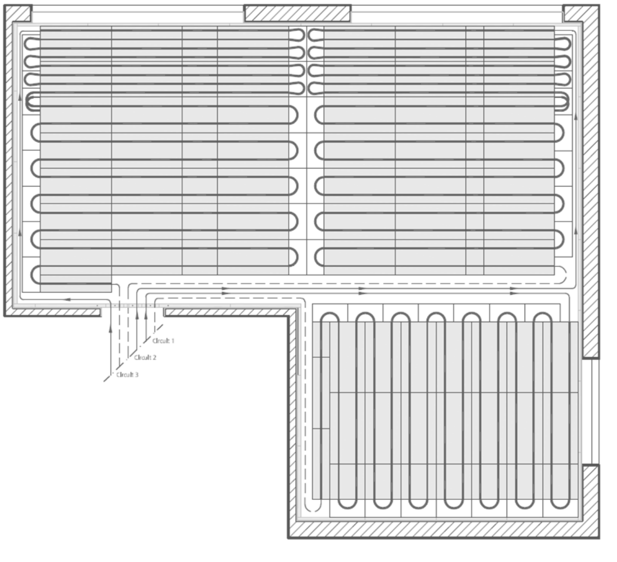
Edge Zone Panel

Header panels to return the pipe at the end of a run are supplied with or without aluminium diffuser plates and are available for both 250mm and 125mm centre systems.

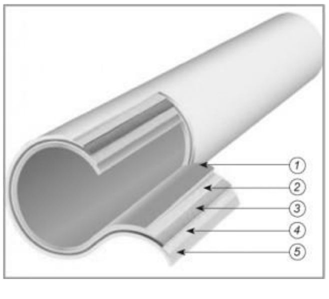
Unheated areas such as under kitchen cupboards, fitted furniture, baths and shower trays can be filled with similar, 30mm thick blank wood fibre insulation panels. Tailored pipe runs can be formed within these panels using a hand router and 16mm routing bit.

Header Return Panels

Additional Panels



The JUPITER multi-layer system pipe is manufactured in Germany to DIN 16836, carries a 10 year warranty and has a minimum design life of 50 years.



1 Polyethylene RT
2 Adhesive
3 Aluminium
4 Adhesive
5 Polyethylene RT

JUPITER Heating Systems Limited
The Barns, Pennypot Lane, Chobham, Surrey, GU24 8DJ
T: 01276 859 066   www.jupiterunderfloorheating.com

Productblad

Icopal Universal WS 7,5 m.

Artikelnummer 059704

Toepassingen

Icopal Universal WS kan worden toegepast op alle dakconstructies; platte en hellende daken, bij nieuwbouw en renovatie. Het materiaal laat zich op diverse manieren eenvoudig verwerken in éénlaagse toepassingen: mechanisch bevestigd of koud gekleefd onder vegetatie daken.
Overlappen worden gelast met hete lucht.
Universal WS kan bij intensieve begroeiing toegepast worden mits gekleefd (Icopal Bond) en met gelaste overlappen. Bij staaldaken met extensieve begroeiing kan Universal WS ook éénlaags toegepast worden.

Voor toe te passen dakbedekkingsystemen zie KOMO attest.

Certificaten

KOMO attest: K91312
KOMO productcertificaat: K66715,
Prestatieverklaring (DoP) volgens EN 13707
NL-BSB certificaat: K66717,
Getest tegen worteldoorgroei volgens FLL en EN 13948.

Verwerking

Conform verwerkingsrichtlijnen uitgegeven door Icopal bv.

Levering

Aflevering
Icopal Universal WS dakrollen worden verpakt in tapes, per 24 stuks op eenmalige pallets, in plastic krimphoes.

Opslag en transport
Icopal Universal WS moet verticaal opgeslagen worden op een droge en vlakke ondergrond, bij een temperatuur tussen 0 en 40℃. Tijdens de opslag moet direct zonlicht vermeden worden.

Product identificatie
Informatie op de rol: Productnaam.
Rol afmetingen.
Keurmerken.
Productiedatum.

Icopal B.V., Hoendiep 316 Postbus 2301, 9704 CH Groningen Nederland
Tel. +31(0)50 551 63 33 Fax +31 (0)50 551 62 23, info@icopal.nl, www.icopal.nl

Productblad

Icopal Universal WS 7,5 m.

Artikelnummer 059704

Product omschrijving

Uiterlijk bovenzijde	PP-Spunbond met aan een zijde een overlapmarkering en een fixatielijn
Coating bovenzijde	POCB coating
Type inlage	Polyester/glasvlies +P/G-versterkingsdraden
Coating onderzijde	POCB coating
Uiterlijk onderzijde	PP-Spunbond

Product prestaties gemeten volgens EN 13707

Product specificaties	Methode	Waarde	Eenheid
Zichtbare gebreken	EN 1850-1	Voldoet	-
Lengte	EN 1848-1	7,5	m
Breedte	EN 1848-1	1,0	m
Rechtheid van kanten	EN 1848-1	Voldoet	-
Massa per eenheid van oppervlakte	EN 1849-1	3,28 ± 10%	kg/m²
Dikte	EN 1849-1	3,2 ± 0,2	mm
Brandgevaarlijk zijn van daken	EN 1187	F_{Roof} *	
Brandgedrag	EN 13501-1	Klasse E	
Waterdichtheid	EN 1928	Voldoet	≥ 300 kPa
Treksterkte (langsrichting)	EN 12311-1	1250 ± 20%	N/50mm
Treksterkte (dwarsrichting)	EN 12311-1	1150 ± 20%	N/50mm
Rek (langsrichting)	EN 12311-1	30 ± 10	%
Rek (dwarsrichting)	EN 12311-1	30 ± 10	%
Weerstand tegen worteldoorgroei	EN 13948	Voldoet	-
Weerstand tegen statische belasting (A, zacht substraat)	EN 12730	≥ 20	kg
Weerstand tegen dynamische belasting (A, hard substraat)	EN 12691	≥ 1250	mm
Nageldoorscheursterkte (langs- & dwarsrichting)	EN 12310-1	300 -0/+250	N
Weerstand tegen pellen van verbindingen	EN 12316-1	50 -0/+100	N/50mm
Treksterkte van lasverbindingen	EN 12317-1	800 -0/+700	N/50mm
Flexibiliteit bij lage temperatuur	EN 1109	≤ -25	°C
Flexibiliteit bij lage temperatuur na kunstmatige veroudering	EN 1296 & EN 1109	-25 +0/-15	°C
Vloeiweerstand bij verhoogde temperatuur	EN 1110	≥ 150	°C
Vloeiweerstand bij verhoogde temperatuur na kunstmatige veroudering door langdurige blootstelling aan verhoogde temperatuur	EN 1296 & EN 1110	150 -0/+30	°C
Veroudering door langdurige blootstelling aan de combinatie van UV-straling, verhoogde temperatuur en water	EN 1297	Voldoet	Klasse 0
Dimensionele stabiliteit	EN 1107-1	≤ 0,1	%
Kleefkracht van korrels	EN 12039	n.v.t.	%
Waterdampdiffusieweerstandsgetal (µ)	EN 1931	20.000	-
Gevaarlijke stoffen		Voldoet	

[1)] Geen meting uitgevoerd (niet vereist volgens EN 13707)

[*)] Aangezien de brandgevaarlijkheid van een dak bepaald wordt door de opbouw van de dakbedekkingsconstructie, kunnen geen prestaties worden afgegeven voor het product alleen (voldoet aan B_{Roof}(t1) volgens K31912)

05-01-2017 versie 1.6 Dit productblad is met de grootste zorg samengesteld. Wij aanvaarden echter geen aansprakelijkheid voor schade, van welke aard ook, welke door het gebruik van deze gegevens of het desbetreffende product zou ontstaan.

Icopal B.V., Hoendiep 316 Postbus 2301, 9704 CH Groningen Nederland
Tel. +31(0)50 551 63 33 Fax +31 (0)50 551 62 23, info@icopal.nl, www.icopal.nl

HEKATHERM

PE-HD heat exchanging system for controlled heat balance in dwelling houses

HEKATHERM-EWT-R:
(coiled product)

PE-HD twin wall pipe DN 200 and selected components for air intake, air distribution and condensed water discharge in heat exchanging systems using geothermal energy

HEKATHERM-EWT-S:
(bars) NEW

For large-scale units we offer pipes and accessories in a size range between DN 200 and DN 600, tailored to the specific project.

For further information please visit our website at www.hegler.de.

HEGLER

Corrugated and Twin Wall Pipes of Plastics

HEKATHERM Heat Exchanging

Summer: Cooling down of outside air

HEKATHERM
Heat Exchanging System

- Made from emission-free polyethylene
- Closed system with no need for pipe connecting elements
- Extensive range of accessories
- Versatile use of individual components

Winter: Warming up of outside air

Low-energy/passive house

Great importance being attached to the heat balance of dwelling houses in view of environment protection and saving of running expenses, the outer skins of low-energy/passive houses are planned and built in a heat-insulating design. Keeping heat inside also means that the house is impervious to air as well however. Therefore, forced venti-lation is required to replace the air inside the house via crossflow heat exchangers, without carrying off heat together with the air.

The degree of energy saving with this concept is even increased with the fresh air being pre-heated in a heat exchanger before led into the building. Depending on the degree of heat insulation and the difference between interior and ambient temperatures, fossile fuel requirements can be reduced considerably in this way.

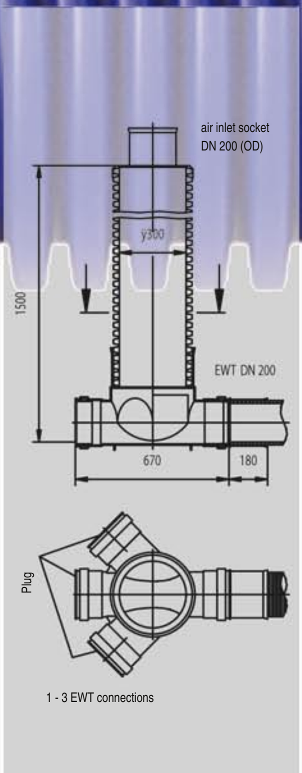
During the warm season, the system works the other way round: Heat is carried off the house by leading outside air, which has been cooled down in a heat exchanger, into the housing space.

HEKATHERM heat exchanging system

For small dwelling units in one or two-family houses, the necessary energy can be supplied in a 200 mm HEKATHERM twin wall pipe of 50 m in length. Various chamber systems and an extensive range of accessories are available to form, with the flexible pipe, an assembly tailored to the requirements of the very project. For the layout, HEGLER's recommendations should be followed.

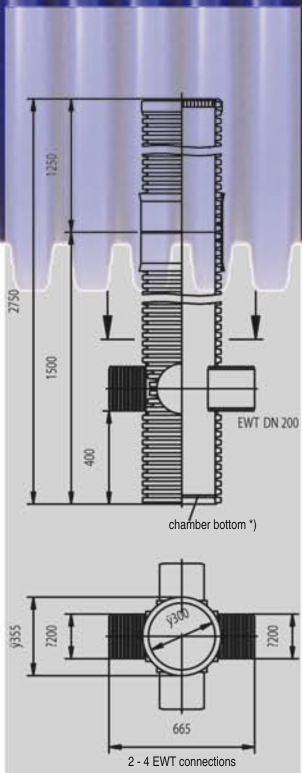
The pipe should be laid in a depth of 1.5 m at a distance of 1 m from the outside wall, i.e. it can be laid in the outermost part of the excavation.

System: a Sound Concept



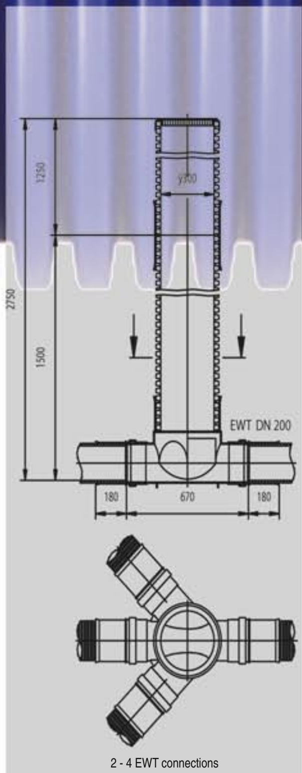
Air inlet chamber *)

*) impermeable or perforated bottom on request



Condensate chamber *)

*) impermeable or perforated bottom, as desired



Distributor chamber

HEKATHERM heat exchanging pipe

HEKATHERM heat exchanging pipes should be bedded in soil of good heat conductivity. The ideal embedding would be impervious and waterlogged soils which do not come up to the static requirements though. An economic alternative is a non-cohesive backfill material of a very fine fraction which also holds water well.

The pipe line should be installed in one piece, that means without a joint, in a gradient of ≥ 2 % towards the low point of the system.

Bends should be performed generously in order to keep flow resistance low; the minimum bending radius is 0.75 m.

HEKATHERM pipes are made from polyethylene of adequate heat conductivity. They are of structured-wall design with a profiled outside wall and a smooth inside beneficial in terms of hydraulics. Facilities of this kind being sensitive from the physiological point of view, all components are exclusively processed from PE materials approved for use in food industry.

Mechanical strength and quality of all components are subject to constant control. If natural ground water has to be taken into account, special solutions can be elaborated before the project is started.

HEKATHERM Heat Exchanging System

Important

- If possible, HEKATHERM-pipes should be transported and stored on site in the original stillages. They should always be stored on an even and smooth surface.
- For installation the recommendations of the manufacturer should be followed. Layout plan and HEGLER's recommendations are to be brought into line with the local circumstances.
- Joints should be made using the recommended lubricant and a profiled seal.
- For embedding DIN EN 1610 should be followed. It is recommended to use sand 0/4 for the embedding.
- Chambers shall be surrounded by a layer of suitable backfill material which is to be compacted in layers.

The information given in this brochure is the most up-to-date available and is intended to provide information on our products and their possible applications. It is not a guarantee of certain features or of their suitability for certain specific applications. Our guarantee applies to compliance with our specifications, within the scope of our General Terms and Conditions.
The schematic drawings (pipe/accessories) are indicative only. They are not binding as to product geometry.

Subject to changes.

HEKATHERM-EWT-R Pipe System (coiled product)

Product	Item No.
HEKATHERM heat exchanging pipe DN 200 (roll length 50 m)	7530020
Coupling DN 200	7531620
Profiled seal DN 200	7531720
Wall entrance DN 200*)	7531500
Plug DN 200	7531820
Adaptor HEKATHERM DN 200 to coupling solid-wall pipe (DIN 19534)	7531502

*) not in applications with natural ground water

HEKATHERM S 300 Chamber System

Product	Item No.
HEKATHERM air inlet chamber (high point) with 1 outlet*), impermeable bottom	7531111
HEKATHERM air inlet chamber (low point) with 1 outlet*), impermeable bottom - trap	7531121
HEKATHERM air inlet chamber (low point) with 1 outlet*), perforated bottom - percolation	7531131
HEKATHERM condensate chamber (low point) with 2 outlets*), impermeable bottom - trap	7531142
HEKATHERM condensate chamber (low point) with 2 outlets*), perforated bottom - percolation	7531152
HEKATHERM distributor chamber with 2 outlets*), impermeable bottom	7531162
HEKATHERM chamber raising piece incl. coupling and seal effective length: 123 cm	7531092
Chamber cover, plastics, with safety lock	7531091
Coupling DN 300	7531095
Profiled seal DN 300	7531090
Plug DN 200 (plug for solid-wall pipe DIN 19534)	7531096

*) on request available with additional outlets DN 200

HEKATHERM-EWT-S Pipe System (bars) NEW

For large-scale units we offer pipes and accessories i.e. complete systems tailored to the specific project, in a size range between DN 200 and DN 600. For further information please visit our website at www.hegler.de.

HEGLER

Corrugated and Twin Wall Pipes of Plastics

HEGLER PLASTIK GMBH · D-97714 Oerlenbach/Germany · Phone +49 9725 66-0 · Fax +49 9725 66-115 · www.hegler.de

SOLIBRO A COMPANY OF Hanergy

SOLIBRO SL2 CIGS THIN-FILM MODULE

Generation 2.0 | 115-135 Wp

Higher yield
- Positive sorting (+5 W)
- Light-soaking effect
- Low temperature coefficient: -0.37 %/K

Outstanding aesthetics
- Uniform black surface
- Ideal for visually sophisticated PV solutions

Easy to clean
- Frameless design means these modules are less susceptible to dirt

Quality controlled
- 100% inspected via electroluminescence test
- Longer, stricter tests than required under IEC 61646

Tests and certification
- Certification: ISO 9001:2008, ISO 14001:2009, BS OHSAS 18001:2007, IEC 61646/61730, MCS, UL 1703 (CSA)

10-year product warranty
25-year performance warranty

About Solibro GmbH

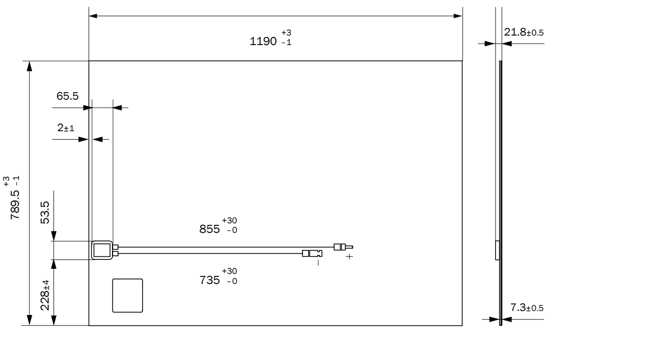
Solibro GmbH is one of the world's leading manufacturers of CIGS thin-film modules, with a production capacity of 145 MW. Solibro has been part of the Hanergy Group since September 2012. Solibro has headquarters in Thalheim, Germany and a research site in Uppsala, Sweden, both of which work to develop trailblazing solutions for the company's CIGS products. Solibro supplies products that are sustainable and cost-effective, with extraordinary aesthetics and top quality "Made in Germany".

www.solibro-solar.com

MECHANICAL SPECIFICATIONS

Length	1190 (+3/-1) mm
Width	789.5 (+3/-1) mm
Height	7.3 mm (+ junction box, 14.5 mm)
Weight	16.5 kg
Front cover	4 mm tempered low iron glass with AR coating
Back cover	3 mm float glass
Frame	None
Cell type	CIGS [Cu (In, Ga) Se_2]
Junction box	Protection class IP 65, with 1 bypass diode; 66 mm x 54 mm x 14.5 mm
Cable type	Solar cable 2.5 mm²; (+) 855 (+30/-0) mm; (–) 735 (+30/-0) mm
Connector	MC4

TECHNICAL DRAWING



All values in mm.

ELECTRICAL CHARACTERISTICS

PERFORMANCE AT STANDARD TEST CONDITIONS (1000 W/m², 25 °C, AM 1.5 G SPECTRUM)[1]

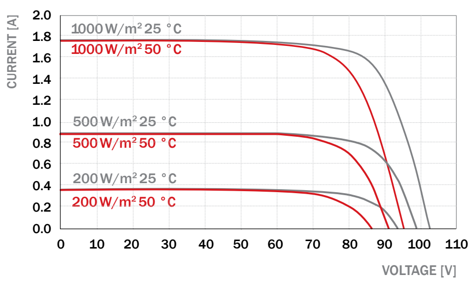
POWER CLASS (+5/-0 W)		[W]	115	120	125	130	135
Minimum Power	P_{MPP}	[W]	115.0	120.0	125.0	130.0	135.0
Short Circuit Current	I_{SC}	[A]	1.73	1.74	1.75	1.76	1.77
Open Circuit Voltage	V_{OC}	[V]	97.3	98.7	100.2	101.6	102.6
Current at P_{MPP}	I_{MPP}	[A]	1.49	1.53	1.56	1.59	1.63
Voltage at P_{MPP}	V_{MPP}	[V]	77.2	78.4	80.1	81.8	82.8
Module efficiency		[%]	≥ 12.2	≥ 12.8	≥ 13.3	≥ 13.8	≥ 14.4

PERFORMANCE AT NORMAL OPERATING CELL TEMPERATURE (800 W/m², NOCT, AM 1.5 G SPECTRUM)[1]

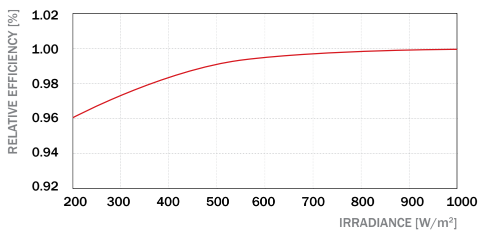
POWER CLASS (+5/-0 W)		[W]	115	120	125	130	135
Minimum Power	P_{MPP}	[W]	82.8	86.3	89.7	93.1	97.5
Short Circuit Current	I_{SC}	[A]	1.39	1.40	1.40	1.41	1.42
Open Circuit Voltage	V_{OC}	[V]	88.8	90.3	91.7	93.0	94.0
Current at P_{MPP}	I_{MPP}	[A]	1.19	1.22	1.24	1.26	1.30
Voltage at P_{MPP}	V_{MPP}	[V]	69.6	70.7	72.3	73.9	75.0

[1] Measurement accuracy P_{MPP}: ± 5%; measurement accuracy I_{SC}, V_{OC}, I_{MPP}, V_{MPP}: ± 10%. All STC measurements are based on a pre-treatment of modules with 43 kWh/m² of light soaking (43 hours at 1000 W/m² and MPP) followed by a cool down to 25 °C. Please consider that the voltage of our CIGS modules can increase slightly after an initial period of exposure to sunlight. Take a safety factor of +2.5% for V_{OC} and V_{MPP} into account when designing the system.

I-V CURVES AT VARIOUS TEMPERATURES AND IRRADIANCE LEVELS



PERFORMANCE AT LOW IRRADIANCE



The typical relative change in module efficiency (with respect to nominal power) at an irradiance of 200 W/m² in relation to 1000 W/m² (both at 25 °C and AM 1.5 G spectrum) is -4.0 % rel.

TEMPERATURE COEFFICIENTS AT STC

P_{MPP} γ [%/K] −0.37 ±0.04	I_{SC} α [%/K] + 0.01 ± 0.02	V_{OC} β [%/K] − 0.29 ± 0.04

NOCT

Nominal Operating Cell Temperature [°C]	51 ± 2

QUALIFICATIONS AND CERTIFICATES

IEC 61646 (Ed. 2), IEC 61730 (Ed.1) application class A, UL 1703 (CSA)

The production site is certified according to ISO 9001 for Quality Management.

40026673

Safety Class II

C US
UL 1703
No 244748

APPROVED PRODUCT

MCS

MCS PV 0151
Photovoltaic System

MADE IN GERMANY

The content of this data sheet is according to DIN EN 50380.

NOTE!
See the Installation and Operating Manual or contact the technical service for further information on approved installation and use of this product.

PROPERTIES FOR SYSTEM DESIGN

Maximum System Voltage V_{SYS}	[V]	1000 (IEC) / 600 (UL 1703)	**Safety Class**	II
Maximum Reverse Current I_R	[A]	4	**Fire Rating**	C
Snow Load (Acc. to IEC 61646)	[Pa]	2400	**Permitted operating module temperature**	−40 °C to +85 °C (−40 °F to +185 °F)
Wind Load (Acc. to IEC 61646)	[Pa]	2400		

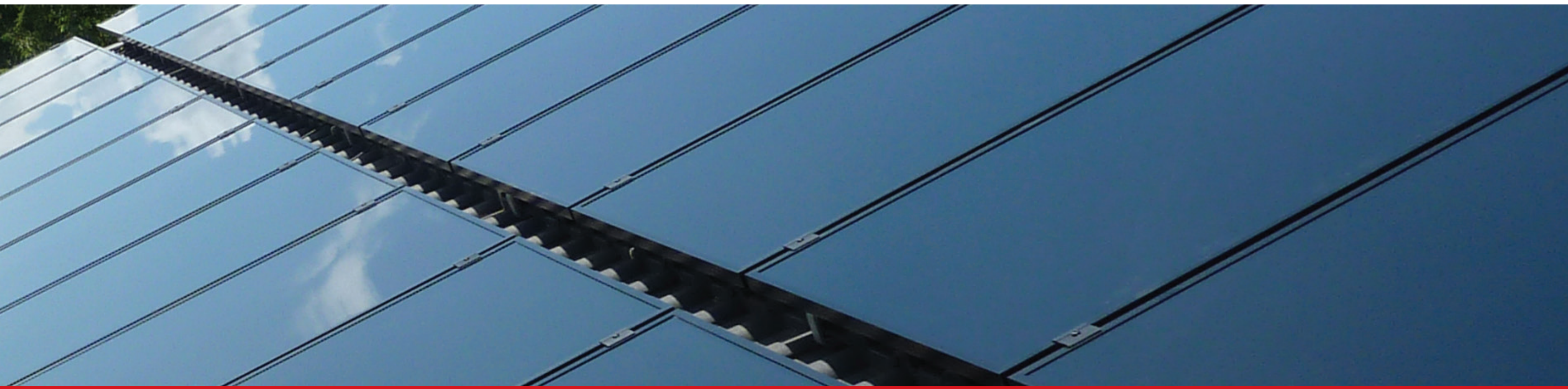
PACKAGING INFORMATION

Measurements including pallet	L 1,313 mm × W 1,131 mm × H 1,016 mm
Approx. gross weight (full box)	770 kg
Maximum no. of stacked boxes for storage	2 on 1 (batch of 3)
Modules per box	44
Max. lorry loading (24 Tons)	30, maximum allowed weight (2 × 8 + 2 × 7)
Max. 40-feet container load (24 Tons)	30, maximum allowed weight (2 × 8 + 2 × 7)

SOLIBRO GMBH
OT Thalheim, Sonnenallee 32–36
06766 Bitterfeld-Wolfen, Germany

EMAIL sales@solibro-solar.com
WEB www.solibro-solar.com

SOLIBRO A COMPANY OF Hanergy



SOLIBRO SL2-F CIGS THIN-FILM MODULE

Generation 2.2 | 125-145 Wp

Higher yield

- Positive sorting (+5 W)
- Low temperature coefficient: -0.32 %/K

Outstanding aesthetics

- Uniform black surface
- Ideal for visually sophisticated PV solutions

Laminate with frame

- Easy to install and specially stable, particularly on smaller rooftop installations

Quality controlled

- 100% inspected via electroluminescence test
- Longer, stricter tests than required under IEC 61646

Tests and certification

- Certification: ISO 9001:2008, ISO 14001:2009, ISO 50001:2011, BS OHSAS 18001:2007, IEC 61646/61730, MCS, UL 1703 (CSA)

10-year product warranty
25-year performance warranty

About Solibro GmbH

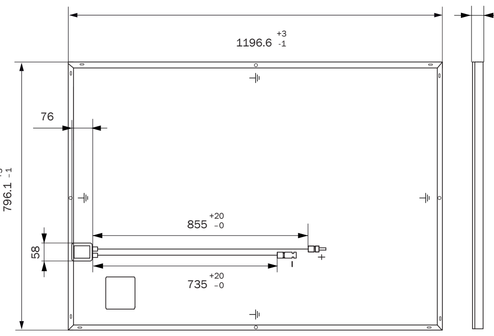
Solibro GmbH is one of the world's leading manufacturers of CIGS thin-film modules, with a production capacity of 145 MW. Solibro has headquarters in Thalheim, Germany and a research site in Uppsala, Sweden, both of which work to develop trailblazing solutions for the company's CIGS products. Solibro supplies products that are sustainable and cost-effective, with extraordinary aesthetics and top quality "Made in Germany".

www.solibro-solar.com

MECHANICAL SPECIFICATIONS

Length	1196.6 (+3/-1) mm
Width	796.1 (+3/-1) mm
Height	30 mm
Weight	18.0 kg
Front cover	4 mm tempered low iron glass with AR coating
Back cover	3 mm float glass
Frame	Aluminum frame, black
Cell type	CIGS [Cu (In, Ga) Se_2]
Junction box	Protection class IP 67, with 1 bypass diode; 76 mm x 58 mm x 15.5 mm
Cable type	Solar cable 2.5 mm²; (+) 855 (+20/-0) mm; (–) 735 (+20/-0) mm
Connector	Renhe 05-6

TECHNICAL DRAWING



All values in mm.

ELECTRICAL CHARACTERISTICS

PERFORMANCE AT STANDARD TEST CONDITIONS (1000 W/m². 25 °C. AM 1.5 G SPECTRUM)[1]

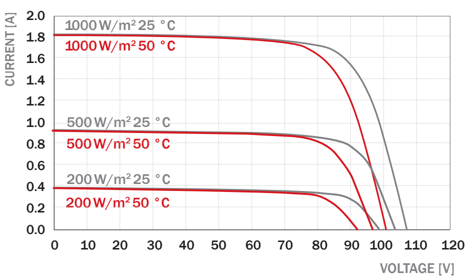
POWER CLASS (+5/-0 W)		[W]	125	130	135	140	145
Minimum Power	P_{MPP}	[W]	125.0	130.0	135.0	140.0	145.0
Short Circuit Current	I_{SC}	[A]	1.73	1.75	1.77	1.79	1.81
Open Circuit Voltage	V_{OC}	[V]	103.4	104.5	105.6	106.7	107.8
Current at P_{MPP}	I_{MPP}	[A]	1.50	1.54	1.58	1.62	1.66
Voltage at P_{MPP}	V_{MPP}	[V]	83.4	84.5	85.5	86.5	87.4
Module efficiency		[%]	≥ 13.1	≥ 13.6	≥ 14.2	≥ 14.7	≥ 15.2

PERFORMANCE AT NOMINAL MODULE OPERATING TEMPERATURE (800 W/m². NMOT. AM 1.5 G SPECTRUM)[1]

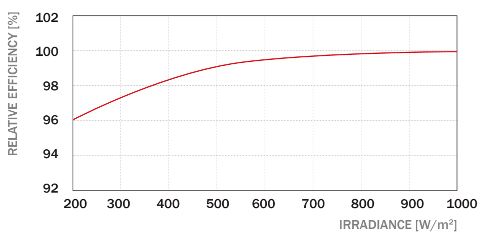
POWER CLASS (+5/-0 W)		[W]	125	130	135	140	145
Minimum Power	P_{MPP}	[W]	94.2	97.9	101.6	105.4	109.3
Short Circuit Current	I_{SC}	[A]	1.39	1.40	1.42	1.44	1.45
Open Circuit Voltage	V_{OC}	[V]	97.8	98.9	100.1	101.2	102.3
Current at P_{MPP}	I_{MPP}	[A]	1.20	1.23	1.26	1.29	1.32
Voltage at P_{MPP}	V_{MPP}	[V]	78.5	79.6	80.6	81.7	82.8

[1] Measurement accuracy P_{MPP}: ± 5%; tolerance I_{SC}, V_{OC}, I_{MPP}, V_{MPP}: ± 10%. All STC measurements are based on a pre-treatment of modules with 20 kWh/m² of light soaking (20 hours at 1000 W/m² and MPP) followed by a cool down to 25 °C.

I-V CURVES AT VARIOUS TEMPERATURES AND IRRADIANCE LEVELS



PERFORMANCE AT LOW IRRADIANCE



The typical relative change in module efficiency (with respect to nominal power) at an irradiance of 200 W/m² in relation to 1000 W/m² (both at 25 °C and AM 1.5 G spectrum) is -4.0 % rel.

QUALIFICATIONS AND CERTIFICATES

IEC 61646 (Ed. 2), IEC 61730 (Ed.1) application class A, UL 1703 (CSA)

The production site is certified according to ISO 9001 for Quality Management.

40026673

Safety Class II

UL 1703 No 244748

APPROVED PRODUCT

MCS PV 0151 Photovoltaic System

MADE IN GERMANY

NOTE!
See the Installation and Operating Manual or contact the technical service for further information on approved installation and use of this product.

TEMPERATURE COEFFICIENTS AT 1000 W/m²

P_{MPP} γ [%/K] –0.32	I_{SC} α [%/K] + 0.01	V_{OC} β [%/K] – 0.27

NMOT

Nominal Module Operating Temperature [°C]	42

PROPERTIES FOR SYSTEM DESIGN

Maximum System Voltage V_{SYS}	[V]	1000 (IEC) / 600 (UL 1703)	Safety Class	II
Maximum Reverse Current I_R	[A]	4	Fire Rating	C
Positive design load (IEC 61215-2)	[Pa]	Up to 3600*	Permitted operating module temperature	–40 °C to +85 °C (–40 °F to +185 °F)
Negative design load (IEC 61215-2)	[Pa]	Up to 1600*		

*tested with a safety factor γ_m of 1.5

PACKAGING INFORMATION

Measurements including pallet	L 1,313 mm × W 1,131 mm × H 996 mm
Approx. gross weight (full box)	585 kg
Maximum no. of stacked boxes for storage	2 on 1 (batch of 3)
Modules per box	30
Max. lorry loading (24 Tons)	40, maximum allowed volume (2 × 10 + 2 × 10)
Max. 40-feet container load (24 Tons)	34, maximum allowed volume (2 × 9 + 2 × 8)

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SOLIBRO


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