Smart façade concept for the renovation of the TU/e main building

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Smart façade concept for the renovation of the TU/e Main Building

(PART I + II)

Krijn Hombrink
February, 2014

TU Delft
Delft University of Technology

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EINDHOVEN UNIVERSITY OF TECHNOLOGY

Stan Ackermans Institute

SMART ENERGY BUILDINGS & CITIES

SMART FAÇADE CONCEPT FOR THE RENOVATION OF THE TU/e MAIN BUILDING

PART I - CORPORATE REPORT

By

K.(Krijn) Hombrink, MSc

A dissertation submitted in partial fulfillment of
the requirements for the degree of
Professional Doctorate of Engineering

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SMART FAÇADE CONCEPT FOR THE RENOVATION OF THE TU/e MAIN BUILDING

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Executive summary

The company assignment proposes a new facade concept for the renovation of the Main Building of Eindhoven University of Technology (TU/e), referred to as Project 3 of Masterplan Campus 2020. The design concept is based on ambitions and targets stated the university Real Estate Management and answers to a practice-oriented problem that can be divided in two parts:

- The façade design is related to existing building constraints and qualities. The building location, shape and construction pose a framework which need to be considered to determine the most suitable façade design;
- The performance of the façade depends on interrelated components. The new façade has to be highly sustainable (1), provide an appealing expression (2) , facilitate user value for building users (3) and reduce total cost of ownership (4).

The report describes a new façade concept, referred to as *Breathing façade*. The concept can be used as guideline for the development of a new, high quality, façade for the high rise of the Main Building. The design concept describes and prioritizes which assets should and shouldn't be included in the façade design to generate the highest value for the TU/e regarding the development of Project 3.

Prior to selecting a combination of high tech technology and devices, such as smart glazing, integrated solar energy panels or a type of intelligent sunshading device, a detailed analysis of the 'problem situation' is performed to determine what is most suitable for the specific building. Secondly multiple performance criteria were defined and prioritized to evaluate which partial solutions generate the most value for the TU/e. As a result, partial solutions are mutually compared on four different performance criteria: sustainability, total cost of ownership, user value and expression. Subsequently, different (partial) solutions are developed based on information from a literature study, workshops and expert consults. As a final result, the façade concept is a prioritization of the best performing partial solutions, 'tailor-made' for the specific situation if the Main Building high rise.

The Breathing Façade is a concept which describes the most suitable design for the facade. However, the performance of the façade is related to the building organisation and applied installation concept. Hence, complementary to the façade concept, the study proposes a building organization- and installation concept. The overall concept proposes a light-flooded volume, open up to the environment and communicative with its surroundings. A relative simple façade design, with an intelligent controllable natural ventilation capacity, would ensure a high amount of fresh air and daylight admittance, while ensuring an efficient cooling of the building. Foremost, the proposed design concept distinguishes itself from alternatives in its ability to facilitate an increased study and work efficiency, which are the core-business of the university. Hence, the Breathing façade can elevate the renovation of the Main Building to a statement for the TU/e as a whole, to potential investors and future students, by providing the best learning environment possible.

The proposed façade concept is the result of a one year, intensive study. Although the relevant information has been gathered in detail and with great care, the scope of the project makes simplifications and assumptions a necessity. The concept proposes a promising perspective on the renovation of the Main Building and provides an innovative design concept which is contrasting to recent building projects on the TU/e campus. As a result, the *Breathing façade* concept proposes a sustainable design attitude that answers to the ambitions of Project 3 and forms a solid foundation for the renovation of the Main Building.

Samenvatting

De bedrijfsopdracht behelst een nieuw façade concept voor de renovatie van het Hoofdgebouw van de campus van de Technische Universiteit Eindhoven (TU/e), genaamd Project 3 van het Masterplan 2020. Het ontwerpconcept beantwoord de gestelde ambities van de universiteit en beantwoord een tweeledig praktijk-georiënteerd probleem:

- *Het gevelontwerp is gerelateerd aan de beperkingen en mogelijkheden van het bestaande gebouw. De locatie, vorm en constructie van het gebouw geven een kader waarbinnen de meest passende oplossing voor het gevelontwerp vastgesteld moet worden;*
- *De prestatie van de gevel is afhankelijk van onderling gerelateerde componenten. Het nieuwe gevelontwerp moet een hoogwaardig niveau van duurzaamheid(1) , uitstraling (2) en gebruikerswaarde(3) bewerkstelligen tegen een gunstige total cost of ownership (4).*

Het rapport beschrijft een nieuw gevelontwerp, Breathing Façade genoemd. Het concept dient als leidraad bij de ontwikkeling van een nieuwe, hoogwaardige, gevel voor de hoogbouw van het Hoofdgebouw. Het ontwerpconcept beschrijft en rangschikt mogelijke deeloplossingen, welke opgenomen dienen te worden in het gevelontwerp, om zo de hoogste totale waarde voor de TU/e te genereren met de ontwikkeling van Project 3.

Als eerste stap, in plaats van het selecteren van een combinatie van hoogwaardige technieken en systemen (zoals smart glazing of een bepaald type intelligente zonwering), is er een gedetailleerde analyse van de het gebouw, ofwel 'probleem situatie' uitgevoerd om zo de mogelijkheden en beperkingen vast te stellen. Ten tweede zijn er meerdere prestatiecriteria gedefinieerd om mogelijke deeloplossingen te toetsen. Deeloplossingen worden geëvalueerd op basis van vier verschillende prestatiecriteria: duurzaamheid, total cost of ownership, gebruikswaarde en expressie. Voorgestelde deeloplossingen zijn ontwikkeld op basis van een literatuur studie, workshops en het raadplegen van experts. Het uiteindelijke resultaat is een prioritering van de meest passende en best presterende deeloplossingen, tailor-made voor de specifieke situatie van het Hoofdgebouw.

Het Breathing Façade concept beschrijft in de eerste plaats de meest geschikte ontwerprichting voor de façade. Echter, de prestatie van de gevel is gerelateerd aan hoe het gebouw verder is georganiseerd en welk installatieconcept wordt toegepast. Daarom, in aanvulling op het gevelconcept, is een totaalconcept voorgesteld. Het totaalconcept behelst een helder en transparant volume, een open omgeving en staat in contact met de omgeving. Een relatief eenvoudig gevelontwerp, met een intelligent regelbare ventilatiecapaciteit als speerpunt, borgt een hoge mate van daglichttoetreding en frisse buitenlucht maar zorgt tegelijkertijd voor een beperkte koellast. Bovenal onderscheid het gevelconcept zichzelf van alternatieven door zijn capaciteit om een hoogwaardige werk- en leeromgeving te faciliteren, namelijk de kernwaarden van de universiteit. Juist daarom kan het Breathing Façade concept de kwaliteit van de renovatie van het Hoofdgebouw optillen naar een hoger niveau en kan het gebouw dienen als een krachtig statement van de TU/e naar potentiele investeerders en toekomstige studenten; het bieden van de beste leeromgeving om te presteren.

Het voorgestelde façade concept is het resultaat van een één jaar durend onderzoek. Ondanks dat relevante informatie is verzameld met uiterste zorg, maakt de scope en complexiteit van het project enige aannames en simplificaties noodzakelijk. Het Breathing Façade concept geeft invulling aan een duurzame ontwerphouding die past bij Project 3 en vormt een solide basis voor de renovatie van het Hoofdgebouw.

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Chapter 1: Introduction

1.1 Project description

The company assignment is a one year during study on the façade design of the Main Building high rise. Outcome of the project is the *Breathing façade* concept, which describes the most suitable design principles for the complete building design. . Hence, the project scope includes the development of the most suitable building organization and installation concept and has a more detailed focus on the façade design. The project includes a detailed building and environment analysis, a study on façade performance criteria and studies the performance of different, mutually related, possible design components. Outcome of the study is translated to a design concept.

1.2. Client

The project commissioner of the company assignment is TU/e Real Estate Management, one of the support services of the university. They are responsible for the entire real estate development and park management of the 75 hectares of land owned by the TU/e. Real Estate Management caters for the project management and management of all buildings, installations and infrastructure of the campus. Moreover, Real Estate Management acts as advisor to the Executive Board, the departments and housing services. The TU/e Real Estate Management is principal of Project 3 of Campus 2020. They have to ensure the desired level of performance facilitated by the Main Building over its total lifespan.

1.3. Context

Eindhoven University of Technology is one of the three technical universities in the Netherlands. It is located on a green campus, positioned in the center of Eindhoven in the middle of the Brainport region. With the implementation of *Strategic Vision 2020*, the university aspires to enhance its international position to within the top-100 universities [1]. The main aim is to increase the size and quality of education and research.

To fulfill stated ambitions, the campus will be transformed according to the Masterplan Campus 2020. Multiple building projects are rolled out to reshape the university campus into a high-grade science park: an attractive environment where, in addition to the university, international institutes, student housing facilities, incubators and industrial partners will be established.

Masterplan Campus 2020, as shown in figure 1, includes a fundamental modernization of the campus and building stock of the university. All departments will be relocated adjacent to the Green Strip, a connecting, car-free zone. Most dominant are four large building projects which will be completed in a pre-arranged order and of which the final project will be completed in 2020 [2].

Project 3 of Masterplan Campus 2020 consists of the thorough renovation of the Main Building and will be tendered as Design & Build project. Constructed in 1963, the iconic building has always been the heart of campus and the true flagship of the university. To meet contemporary demands, the colossal building will be completely stripped and refurbished. The Main Building will house both departments of Industrial Design (ID) and Industrial Engineering & Innovation Sciences (IE & IS), as well as several support services of the TU/e. Renovation starts in 2015 and completion is expected end of 2017 [3].

Figure 1. Impression of Masterplan Campus 2020 (source: Masterplan TU/e Sciencepark)

1.4. Project objectives

Key to the success of the renovation of the Main Building high rise is the development of a new façade, since the façade has a large influence on the overall capability of the building to meet targets and ambitions of Project 3. The company assignment has been performed in an early stage of Project 3, prior to tendering. In this early stage, insight in the performance of possible façade components can greatly improve the quality of the final façade design by defining the requested demands for the tender of Project 3. As a result of this study, a design concept has been developed that can function as a guideline for the development of Project 3.

As a first objective, the performance criteria of the façade design concept have been defined. The quality of the proposed design concept is based on two parts:

1. The façade design is related to existing building constraints and qualities. The building location, shape and construction offer opportunities and constraints to which the façade concept needs to relate;

2. The façade design has to fulfil interrelated performance criteria in long-term perspective, as to guarantee a high level of sustainability (1), enhance the corporate identity, relate to cultural historical values (2), facilitate building users (3), and insure low total costs of ownership (4).

An overview of the extensive amount of aspects is given in appendix I. Prior to the development of the design concept, the design constrains and criteria related to both these parts are studied and defined.

As a second objective, the performance of possible partial façade solutions have been studied: The façade design is a complex system with interrelated components, varying from more abstract components such as the climate installation principle and façade type, to more specified components such as the type of glazing or sunshading. The façade concept relates and defines optimal solution per component and poses a hierarchy between all components. This way, the façade concept can be beneficial on more abstract levels only, or give guidance on more itemized levels of design.

Chapter 2: Approach

2.1. Methodology

Main target of the company assignment is to develop a theory, by means of a design concept, which supports the decision making process related to Project 3 of Masterplan Campus 2020. The developed concept is based on information obtained by different research techniques:

- Building analysis, including building performance simulation;
- literature survey;
- workshops and expert consults.

The project problem has a large complexity, as a result of the interrelatedness of design components, and a large project scope. These two aspects make it too difficult to define one comprehensive solution, a global optimum. Therefore the following approach is taken. The design concept will be developed in phases, as shown in appendix F. An object analysis is performed to define object opportunities and constraints. This is a refinement of the project problem. Second, based on obtained information, different partial solutions are generated. By means of a performance study, local optima per partial solution are defined and a prioritization between partial solutions is posed. Finally, the information is interpreted in one coherent and communicative idea, the façade concept.

2.2. Definition of values

Project 3 will be tendered as a Design and Build project and performance will be managed by means of output specifications that describe the (intangible) capacity of the building. After renovation, the building will house two departments and most TU/e support services. Moreover, located at the heart of campus, the building will be restored as the flagship of the university. In order to facilitate the long-term interests of the TU/e, the building need to fulfil several, interrelated, conditions, regarding architectural expression, total cost of ownership and sustainability. However, most significantly, the aim of Project 3 should be to create a building which facilitates and expresses an optimal environment for students and researchers to excel in their endeavours.

The façade design is part of the building and its performance is interrelated with other building elements. Main question for this study is what (basic) façade design principles generates the most value to the TU/e? In which façade components, such as an additional façade layer, dynamic sunshading or a higher quality of glazing should be invested? Both tangible and intangible values provided by the façade design have to be considered in this perspective.

2.3. Performance criteria

To compare the value of different partial solutions, or components, multiple performance criteria were defined. The performance criteria are described in more detail per partial solution and are further explained in the technical report:

1. *Sustainability* - The TU/e is obliged to enhance their sustainable performance of the campus, related to material, water and energy efficiency. The Greencalc (4.0) A+ label, MIG score of 330-490 is used in Project 3 as target for the desired ambition level of sustainability. Water use is not significant for the façade design. Material- and energy efficiency are defined as tangible performance criteria for the façade concept;

2. *Expression* – The Main Building is of historical and cultural relevance to which the façade concept needs to relate [4]. Moreover, the Main Building is the flagship of the TU/e, an icon that is noticeable immediately when visiting the campus. Enhancing the corporate image of the university results in higher student subscriptions and international attractive environment for top-researchers;

3. *User value* – A high quality environment provided by the design concept support less tangible values as health, comfort, productivity and less absenteeism of students, staff and researchers. These values are related to the core activities which the university should facilitate: performing research and education. The user value related performance is defined by building physical and architectural qualities.

4. *Total cost of ownership* – Investment costs and operational costs are considered over time. Although it is difficult to define related costs per solutions in this early, abstract stage of the design process, as explained in appendix H, some indications can be given:

   - TU/e is able to buy electrical energy at 0,07651 €/kWh [5]. This is a low energy price which makes potential investments in energy saving solutions less financially attractive;

   - Assumed investment and maintenance costs of different partial solutions are derived from cost indications as defined by relevant market leaders, shown in appendix C;

   - The effect of an investment in user value (the effect of increased healthiness, productiveness, occupancy rate on the endeavours of staff and students) is difficult to quantify. Most tangible is absenteeism due to sickness. The Main Building will house most supporting staff and two large departments. Decreasing total personnel absenteeism by 1% would save €42.000/year [6, p. 103];

   - However, the effect of increasing user value is far greater. Based on cost indications, as described in appendix H, the ratio between the financial savings, due to an increase of user value compared to additional energy savings, could be estimated: TU/e has low annual costs related to energy use (±6,3 million) and high costs regarding staff and students (±€200 million) [6, p. 78]. The ratio between both expenses (energy: users) is 1:32. Hence, increasing the effectiveness of staff and student endeavours by 1% could be considered equal to an energy saving of 32%.

Chapter 3: Building analysis

The Main Building high rise, shown in figure 2, is a distinctive shape and construction in a distinctive environment. As a starting condition for Project 3, the existing façade of the high rise will be completely removed and the building will be stripped to its concrete construction. The remaining building construction is of great influence on the performance of the new façade design. An extensive analysis of the existing object has been performed to distinguish multiple potential benefits and threats to which the façade design should relate. A brief overview is given below.

3.1. Opportunities

A most fitting façade design depends on the opportunities provided by existing building construction and its environment. As a results of a broad analysis of the building and its environment, several opportunities were defined to which the design of the façade should relate:

1. The environment offers distinctive characteristics: the building is positioned in the heart of an attractive green park landscape with clean air and a friendly wind climate/ Moreover, despite the inner city location, there is almost no noise pollution. The environment allows a façade which is open to exterior which could be exploited by uses natural ventilation and possible view.

2. Moreover, unlike compact building shapes such as the Meta Forum high rise, the slender shape of the high rise allows a deep daylight admittance, easily able to cover 50% of total floor area, and an easy and deep access of natural ventilation through the façade.

3. The high rise construction consists of alternately fixed heavy mass structural floors and flexible lightweight floors. The existing structural principle offers several potential qualities:

    - Organizing the high rise in compartments of two floors height, in total approximately 1000 m^2, offers the most overall value regarding fire safety, flexibility, costs and user value;

    - Openings in each structural floors allow the placement of multiple vertical installation shafts. This organization principle should be used to avoid potential problems with limited floor heights between floors;

    - When 50% of flexible floors are fulfilling programmatic needs, placement should be done adjacent to alternately the east- and west façade, to create a better controllable, energy efficient east/west-zoning with an optimal use of daylight;

    - Enabling ventilation through the façade avoids potential problems with the placement of, and dependency on, additional needed installations for mechanical air inflow.

3.2. Constraints

In addition of taking benefit from distinctive qualities, the façade should be designed to avoid or reduce the effect of existing threats. When considering the integral performance of the façade, several potential difficulties for the façade design are distinguished:

1. Due to its shape and orientation, the Main Building high rise forms a ‘perfect solar collector’. Especially during warmer months, this will cause a high cooling load. However, blocking solar

radiance is not always a beneficial option: It can result in lower user comfort and an increase of heating demand in colder periods. Because of the high (financial) efforts needed to repel direct solar radiance and its negative effect on other aspects, the focus of the façade design should not skew too much on repelling solar radiance admittance. Increasing the energy efficiency of the building should be achieved by other means as well.

2. A high transparent façade, in line with TU/e corporate architecture and stated cultural historical values of the Main building can be expected. Moreover, an efficient use of floor space will result in a high internal heating load. For these two reasons, a high accumulation of heat and related internal cooling load can be expected. Even when repelling external energy gains most efficient, the building will accumulate heat which can cause comfort problems and a high cooling load. Expelling this heat must be done in the most energy efficient way.

3. The high rise structural principle offers few threats relevant to potential façade design:

   - Major constraint of building construction is the limited floor height between a structural and flexible floor. Ensuring a large floor height in work and study spaces is essential for the quality of use. Especially ducts for central mechanical ventilation and suspended ceilings pose a threat for available the free floor height;

   - Covering structural floors with installation floors or suspended ceilings will reduce the capacity of available thermal mass to absorb or radiate thermal energy.

Figure 2. Photograph of the Main Building (10-12-2013).

Chapter 4: Performance study

A façade design consists of a combination of different, interrelated, partial solutions. As a result of performed literature study, different partial solutions were defined, as shown in figure 3. Based on all four mentioned (p.3) performance criteria, local optima are defined for each partial solution and a comparison is made between local optima in order to prioritizes the importance of different partial solutions. This performance study is described in full detail in the technical report. A short description and overview of the performance of different partial solution is given below.

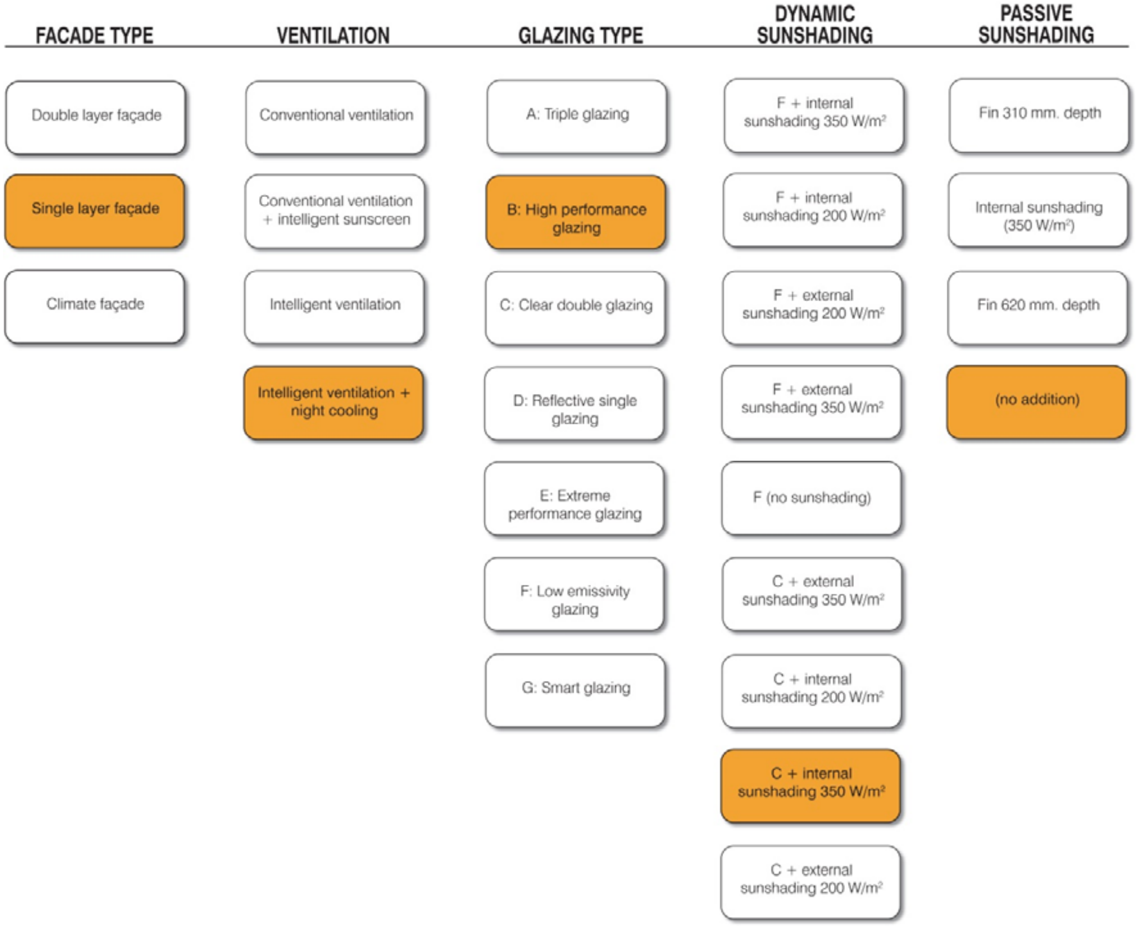


Figure 3. Overview of partial solutions, local optima are given in orange

4.1. Façade types

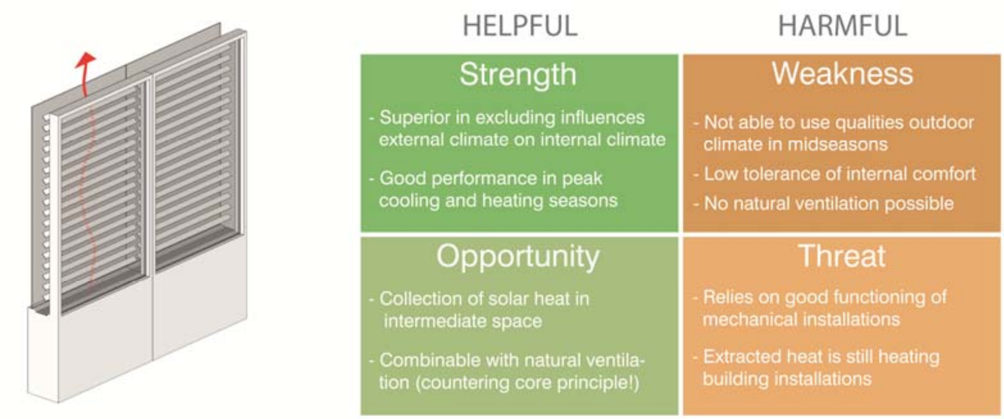
Since the decision to fully renew the façade is outside the scope of the project, primary importance of the performance study is to determine which type of façade is most effective. Basically, the façade could have an additional layer to increase performance. There are two basic, highly contrasting, organization principles for adding a second layer, namely a double layer façade or a climate façade. Both principles are considered as additions to a basic, single layer, façade. Hence, both type of façade are described below and compared to the characteristics of a single layer façade (shown in figure 4.).

HELPFUL	HARMFUL
Strength - Cost efficient and robuust, low risk, solution - Most slim construction	**Weakness** - Unprotected external sunshading - Lower thermal performance in peak high summer and winter season
Opportunity - Savings due to 'simpler' façade concept can be used otherwise, (e.g. higher quality materials) - Façade design partly self-shading	**Threat** - Soiling and damaging of unprotected external sunshading due to heavy windload, rain etc. - Higher risk night ventilation due to uncontrollable openings/rain

Figure 4. Characteristics single layer façade

Climate façade

The characteristics of a climate façade is summarized in figure 5. Mainly, a climate façade will mostly performs better than a single layer façade when outside condition is far too cold or too warm. This way, especially in summer and winter season, the heating/cooling load for HVAC installations is as low as possible. The Main Building is positioned in a relative soft climate with small temperature differences. Moreover, it will provide benefits when there is external noise pollution and provides a good solution or when natural ventilation is not possible due to heavy wind load anyway.



HELPFUL	HARMFUL
Strength - Superior in excluding influences external climate on internal climate - Good performance in peak cooling and heating seasons	**Weakness** - Not able to use qualities outdoor climate in midseasons - Low tolerance of internal comfort - No natural ventilation possible
Opportunity - Collection of solar heat in intermediate space - Combinable with natural ventilation (countering core principle!)	**Threat** - Relies on good functioning of mechanical installations - Extracted heat is still heating building installations

Figure 5. Characteristics climate façade

However, potential benefits are not useful for the Main Building: Large temperature differences between internal and external climate are scarce, external climate can be even beneficial. In addition, natural ventilation is a good possibility on the campus and there is almost no noise pollution.

Double skin façade

The characteristics of a double skin façade are given in figure 6.. In contrary with climate facades, a double skin façade creates a buffer layer which allows high rise buildings to keep interacting with the outdoor environment. Main advantage of a double skin façade is the possibility of natural ventilation in situations where otherwise ambient environment would be too noisy or windy. With advanced control, heating load might be lowered. Additional advantage is the intermediate placement of sunshading, almost performing as well as external sunshading but greatly reducing negative effects and still allows a possible smooth façade expression.

HELPFUL	HARMFUL
Strength - Good adaptibility to outdoor climate, (using natural ventilation, closing cavity in peak seasons) - Protection external sunshading	**Weakness** - High (operative) costs - Own weight is relative high - Optical 'distance' interior-exterior
Opportunity - Good ventilation of solar panels, resulting in higher yield - Good controllable night ventilation	**Threat** - Thickness facade (600 mm.) : not matching with table-construction - High risk: ventilation rate in intermediate space is crucial

Figure 6. Characteristics double skin façade

However, as aforementioned, the main advantages of a well-designed double skin façade are not beneficial for the situation of the Main Building. Moreover, a double skin façade is costly, demands the use of additional material and will be a higher structural load. In addition, the ventilation of the intermediate space is very sensitive for design errors and when not designed accordingly, major cooling problems can occur which poses an additional risk.

Total cost of ownership

Although costs are difficult to estimate in an early stage of the design process, literature gives an indication of 100-150 €/m^2 additional costs for a double skin façade [7]. Additional cost related to a climate façade are assumed to be half. Since the Main Building high rise has a relative large façade surface, additional costs would be significant, approximately € 0.75 million (climate façade) € 1.54 million (double skin façade) which would be over 10%-15% of assumed total budget estimated for the façade construction.

Conclusion

Study shows that the advantages of both type of additions of an extra façade layer prove to be few or less valuable than included disadvantages, related to expected extra costs material use and risks. An investment of 10-15% of assumed total budget is simply not worth the very limited advantages. Moreover, disadvantages can be even more dominant, making the investment even less attractive. An overview of the performance of each type of façade is given in appendix D, table 3. Concluding, a single layer façade type is the best trade-off for the high rise of the Main Building.

4.2. Glazing

There are many different sorts of glazing available, varying greatly in costs, energy efficiency, quality of daylight admittance and architectural expression. Most common and promising are spectral selective coatings. Advantages and disadvantages of coatings are given in figure 7.

HELPFUL	HARMFUL
Strength - Repels solar energy up to 75% and 60% light admittance - Almost no operational costs	Weakness - Green/greyish colour instead of clear glazing
Opportunity - 'Smooth' appearance of facade	Threat - Non adaptable, reducing yearly performance by repelling 'free' solar heat and daylight in colder/darker days.

Figure 7. Glass coating principle

The performance of glazing can be defined according four aspects:

- Firstly, the *total solar energy transmittance g*, which denotes the share of the incoming solar energy, which is converted into heat inside the indoor space;
- Secondly, the *thermal transmittance U* that describes how much heat is transferred through the glazing per square meter and Kelvin temperature difference between inside and outside;
- Moreover, investment costs **(€) are relev**ant. Operational costs are considered to be equal between different types of glazing;
- and light admittance (LT, or *licht toetreding factor LTA*) are important aspects to determine which type of glazing offers highest performance.

Representing the broad scope of available glazing types, six different types of glazing chosen, as described in appendix C, table 1. The types of glazing were compared on difference in performance:

1. *Energy performance* - The thermal performance of all six types of glazing is mutually compared on the difference in total thermal load and the balance in cooling and heating load, as shown in appendix A, figure 10. Glazing type E and B provide best thermal performance. In

addition to thermal energy efficiency, glazing type B allows a higher amount of daylight admittance (related to LT-factor), which will significantly reduce use of artificial lighting, resulting in further electrical energy savings. Regarding to these three aspects, the performance of glazing type B is considered most optimal.

2. *User value* - Regarding glazing, thermal comfort (downdraft and cold radiance), and visual comfort are most relevant. When comparing type B and E, glazing type B has a LT factor of 70%, which allows 17% more daylight admittance than glazing type E. Furthermore, the light will be less coloured, dependant on the type of coating, compared to glazing type E.

3. *Total cost of ownership*- When comparing annual costs and savings due to energy efficiency, the performance of different types of glazing are compared to conventional, standard double glazing. All types of glazing have equal, low, operative costs, which are left out of the cost comparison. Investment costs and financial savings due to energy savings over time vary greatly for different types of glazing. Glazing E and B, which are most promising due to related energy savings, are compared on total costs over time, as shown appendix B, figure 17.

   Excluding interests, both types of glazing will deliver in time a return of investment. As shown in table 1 of appendix C, glazing type B has a significant lower investment cost compared to glazing type E and a payback time of about thirty years. Glazing type E will cause a larger additional investment cost of around € 311.000 compared to glazing B and will have a payback time of around 55 years, 25 years longer than type B. Moreover, it is questionable that the building will not be refurbished after 40-50 years. When interests are included, glazing type E causes annual losses. Glazing type B will have payback time which extends beyond 60 years. Based on cost performance, glazing type B performs best.

4. *Material efficiency* - Glazing type D only has a single pane, using far less material than glazing type , B, C and E. Glazing type A has three panes, This is shown in appendix C, table 1, resulting in additional use of material.

Conclusion

Six different types of glazing, representing the broad scope of options, are compared on their integral performance, as shown in appendix D, table 4. Glazing type B and E perform the best on thermal energy efficiency. Although glazing type E results in a more preferred energy balance, costs are far higher, savings on artificial lighting are lower and especially visual comfort is greatly reduced. Glazing comparable to type B, conventional high performance glazing, performs best because it offers a better balance in energy efficiency, costs, and provided comfort.

4.3. Dynamic sunshading

Major function of a sunscreen device is to regulate sunlight admittance to the building. Instead of fixed, passive, coatings, the performance of glazing could be enhanced by the addition of dynamic, adaptable sunscreen devices. Combining both solutions is another possibility but far less efficient. The performance of internal and external positioned sunshading devices are given below:

- *External sunshading* - External sunshading is mounted exterior surface of the façade. The system exist of a motor to adapt the position of the shading, control system and some sort of shading screen or lamellae. The system can be integrated in the façade and need some sort of frame or guidelines for fixation. Advantages and disadvantages of an external sunshading device are given in figure 8.

HELPFUL	HARMFUL
Strength - Repels direct sunlight best - Adaptable over time - Active untill windpower 7-8 Bft	Weakness - High (operation) costs - High rise gives low accessibility
Opportunity - Allow entrance of 'free' heat during colder days - Clear glass, offering better quality daylight (less green-/greyish) and contact in- exterior	Threat - High risks on malfunctioning, causing disturbance (in appearance and work environment)

Figure 8. External sunshading principle

- *Internal sunshading* - Internal sunshading device is comparable to external sunshading except for the positioning. Positioned behind the protective inner side of the façade, internal sunshading performs less in repelling solar radiance but requires less investment and operative costs. Appearance might be another reason to apply internal screens. Advantages and disadvantages of an internal sunshading device are given in figure 9.

HELPFUL	HARMFUL
Strength - Repels direct sunlight average - Adaptable over time - High accessibility	Weakness - Average (operation) costs - Less effective with coated glazing than non-coated glazing
Opportunity - Clear glass is possible, offering better quality daylight (less green-/greyish) and contact in- exterior - Low impact on expression facade	Threat - Not the same as light regulation - High risks on malfunctioning, causing disturbance (in appearance and work environment)

Figure 9. Internal sunshading principle

Performance

The performance of sunshading devices depends on the type of glazing, positioning and the control criteria:

- As described, the positioning of the sunshading device has a great effect on energy efficiency, appearance and operative costs. Both internal- and external devices are considered;

- The performance of sunshading devices is related to the applied type of glazing. If the glazing is already reflective due to coatings, the effect of additional sunshading will be less. Therefore, clear double glazing and glazing with only a low-emission coating, both cheap types of glazing with a higher solar energy and daylight admittance, are considered;

- Different configurations of sunshading control can be applied. Activation at an insolation level of 200 W/m^2 (raise at 175 W/m^2) and 350 W/m^2 (raise at 300 W/m^2)are considered ;

As a results, eight different configurations of sunscreen devices are distinguished that represent available solutions. Performance are mutually compared and compared to a solution with low emissivity glazing (glazing type F)with no sunshading device on integral performance:

1. *User value*- Sunshading device, unlike light regulation devices, can have a negative effect on provided visual user comfort. Activation of sunshading at 200 W/m^2 insolation results in a low daylight admittance which results in less visual comfort *[8]*. Therefore, sunshading devices with a control criteria of 350 W/m^2 perform less than when controlled with 200 W/m^2 criteria.

2. *Material efficiency* - External sunshading has to withstand heavy wind loads, requiring more robust material use for cabling and screens. Internal sunshading can be dimensioned light and be composed out of materials which do not need to withstand external hazards. From the perspective of material use, internal sunshading is preferred over external sunshading.

3. *Total cost of ownership*- External sunscreen devices are more expensive on long term perspective due to maintenance and replacement costs, as shown in table 2 of appendix C. Differences in energy savings have less influence on a mutual comparison of financial performance. Cost over time are shown in figure 18, appendix B.

4. *Energy efficiency* - Thermal energy performance of each configuration are given in appendix A, figure 12. Moreover, savings on artificial lighting are considered. Shading devices with a control criteria of 200 W/m^2 (compared to 350W/m^2)result in far higher energy use on artificial lighting.

Partial conclusion

The performance of a sunshading is related to the type of glazing, control criteria and position of the screen. Nine different configurations are compared, as shown in appendix D, table 5. Most significant is to estimate which type of sunshading device would be most beneficial, to compare its performance with fixed coatings. As a result, internal sunshading devices, activated at an insolation level of 350 W/m^2 (solution H) provide the best overall performance and will be compared to the highest performing coating (glazing type B).

4.4. Comparison of glazing with dynamic sunshading

Different techniques are available to regulate sunlight. However, most significant in early stage of the project is to estimate compare the performance of a dynamic sunshading combined with a cheaper, clear type of glazing and a glazing with a fixed reflective coating.

1. *Energy efficiency* - The thermal energy performance of sunshading device are compared with the best performing coating, as shown in appendix A, figure 13. Moreover, the performance of a combination of both is showed. Thermal energy savings due to best overall performing internal sunshading device is far less when compared to the thermal energy savings caused by coatings. A combination of both gives even a higher thermal energy savings, but the difference with only reflective coating is only minimal. However, to compare the effect on of both solutions on daylight admittance (and related energy savings on artificial lighting, further study is needed. Coatings reduce daylight admittance by 20-35% compared to clear glazing. Dynamic sunscreens reduce daylight admittance when active and remove exterior view. The differences in energy savings related to daylight admittance are assumed to be relative small compared to differences in thermal energy savings. Therefore, the energy performance of glazing B is best.

2. *User value*- Glazing B causes less thermal discomfort, due to cold radiance and downdraught are less on cold days (when sunscreen device is not active). As described in the technical report, both alternatives need an additional light regulation device. As described in the section of energy efficiency, further study is needed to determine the effect related to visual comfort.

3. *Material* - Compared to coatings, a sunshading device is an addition which is far less material efficient.

4. *Total cost of ownership* – Investment cost and maintenance cost are given in appendix C, table 2. The costs over time of best performing coating and both the best performing internal and external sunshading device are given in appendix B, figure 18. Cost indications are obtained from different relevant market leaders. Cost related to internal and external sunshading devices are far higher in both investment costs as maintenance costs when compared to a reflective coating. Coated glazing need no additional maintenance and cleaning cost compared to clear glazing. Therefore these costs are left out of the comparison. Sunscreen devices need to be replaced once every 20 years and require additional yearly maintenance.

Partial conclusion

The performance of a the best performing sunshading device, combined with cheaper, more transparent glazing, and glazing with fixed reflective coatings are compared. Overall, glazing with a reflective coating, comparable to the characteristics of glazing B performs overall better than the best performing configuration of sunshading device, as shown in appendix D, table 6, and should be given priority in the façade concept.

4.5. Ventilation

In addition to regulating insolation and daylight admittance, the façade can regulate the ventilation of the building. Making use of natural ventilation and enabling a high quality of daylight entrance increase user values and reduces energy use for mechanical ventilation and artificial lighting. However, both aspects can result in higher thermal loads and thermal discomfort. An intelligent and dynamic control of the ventilation capacity could significantly reduce thermal losses. As a result of the performed study, a suitable ventilation concept is defined. The proposed concept comprises an automatically controllable façade openings (grills and windows), which can be regulated based on external temperature or internal CO^2 concentration. This concept is described in more detail in the technical report. The performance of proposed, intelligent, ventilation concept is compared to different alternatives, including intelligent controlled sunscreen device:

A. High performance glazing, no intelligent ventilation device and no intelligent sunscreen device

B. High performance glazing, intelligent sunscreen device but no intelligent ventilation

C. High performance glazing, intelligent ventilation 3,0 $dm^3/s/m^2$ during daytime only

D. High performance glazing, intelligent ventilation (1,75 $dm^3/s/m^2$; 9,0 $dm^3/s/m^2$, night cooling)

The performance of each solution is given below:

1. *Energy performance* - The thermal performance of all four solutions is given in appendix A, figure 14. When comparing the performance of four alternatives, solution D performs best, reducing thermal energy use by 30% compared to solution A and B. Moreover, intelligent ventilation does not reduce daylight admittance. Despite sunscreens are only activated at 350 W/m^2, it will always reduce daylight admittance, which will result in an increase of energy used for artificial lighting. In addition, solution D reduce the need for mechanical ventilation, further increasing energy efficiency. Solution D performs better than C due to the ability of night ventilation.

2. *Total cost of ownership*- The additional cost related to intelligent ventilation device are given appendix B, figure 19. Initial investment costs are derived from costs of internal sunshading: costs for internal sunscreen device are related to the cost of motor device, control system and screens. The costs for motor and control system for ventilation system are assumed to be approximately equal. Cost for additional openable windows are assumed to be equal to the costs of the screens.

   Regarding operative costs, replacement time of a ventilation device is comparable to the replacement time of sunscreen devices. However, costs are assumed to be lower since only the motor and actuator system need to be replaced, keeping the openable windows and grills. A sunscreen device needs to replace the screens as well. Replacement costs of an intelligent ventilation concept are therefore assumed 50% of the replacement costs of sunscreen devices.

   Total cost over time of solely glazing B are lowest. Sunshading devices have the highest operational costs. Even when additional financial savings due to energy savings on lighting and ventilation are left out of the comparison, the intelligent ventilation solution provides higher savings. When additional savings or an increase in comfort is desired, an intelligent ventilation device proves to be the most efficient addition.

3. *Material efficiency* - All solutions use the same amount of glazing and type of façade construction. Sunscreen devices are the largest addition to the façade. However, effect on material use is minimal and material efficiency is less significant in determining integral performance.
4. *User value*- The performance related to user value of different solutions are given below:
   - As mentioned before, sunshading device, unlike light regulation devices, can have a negative effect on provided visual user comfort. To reduce visual discomfort, the device is only active at 350 W/m^2. However, provided visual comfort remains lower compared to other solutions.
   - Intelligent ventilation devices make ventilation visible for building users. In addition, it provides a higher indoor air quality more effective. Intelligent ventilation provides a greater interior comfort compared to intelligent sunshading devices.
   - Intelligent ventilation makes ventilation through the façade more feasible. Intangible effects of façade ventilation are significant, the smell of fresh air coming for outside, being in contact with exterior environment and the provides thermal comfort due to slight fluctuations in temperature.

   From the perspective of user value, including comfort, productivity and health, intelligent natural ventilation, solution C and D, perform better compared to other studied solutions.

Figure 10. Impression of an intelligent ventilation concept (product: Windowmaster, project: Gensler Architecture, PNC Plaza, 2015)

Conclusion

The comparison of integral performance is shown in appendix D, table 7. The performance of adding such a ventilation concept to the façade design is compared to alternative solutions of a conventional, central mechanical ventilation concept (solution A) and the addition of an intelligent sunscreen device (solution B). Intelligent natural ventilation including night cooling, provides the highest integral performance. When compared to the same type of glazing with conventional ventilation concept, costs are estimated to be considerably higher. However, performance on energy efficiency and user value are far greater, making a façade with intelligent natural ventilation a more beneficial solution compared to alternatives.

4.6. Passive sunshading

The performance of the façade can be enhanced by alterations or additions which cause some form of self-shading that can increase energy efficiency. The façade can be modified in different ways. An impression can be seen in appendix E, figures 20-22. Two different fin-configurations are considered to be the most effective solution and their integral performance is compared with two alternatives:

A. Façade with glazing B + vertical fins of 310 mm. depth for east and west façade;

B. Basic, flat, façade with glazing B and internal sunshading device;

C. Façade with glazing B + vertical fins of 620 mm. depth for both east and west façade;

D. Basic, flat, façade with glazing B, high performance glazing.

A brief summation of overall performance of these four alternatives is given below:

1. *Energy performance* - The performance of a fin addition to the façade is given in appendix A, figure 15. A fin construction of 620 mm. depth would reduce the cooling load significantly. A fin of 310 mm. depth, reduces energy use by 7% which is still slightly more effective in saving energy compared to intelligent internal sunshading device, solution B. In additional a fin reduces daylight admittance, increasing use of artificial lighting.

2. *Total cost of ownership* - The additional costs for a fin construction are difficult to estimate. It depends greatly on material use and quality of imbedding in the façade. However, costs are always higher compared to no addition. Moreover, compared to a flat façade, maintenance costs would increase due to difficulties with cleaning and cleaning of the fins itself. In addition, comparing a low-tech fin construction with a high-tech, dynamic sunshading device, costs would certainly be lower. Finally, energy savings of a fin construction is greater, resulting in larger financial savings on energy.

3. *Material use* - The fins are made of robust materials which are able to withstand weather conditions and have a desired architectural impression. When the fins would be made from aluminium, wood or semi-transparent glass, the material use for the façade would increase, decreasing sustainable performance of the façade design.

4. *User value* - Fins will decrease the diffuse and direct light admittance to the interior. Moreover, visual contact to exterior environment is reduced. This negative effect is far less when the fins are reduced from 620 mm. to 310 mm. In addition, additional research has to point out if fins do not provide acoustic discomfort or reduce the possible ventilation rate of the façade.

Conclusion

The performance of a fin construction compared with alternatives is shown in appendix D, table 8. When comparing fin construction with alternative of intelligent sunshading, the overall performance of solution A is not convincing but slightly better than solution B, dynamic sunshading devices. Most of all, further research would be needed to estimate additional risks related to acoustic discomfort and alteration of the ventilation capacity of the façade. Until effects are more certain, fins or other passive sunshading additions should not be included in the façade design.

4.7. Summary of façade performance

A façade can be as complex as desired, able to adapt and perform to changing circumstances. However, a limited budget demands that the effect of different partial solutions have to be compared on their integral performance. Benefits of different alternatives per partial solutions are compared to determine local optima. In addition, local optima are mutually compared to determine which solution will deliver the highest overall value. Outcome of the performance study is stated below:

1. As basic principle, the façade should be a single layer façade. More complex facades, double layer and climate facades, are less suitable for the situation of the Main Building or benefits are not (cost) efficient enough;
2. A study on available types of glazing shows that glazing with both high transparency and energy transmittance, such as conventional 'high performance glazing', is integrally performing better compared to market available alternatives;
3. Comparing the performance of different configurations of in- and external sunshading devices shows that internal sunscreens with automatic control device offers the best performance when related to operative costs;
4. However, if budget is limited, an intelligent ventilation system using natural ventilation provides even more integral value;
5. Independent of the implementation of a sunshading device, an additional light regulation device should be part of the façade design to ensure visual comfort;
6. Additional passive sunshading devices, such as vertical fins, provide significant savings on cooling, but reduce visual comfort and material efficiency. Moreover, fins pose a risk several risks related to noise pollution and wind flows, which need further study. Until then, the performance of passive sunshading, such as fins, is assumed to be less compared to a dynamic internal sunshading device.

The proposed façade concept consists of multiple aspects which are studied by different means. As shown in figure 3, the concept is stooled on a more abstract idea of building organisation on which the following, more concrete, aspects are based. Study outcome results in a hierarchy of optimal solutions, as shown in figure 11.

Chapter 5: Design concept

The *Breathing Façade* is a design concept which prioritizes and defines best performing partial solutions which will bring overall highest value to the TU/e. The design concept functions as tool, or guideline, for the design process of Project 3 in order to achieve the best, integral, long-term performance for the specific situation of the high rise of the Main Building. The outcome of performed study has resulted in a list of guidelines which are organized in the three levels: Building organization-, installation- and façade level. Design guidelines are summed up below:

5.1. Building organization

The façade design is related to the integral building design. Based on performed analysis and literature study, the following guidelines apply for the design of the Main Building high rise:

- Utilize possibilities provided by available clean air, low noise pollution and friendly wind climate;

- Relate to the qualities of the green and open campus;

- Use the slender shape of the high rise to create a light-flooded volume, open up to the environment and communicate with its surroundings;

- Repelling solar radiance above reasonable amount is costly and greatly reduces provided comfort, mainly due to the large façade surface and orientation of the building. Moreover, it will reduce daylight admittance and increase the need for artificial lighting. A higher energy efficiency could be achieved more effectively by reducing active ventilation and artificial lighting;

- Allow natural ventilation through the façade to save on active cooling by expelling accumulated heat efficiently;

- Per compartment, 50% of the flexible floors should be placed alternately adjacent to east or west façade, to make optimal use of the admittance of daylight and to create an eastern and western zone per compartment. An axonometric of the organisation principle can be seen in appendix G, figure 26 and 27.

5.2. Climate installation

The performed study has resulted in a most beneficial climate installation concept, consisting of a ventilation concept and a heating/cooling aspect. When intelligent controls are enabled, natural ventilation has the potential to save significantly on annual active cooling load and dependency on mechanical ventilation. In addition to savings on (operational) costs and energy, the most significant argument of the proposed design is that a well, natural, ventilated educational building makes interior spaces more healthy and pleasant for occupants. The design distinguishes itself from alternatives in its ability to facilitate an increased study and work efficiency, which are the core-business of the university. A brief description of the proposed climate installation concept is stated below :

- Air outflow is centrally positioned, using vertical shafts, as shown in appendix G, figure 27 and figure 30, that function as ‘trees’ that facilitate stacked compartments. The necessary draught could be generated naturally with mechanical capacity as back-up.

- Air inflow is arranged via passive, natural ventilation through the façade. Air inflow functions as passive cooling, reducing active cooling load, as can be seen in appendix G, figure 31. Desired capacity is generated twofold:

    - Ventilation grills with acoustic insulation, positioned at high level and horizontally, with a capacity of approximately 1,75 $dm^3/s/m^2$ should be used for constant ventilation;

    - Openable, vertical shaped, windows or panels with a capacity of approximately 7,25 $dm^3/s/m^2$ should be used for purge ventilation.

- An intelligent control system based on internal CO^2 concentration and outside temperature, should be used for both types of ventilation to increase energy efficiency and comfort level.

- Concrete floor slabs should be kept in open contact with the interior climate to make the most use of the existing thermal mass for (night) cooling.

- Low temperature heating and cooling, as shown in appendix G, figure 32, is most beneficial with the availability of the existing Aquifer Thermal Energy Storage (*WKO*) system on the campus. Apply low temperature floor and ceiling heating/cooling, controllable independently for each compartment's east and west zone, as shown in the intersection and floor plan (appendix G, figure 28 and 29).

5.3. Façade

Based on performed analysis and literature study, the following design guidelines apply for design of the façade. An impression of a possible interpretation is given in appendix G, figure 34:

- The façade is based on a curtain wall façade principle, which can consist of either a prefabricated elements or more conventional framework system.
- The façade consists of a single layer. This façade principle provides a higher integral performance compared to more complex double layer- and climate façade principles.
- The amount of openness is a trade-off between user value and energy efficiency. Exact openness is dependent on a large amount of criteria and cannot be predetermined. However, an indication for the optimal openness is given per orientation:
    - Approximately 60% openness for south orientation;
    - approximately 50-60% openness for east and west orientation;
    - Approximately 50-70% openness for north orientation.
- Glazing performance should be in the range of more conventional types of modern glazing (in the range of U=1,1 W/m^2, g-factor 0,40 and light transmittance 0,70). This will provide the highest integral performance. Benefits of available, more extreme performing, types of glazing are less significant and cause additional negative effects.
- Enabling natural ventilation through the façade provides higher integral value than the addition of sunscreen devices. Therefore, natural ventilation, as described in the ventilation concept, is preferable over sunscreen devices or other façade additions that provide shading.
- Vertical fins, saw-tooth principle or other 'self-shading' additions cause insufficient savings on cooling compared to the negative effects, such as adding material and reducing visual comfort. These shading devices should therefore not be included.
- Manual controllable light regulation should always be included, independent of additional sunscreen devices.
- An intelligent controlled internal sunscreen, controlled by presence detection and insolation of approximately 350 W/m^2, provides highest integral performance compared to alternative sunscreen concepts.
- the facade design allows a the future placement of PV panels if opaque panels are used in the façade design.
- The following rules apply for the façade expression:

- The facade is expresses a certain neutrality, according to the ambition of project 3: Generic expression of exterior, specific expression of interior (‘*Generiek van buiten, specifiek van binnen’)*;

- The facade expression relates to the corporate architecture on the campus, including the dimensioning based on the modular size of 1,24 meter, as described in the Masterplan TU/e Sciencepark. An interpretation is given in figure 35;

- The facade expresses the building organization principle as described in this study and shown in appendix G, figure 25;

- The facade expresses a certain plasticity and depth, as a result of applied techniques and façade elements, an interpretation in shown in figure 36;

- The façade design is related to existing iconic elements of the Main Building, in particular the concrete table and the two staircases;

- The dynamic natural ventilation capacity of the façade is distinctive quality which should be expresses in the façade design, an interpretation is shown in figure 36.

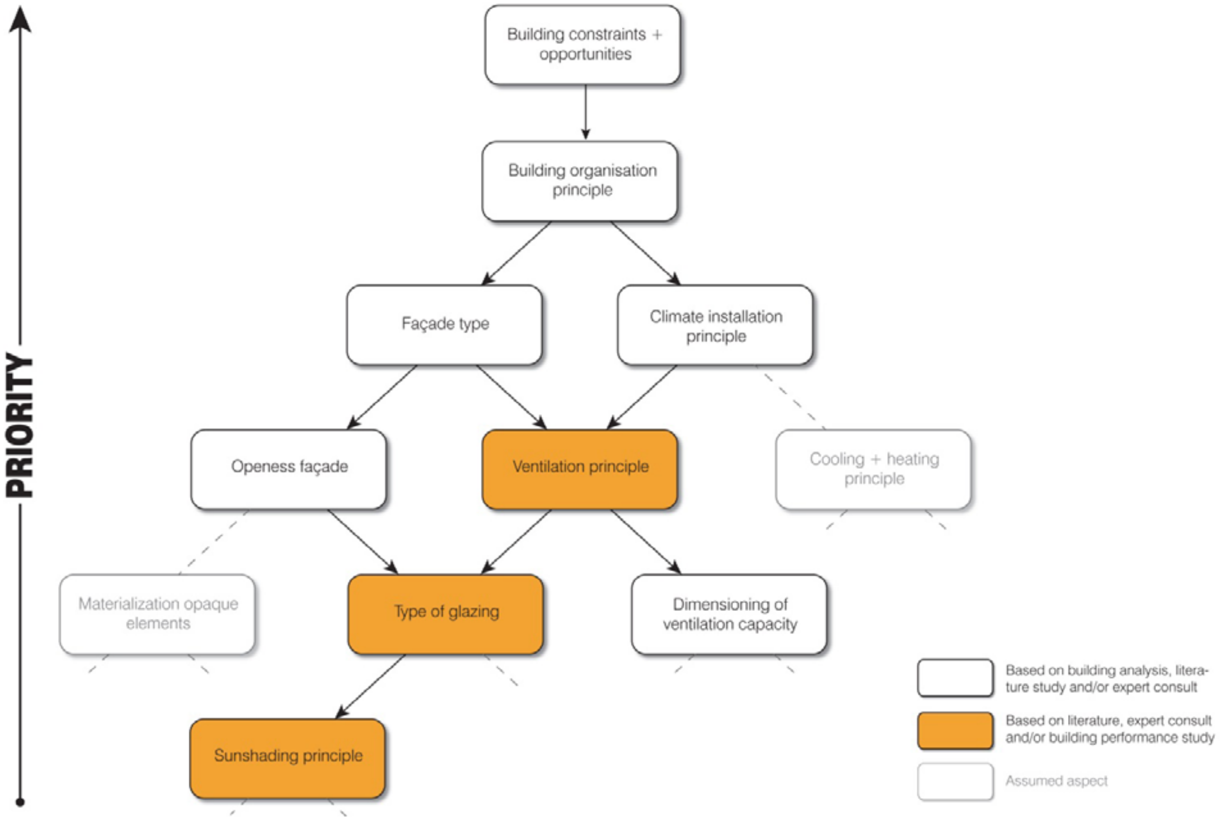


Figure 11. Overview of project scope and methodology

Chapter 6: Recommendations

The design concept is the result of a one year during study. Information is gathered by means of object analysis, literature study, workshops and expert consults and described in full detail in the technical report. Although the proposed design concept is based on a structured methodology and rationale considerations, several recommendations are stated below which have to be taken into consideration when the façade concept is applied.

- A model is used to quantify thermal energy performance. However, savings on artificial lighting due to the increase of daylight and savings on mechanical ventilation due to the use of natural inflow of air are only qualitatively assessed. For example, coatings reduce daylight admittance by 20-35% compared to clear glazing. Dynamic sunscreens reduce daylight admittance and remove exterior view when active. Further research is needed to give a better insight in this topic;

- Regarding energy savings related to ventilation and lighting, considerations are based on valid but qualitative considerations. A more complex model which could quantify should be developed to specify more exact the amount of potential savings on these aspects, in relation to thermal energy savings,;

- Proposed openness of the façade concept is based on literature study. Although extensive amount of aspects were taken into account, like most validations in empirical methodology, the study validates an hypothesis, not a applicable solution and some uncertainties for the given situation remain. Moreover, during expert consults, different ratios of openness were mentioned. Often based on practice rather than science, the ratios mentioned suggested a lower amount of openness than suggested by literature, often to reduce energy losses. However, aspects related to user value such as health and visual comfort could be valued properly. Stated amount of façade openness should be used as a starting point, a guideline, not as static fact;

- The option of passive sunshading by the addition of vertical fins to the west- and east facade is studied. As outcome, fins should not be included. However, thermal energy savings as simulated with the model were significant. Uncertainties regarding the effect on visual comfort and foremost the generation of noise due to wind made were important aspects in made consideration which resulted to exclude fins from the façade concept. Further research on the effects of vertical fins could prove if fins could prove to be a valuable asset;

- The proposed ventilation concept includes a vertical shaft for outflow of air. As described in the report, generated thermal current or altered wind flows could potentially generate a natural underpressure which could result in the desired outflow of air and reduction of energy use caused by mechanical ventilation. However, these wind behaviour is far from clear and topic of scientific discussion. The option to include natural outflow in the Main Building is promising, but needs further research.

- The proposed building organisation principle is partly based on the assumption that for fire safety, a sprinkler installation would be a more expensive solution compared to a compartment strategy. However, a more detailed study on this matter should be performed to validate this assumption.

Chapter 7: Conclusion

The Breathing Façade is a design concept that can be used as a solid guideline for the renovation of the high rise of the Main Building on the TU/e campus. The concept comprises of interrelated building organization, climate installation, and façade concepts.

The proposed design concept organizes the high rise into large compartments, that are partitioned into an east and west zone. Each compartment consists of a double array of smaller offices/study rooms and a large open office/atelier space. The east and west zones have a separated loop of floor and ceiling heating. All compartments are connected to central ventilation shafts, which ensure a controlled outflow of air. The façade concept proposes and prioritizes a set of optimal partial solutions. Foremost, the design consists of a single layer façade with an openness that differs per orientation. The performance of the most suitable type of glazing poses a balance between a solar energy transmittance and a light transmittance factor. The façade includes ventilation grills with acoustic insulation for continuous ventilation and openable windows for purge ventilation, both controlled automatically via the central building management system. The façade is mounted with an internal manual controllable light regulation device for visual comfort, in addition, to an automatically controllable internal sunscreen device.

As a result, the Main Building high rise could, with modest resources, ensure a high amount of fresh air and daylight admittance, while ensuring an efficient cooling of the building. Moreover, the smooth façade will accentuate the slender shape of the high rise and the monumental expression of the concrete table. The design concept poses a promising perspective for the renovation of the Main Building and provides an innovative design concept that differs strongly from the current trend in energy efficient building design. Instead of aiming for a compact, energy-saving, yet almost ‘sealed off’ building, the overall concept of this project proposes a slender, light-flooded, volume, open up to the environment and communicative with its surroundings.

The concept proposes a promising perspective for the renovation of the Main Building. Foremost, the proposed design concept distinguishes itself from alternatives in its ability to facilitate an indoor environment that greatly supports an increased study and work efficiency, which are the core - business activities of the university. Hence, following the Breathing Façade concept as underlying guideline for the renovation of the Main Building would be a statement of the TU/e to potential investors and future students: Facilitating the best learning environment possible.

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Appendices

Appendix A. Energy performance

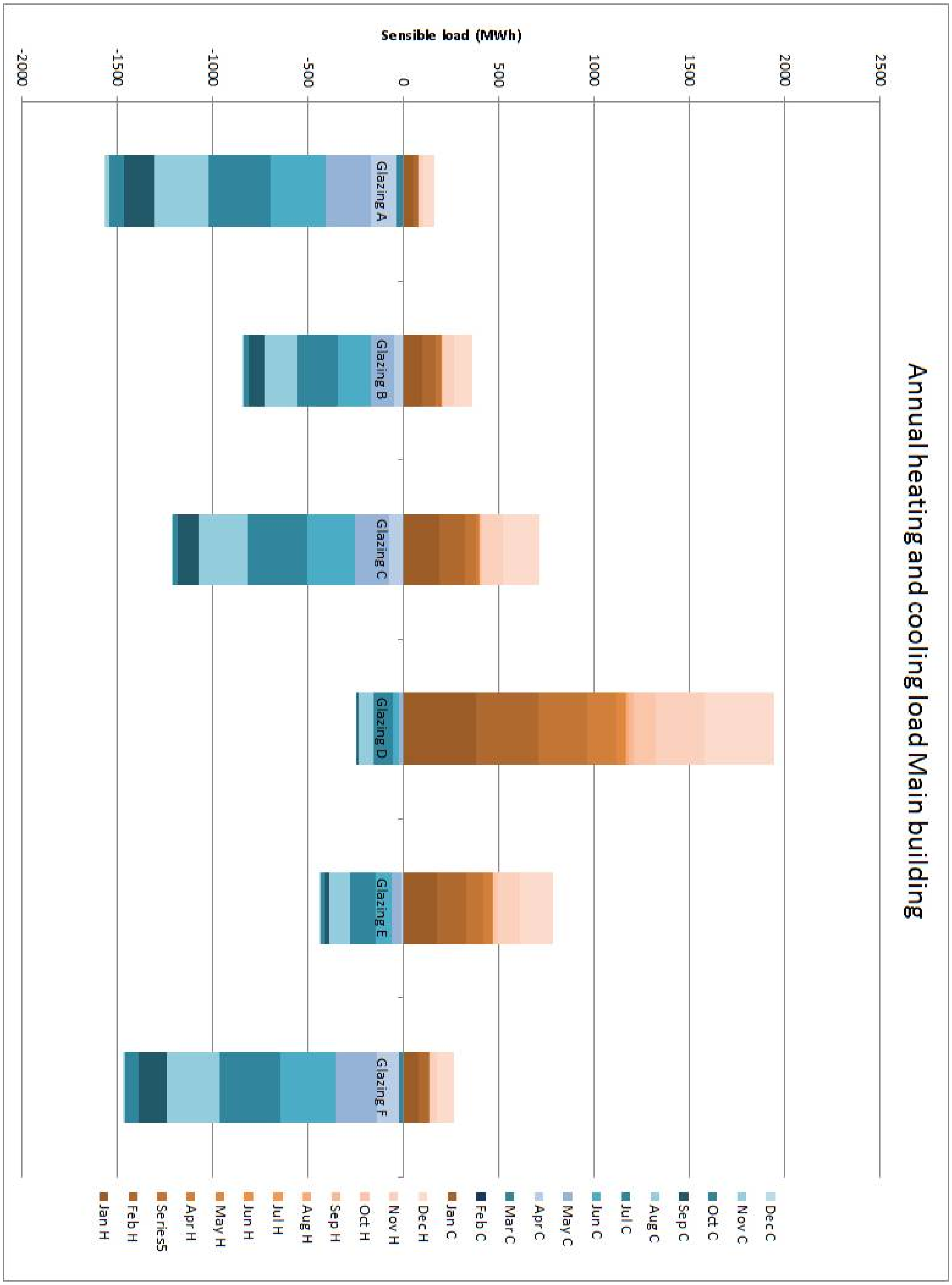


Figure 12. Glazing types - thermal energy performance

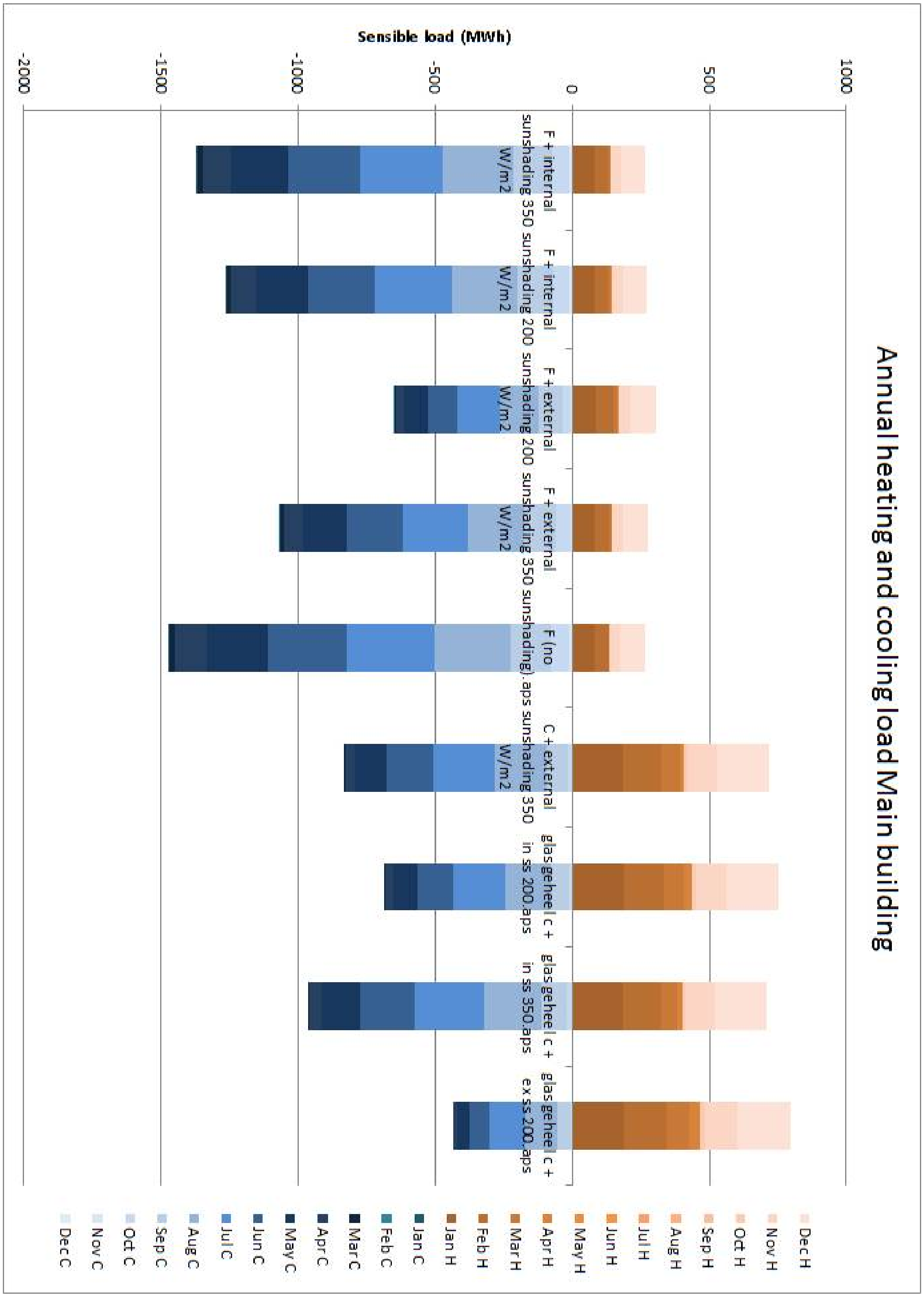


Figure 13. Sunshading devices - thermal energy performance

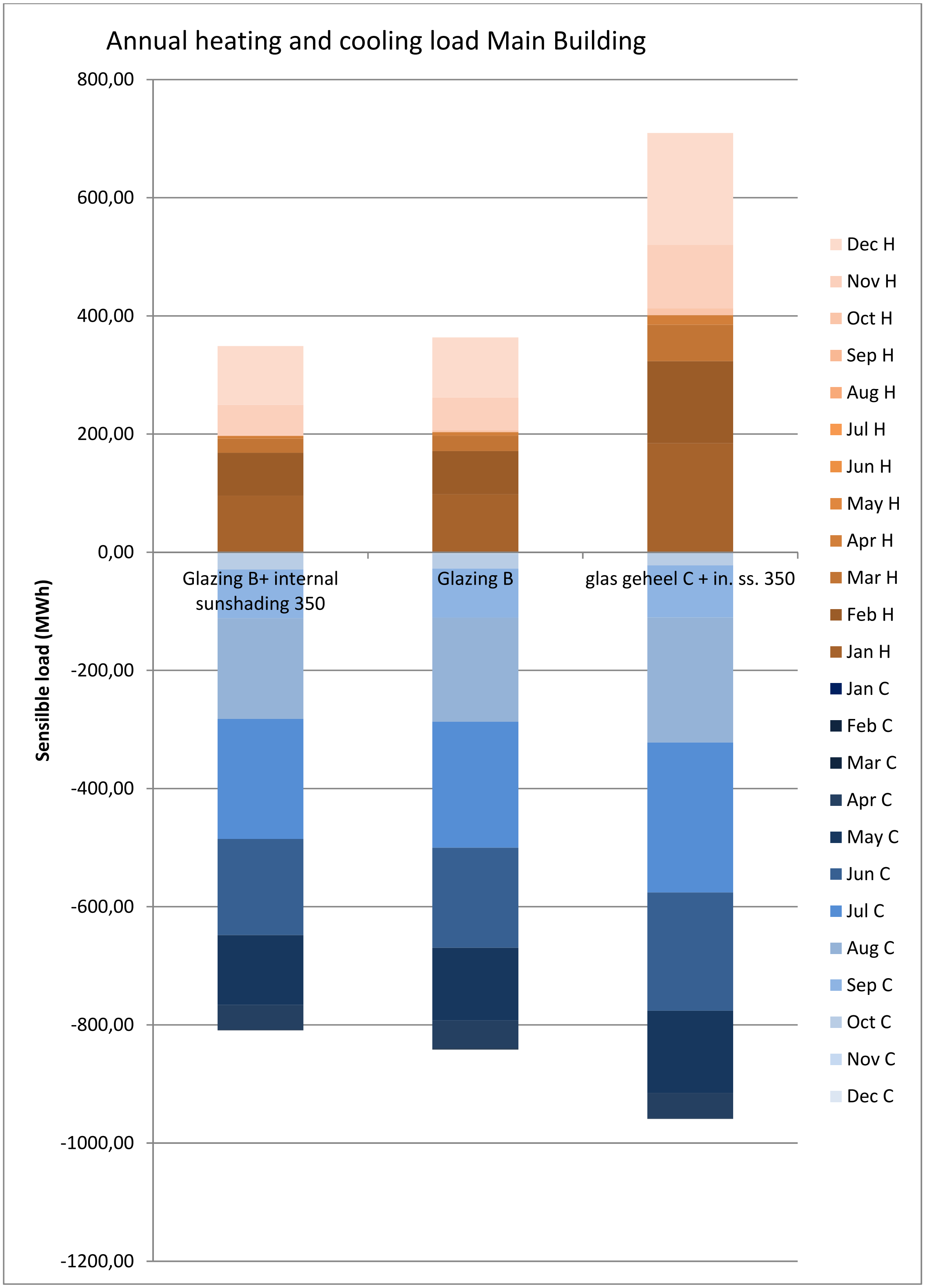


Figure 14. Optimal coating and sunshading device - thermal energy performance

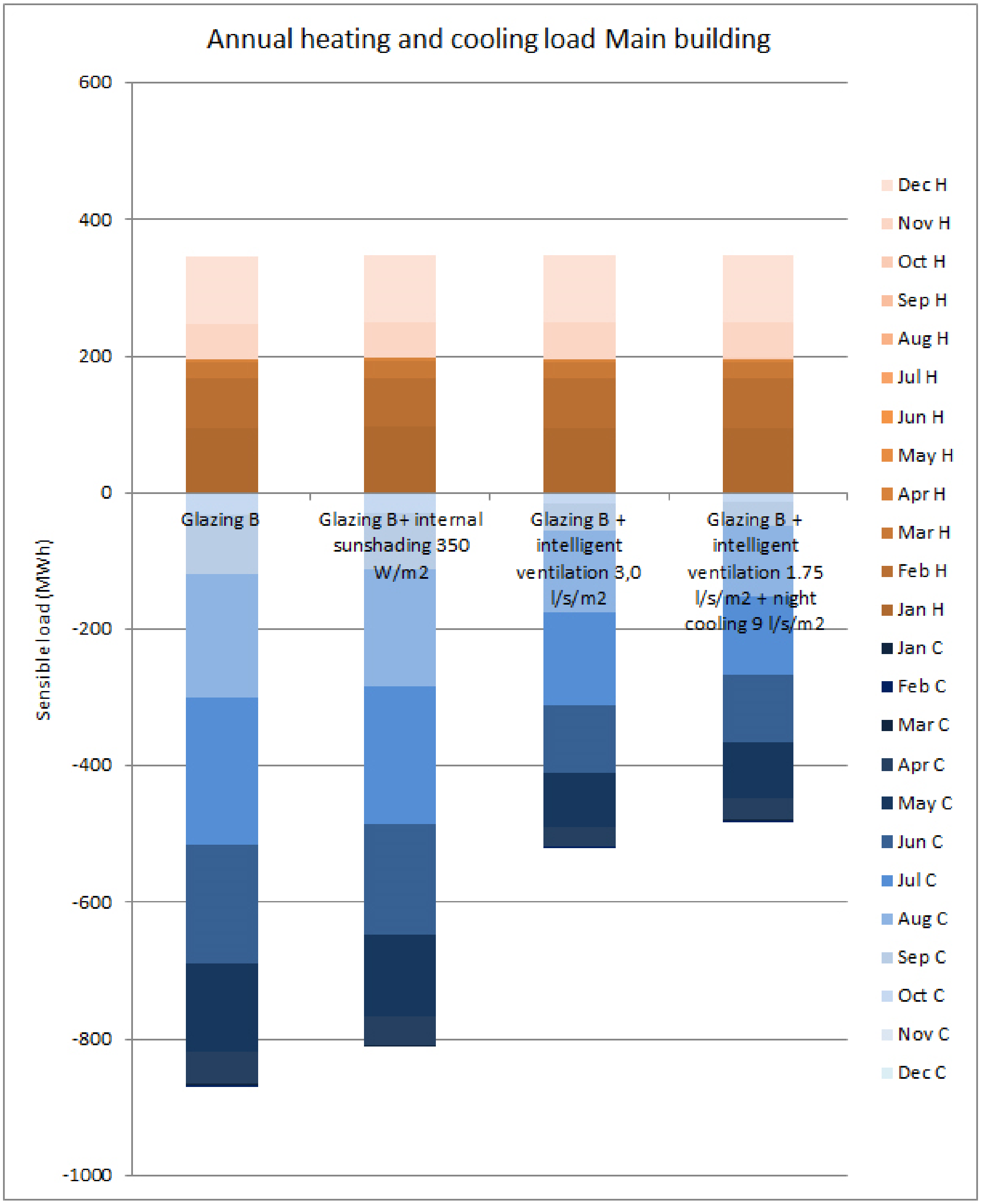


Figure 15. Ventilation concept - - thermal energy performance

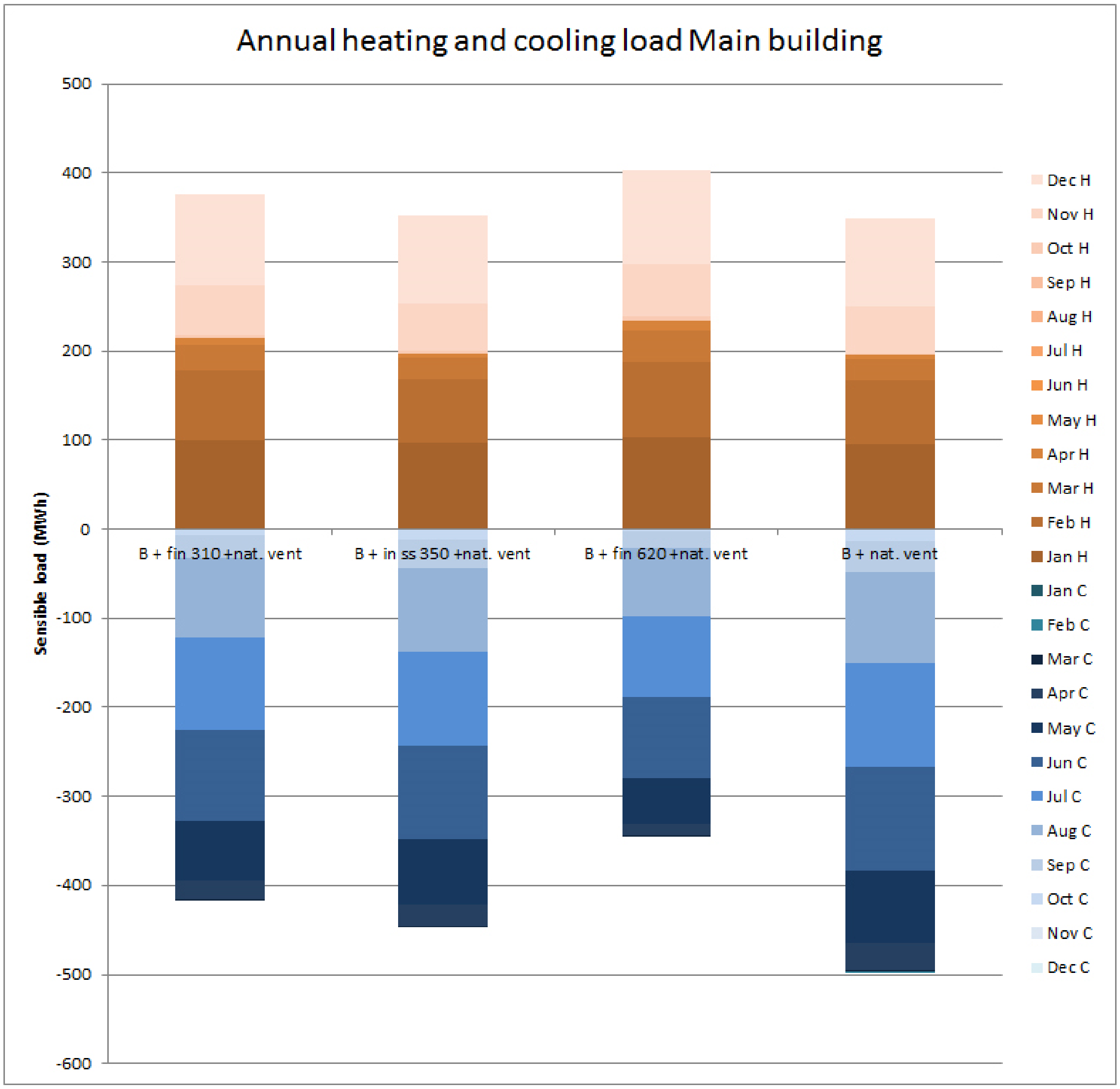


Figure 16. Passive sunshading ‘fin façade’ - thermal energy performance

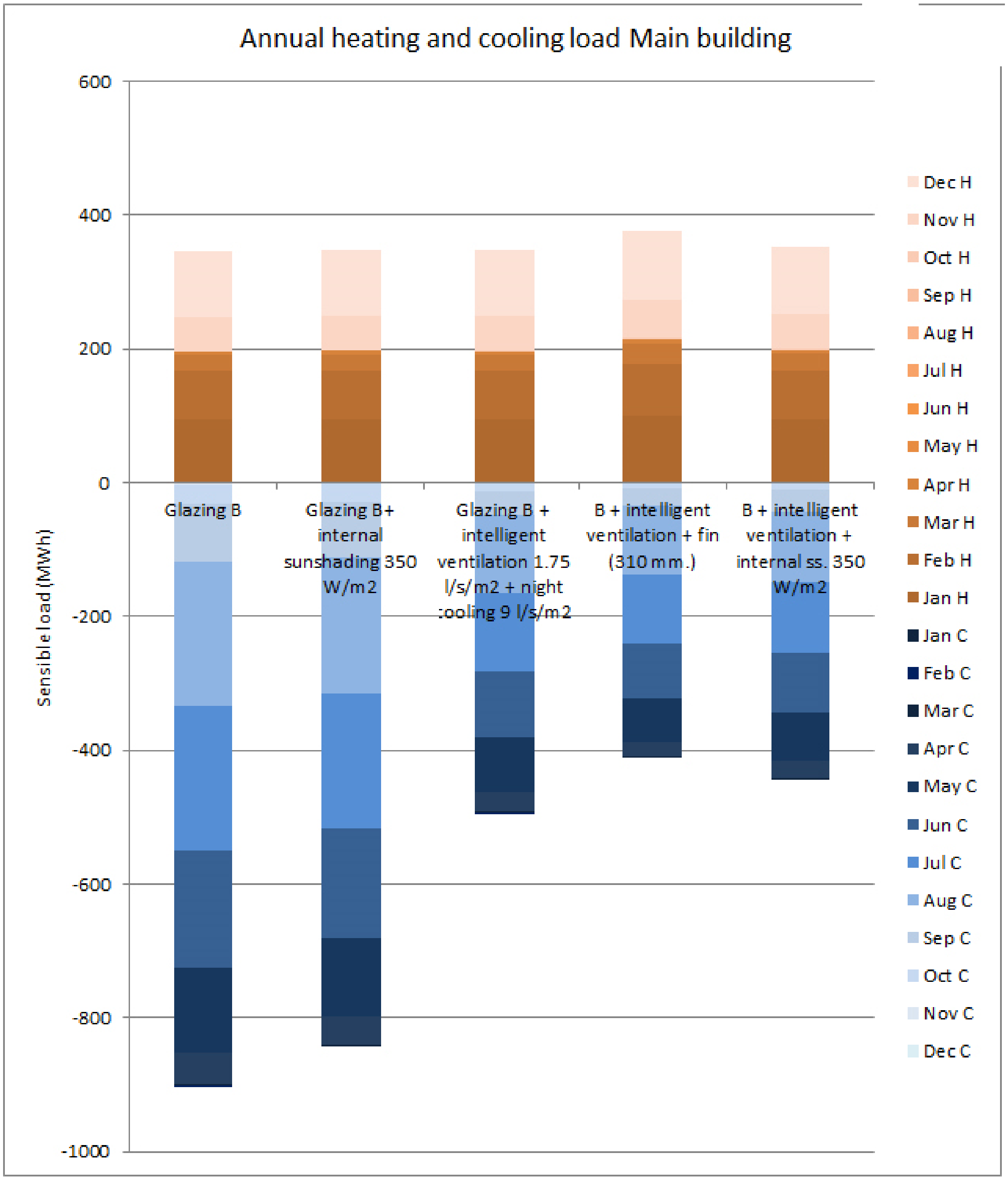


Figure 17. Overview thermal performance of optimal partial solutions. Most right is thermal performance of proposed façade concept.

Appendix B. Total cost of ownership

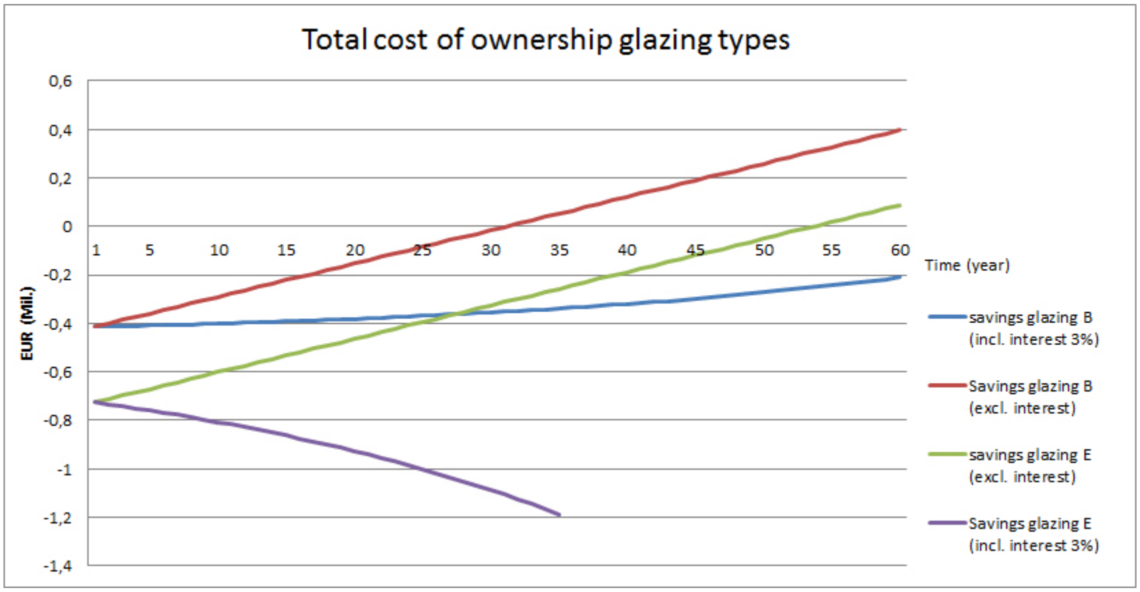


Figure 18. Total cost of ownership of different types of glazing

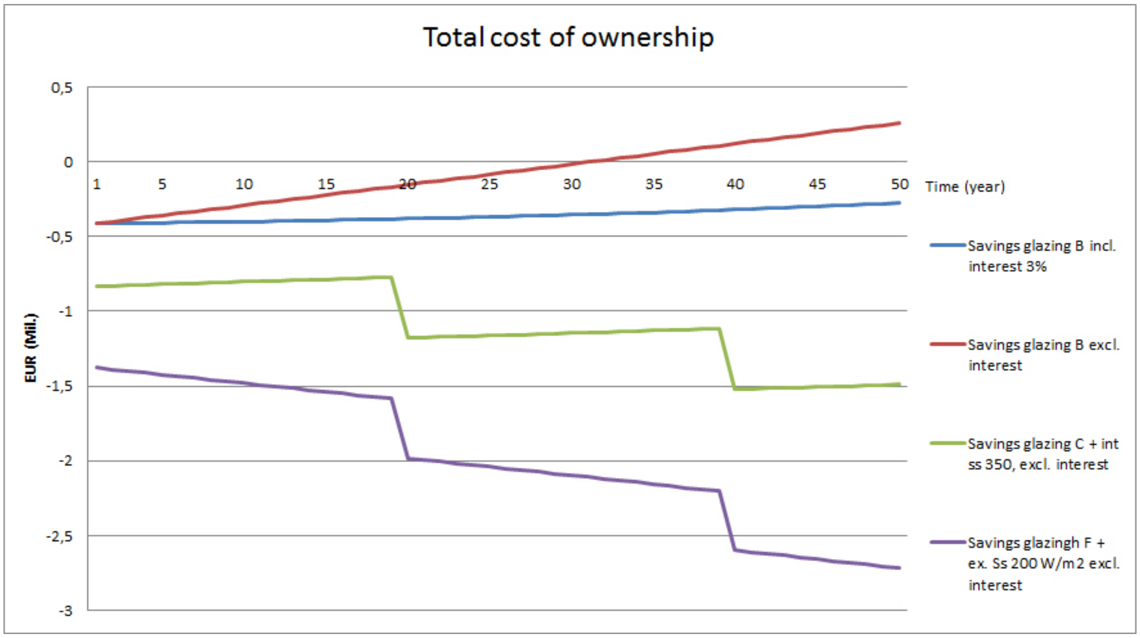


Figure 19. Total cost of ownership of different sunscreen devices

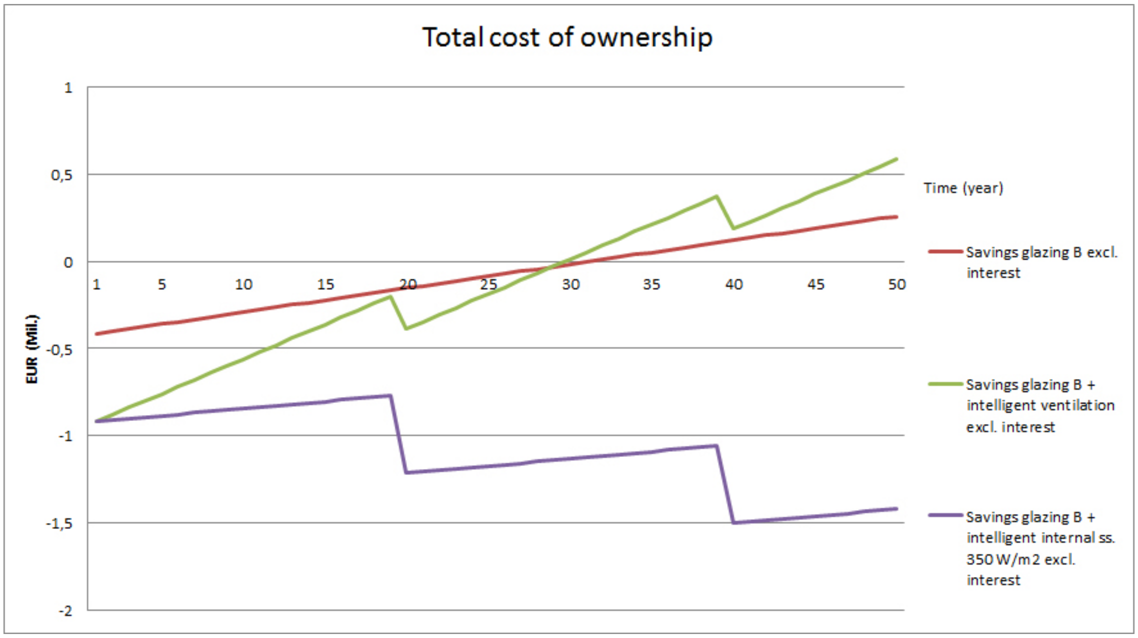


Figure 20. Total cost of ownership ventilation concept compared with alternatives

Financial savings due to ventilation energy savings on ventilation:

25% of total electricity use on the TU/e campus is caused by mechanical ventilation. In addition to financial savings due to thermal energy savings, an intelligent ventilation device would reduce operative costs when compared to sunscreen devices. By obviating a mechanical air supply, electricity costs for air circulation can be reduced. To give an estimation, alone with a 2.5 fold air change per hour in offices, provided by a central mechanical ventilation plant, roughly 15-25 kWh of energy will be consumed per square meter of ventilated floor area per year to power the fans.

The proposed ventilation concept would only need mechanical outflow, assumed to be half of the energy load (12,5 kWh/m^2/y [7]*). This is equivalent to about 0,96 €/m^2 per year.*
Assuming a total floor surface of approximately 26.395 m^2 (50% use of flexible floors), this results in energy savings of approximately 25244 €/y in addition to thermal energy savings, when comparing the ventilation device with other façade additions which do not contribute to ventilation savings, such as sunshading device.

Financial savings due to thermal energy savings:

The amount of thermal energy savings is determined by the outcome of a verified model performance study. The thermal energy savings are converted to electrical energy savings, assuming a certain efficiency related to the ATES system on the campus, which will generate the demanded cold and heat for the Main Building. Finally, the electrical energy (kWh) is converted to financial savings, using the energy price as described in table 9, 0,0765 €/kWh.

Appendix C. Product information

Table 1. Characteristics of different glazing types [9]

Type	Description	U [W/m2K]	g-factor (ZTA)	g/U (m2K/W)	LT (LTA)	Basic price (€) [9]
A Triple glazing	6-12-4-12-6 mm. (argon); *SG Climatop Ultra N*	0,6	0,63	1,05	0,3	164.00
B Double, high performance glazing	6-12-4 mm. (argon); *SG Climaplus SUN*	1,1	0,4	0,36	0,7	112,55
C Double glazing	6-12-4 mm. (air); no coating	2,7	0,77	0,29	0,8	52,20
D Single glazing	6 mm.; *SG Cool lite classic*	5,1	0,28	0,05	0,2	unknown
E Double, extreme performance glazing	6-12-4 mm. (argon); SG Cool *lite climaplus SK SKN 154*	1,1	0,28	0,25	0,6	157,95
F Low emissivity glazing	6-15-4 mm. (argon) *climaplus Ultra N*	1,1	0,63	0,57	0,8	71,20

Table 2. Financial indications of sunshading and ventilation devices

solution	device	dimensions	size (m^2)	lifetime (year)	Replacement costs (€)	Device (€)	control mech. (€)	Invest. cost/m^2	operative cost (€)/p.p./y	operative costs (€)/m2/y
External sunshading [10]	Screen + control	1,2 * 1,5	1,8	20	119,45	238,89	250	137,36	7	4,67
Internal sunshading [11]	screen + control	2,35 * 3,20	7,52	20	68,70	137,36	250	73,36	1,4	0,93
Intelligent ventilation device	Control + actuator	-	-	20	34,34	137,36	250	73,36	1,4	0,93

Appendix D. Integral performance

Table 3. Integral performance facade types

Solution	Description	user value	cost	energy	material
A	Single layer façade	+	+	0	+
B	Double layer façade	0	-	0	-
C	Climate façade	-	0	0	0

Table 4. Integral performance of glazing types

Solution	Description	comfort	cost	energy	material
A	Triple glazing	+	-	-	-
B	High performance glazing	+	+	+	0
C	Clear double glazing	0	0	0	0
D	Reflective single glazing	-	-	-	+
E	Extreme performance glazing	-	-	+	0
F	Low emissivity glazing	-	0	-	0

Table 5. Integral performance of sunshading devices

Solution	Description	comfort	cost	energy	material
A	F + internal sunshading 350 W/m^2	+	0	-	-
B	F + internal sunshading 200 W/m^2	-	0	-	0
C	F + external sunshading 200 W/m^2	-	-	+	0
D	F + external sunshading 350 W/m^2	+	-	0	-
E	F (no sunshading)	0	+	--	+
F	C + external sunshading 350 W/m^2	+	-	0	-
G	C + internal sunshading 200 W/m^2	-	0	0	0
H	C + internal sunshading 350 W/m^2	+	0	0	0
I	C + external sunshading 200 W/m^2	-	-	+	-

Table 6. Integral performance of optimal coated glazing and sunshading device

Solution	Description	user value	cost	energy	material
A	Fixed coating (glazing B)	0*	+*	+	+
B	Clear glazing with internal sunscreen internal sunshading	0*	-*	-	-

* *To compare the effect of both solutions on daylight admittance and its effect on visual comfort and energy savings on required electrical lighting, further study on daylight performance, is needed.*

Table 7. Integral performance of ventilation device compared with alternative solutions

Solution	Description	comfort	cost	energy	material
A	Glazing B + conventional ventilation	0	+	-	+
B	Glazing B + conventional ventilation + internal sunscreen 350 W/m^2	-	-	-	0
C	Glazing B + intelligent ventilation (3 dm^3/s/m^2; daytime)	-	0	+	0
D	Glazing B +intelligent ventilation (0,88-1,75 dm3/s/m2 daytime + 9,0 dm^3/s/m^2 night cooling)	+	0	+	0

Table 8. Integral performance of passive sunshading solutions compared with alternative solutions

Solution	Description	comfort	cost	energy	material
A	Glazing B + ventilation + fin 310 mm. depth	-	0	+	-
B	Glazing B + ventilation + internal sunshading (350 W/m2)	-	-	0	0
C	Glazing B + ventilation + fin 620 mm. depth	--	0	+	-
D	Glazing B + ventilation (no addition)	+	+	-	+

Appendix E. Passive sunshading study

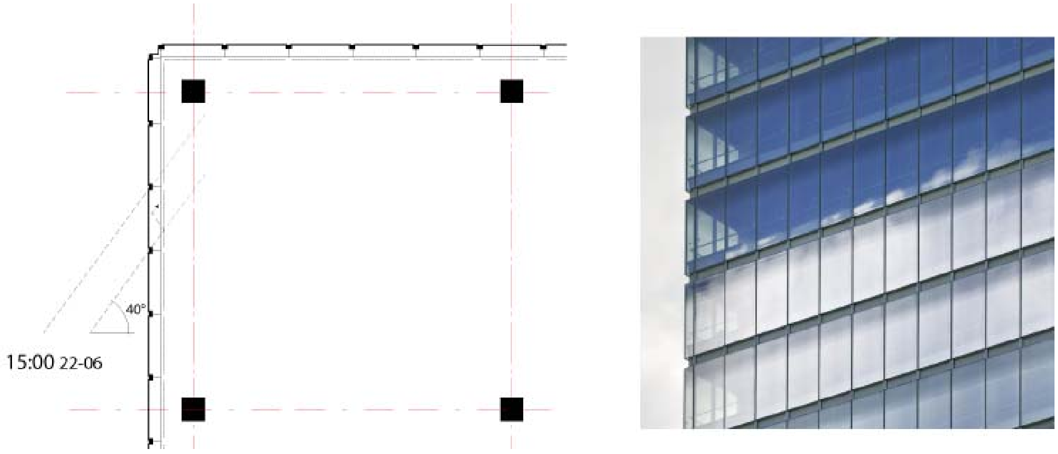


Figure 21. Impression flat façade

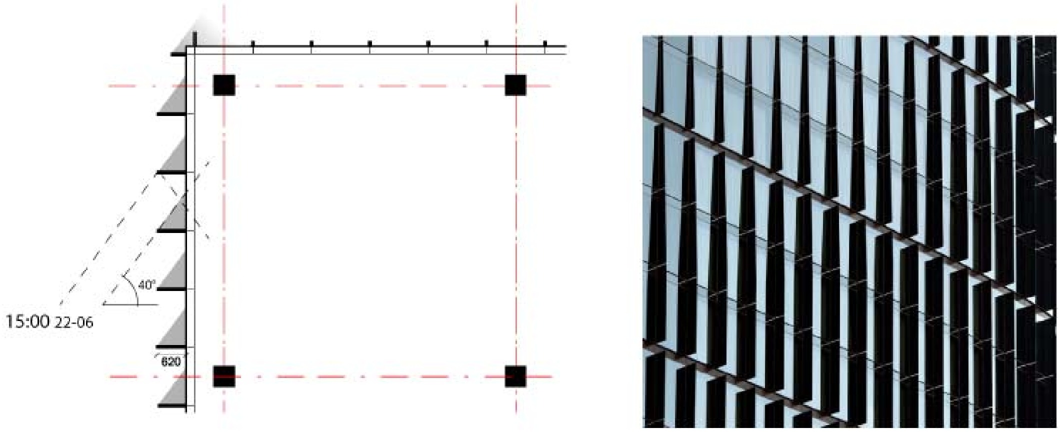


Figure 22. Impression 'Fin' façade

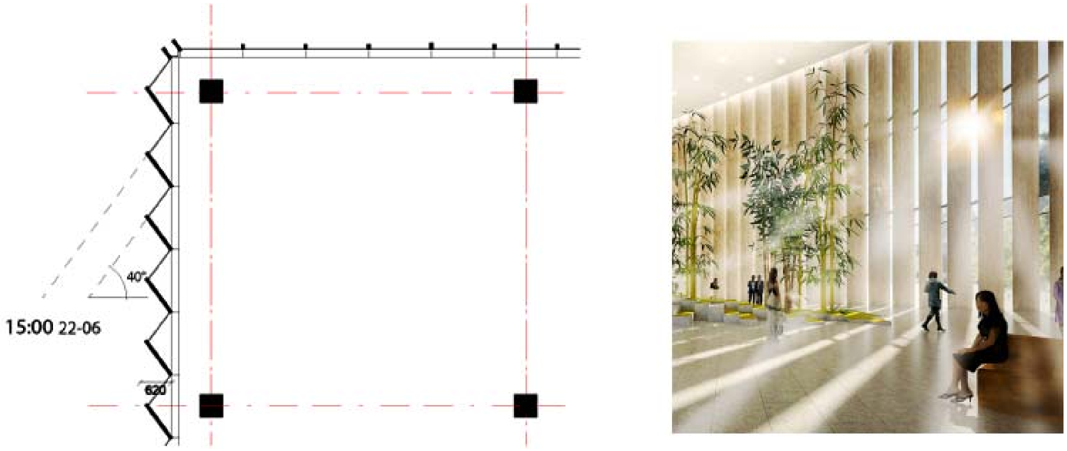


Figure 23 Impression 'sawtooth' façade

Appendix F. Project phases

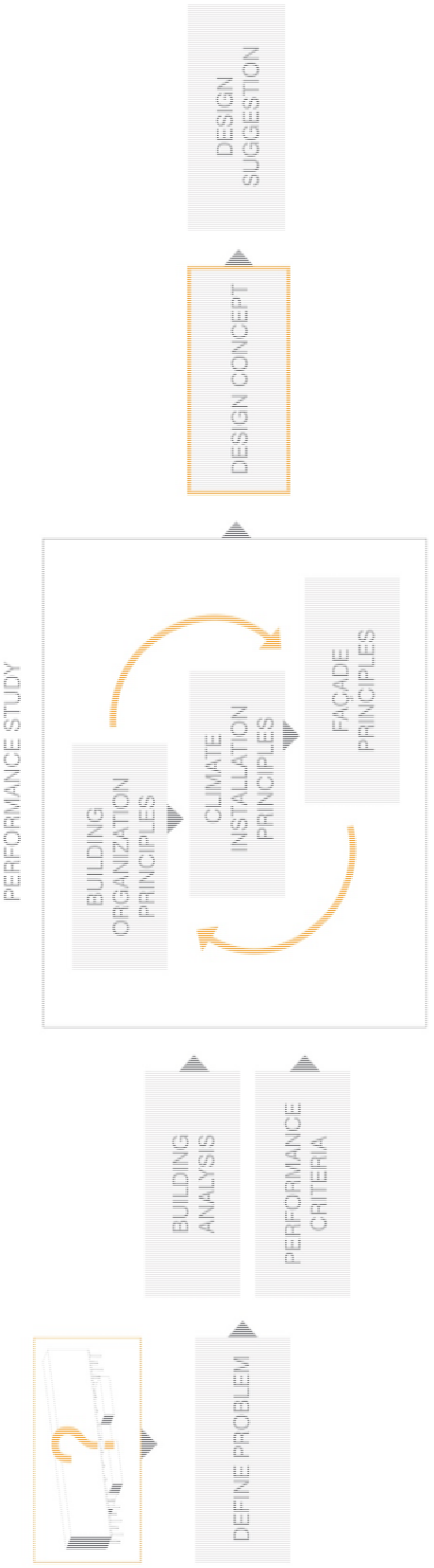


Figure 24. Overview project phases

Appendix G. Design concept

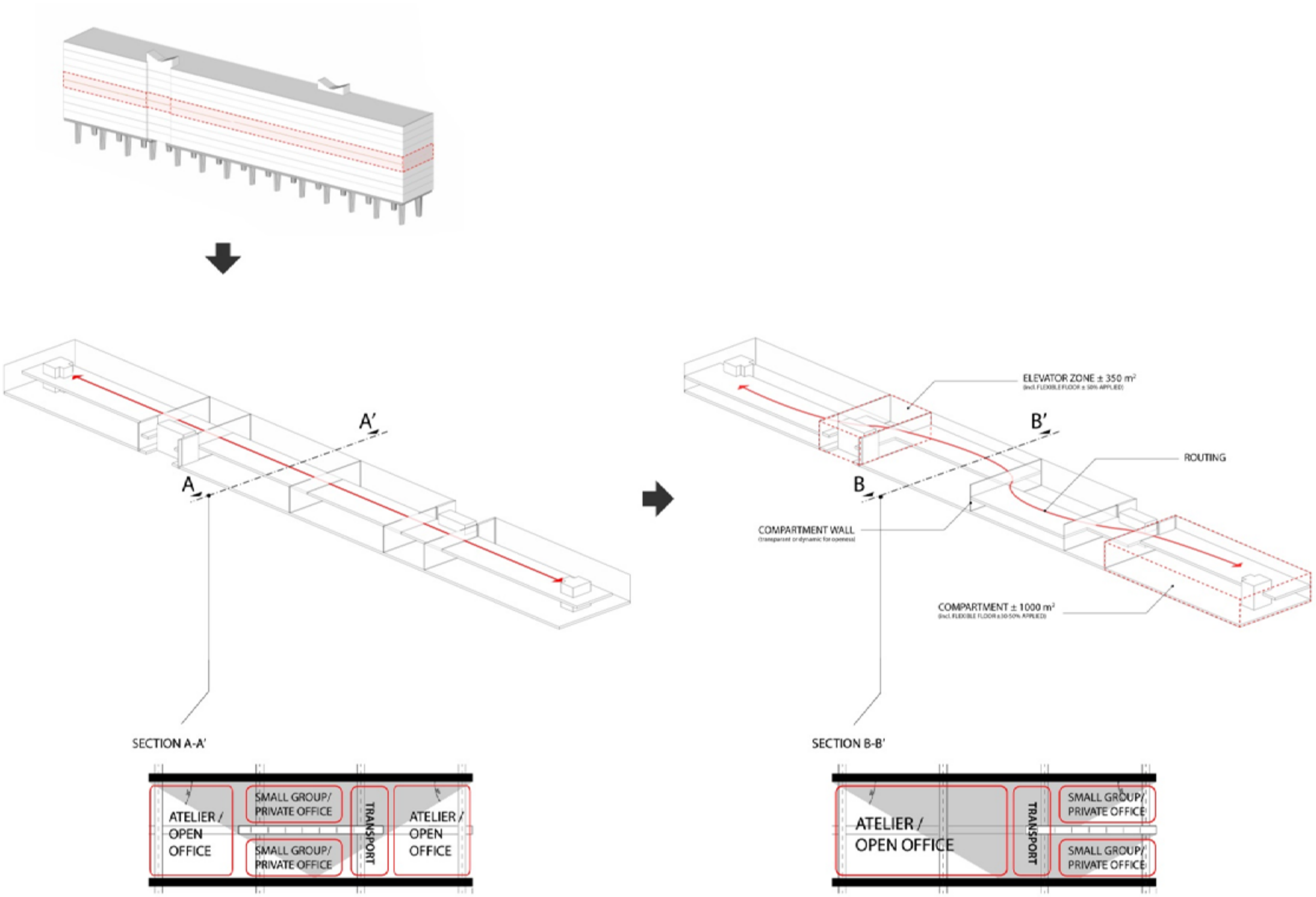


Figure 25. Overview Main Building high rise and axonometric of organisation principle

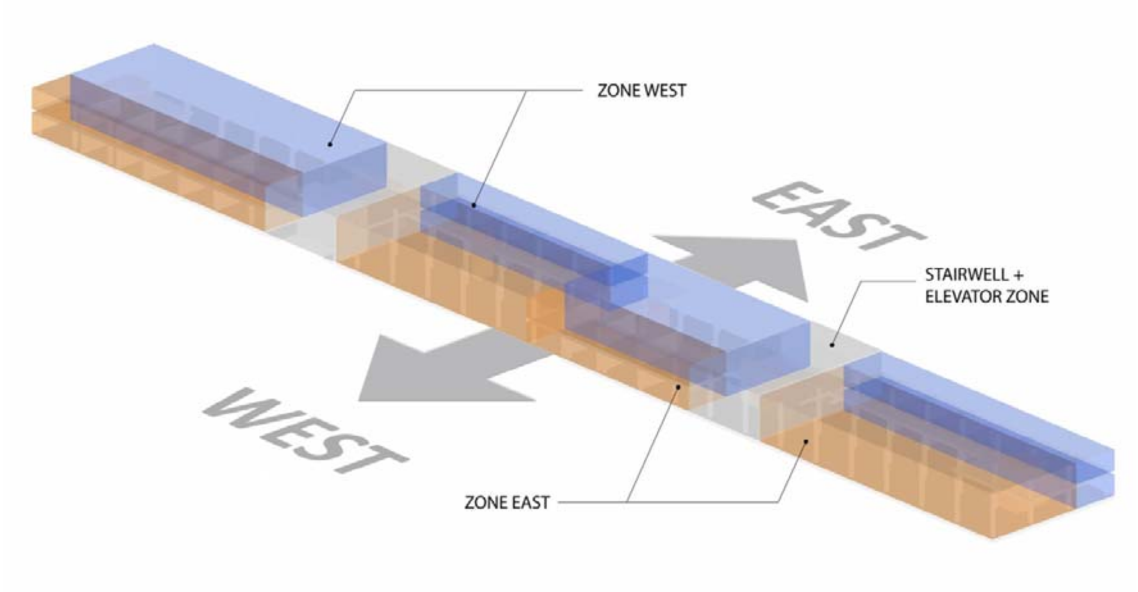


Figure 26. Zoning principle, axonometric

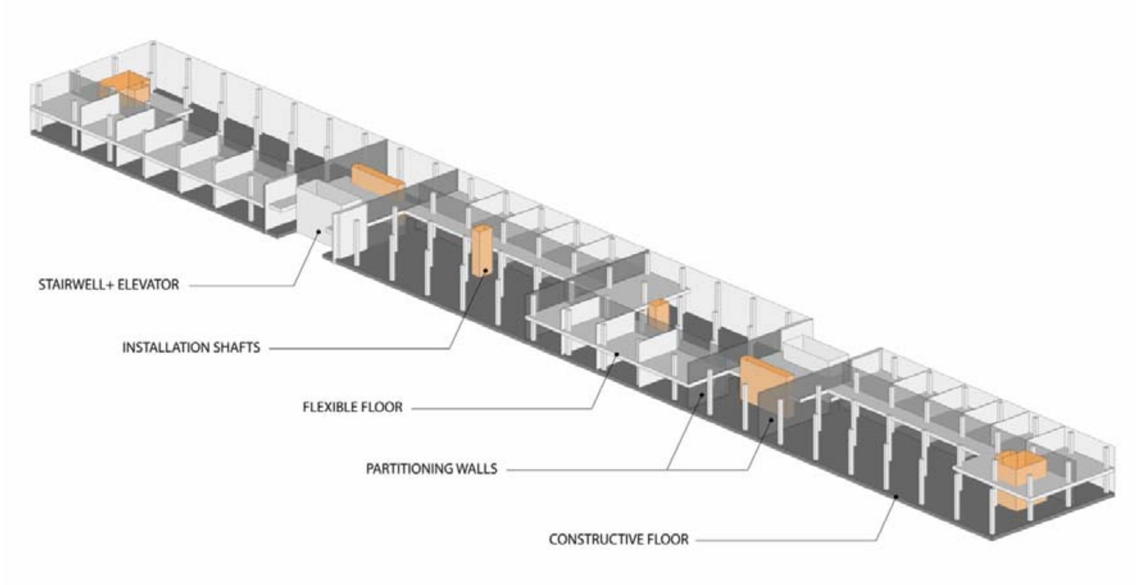


Figure 27. Organisation principle, axonometric (design suggestion)

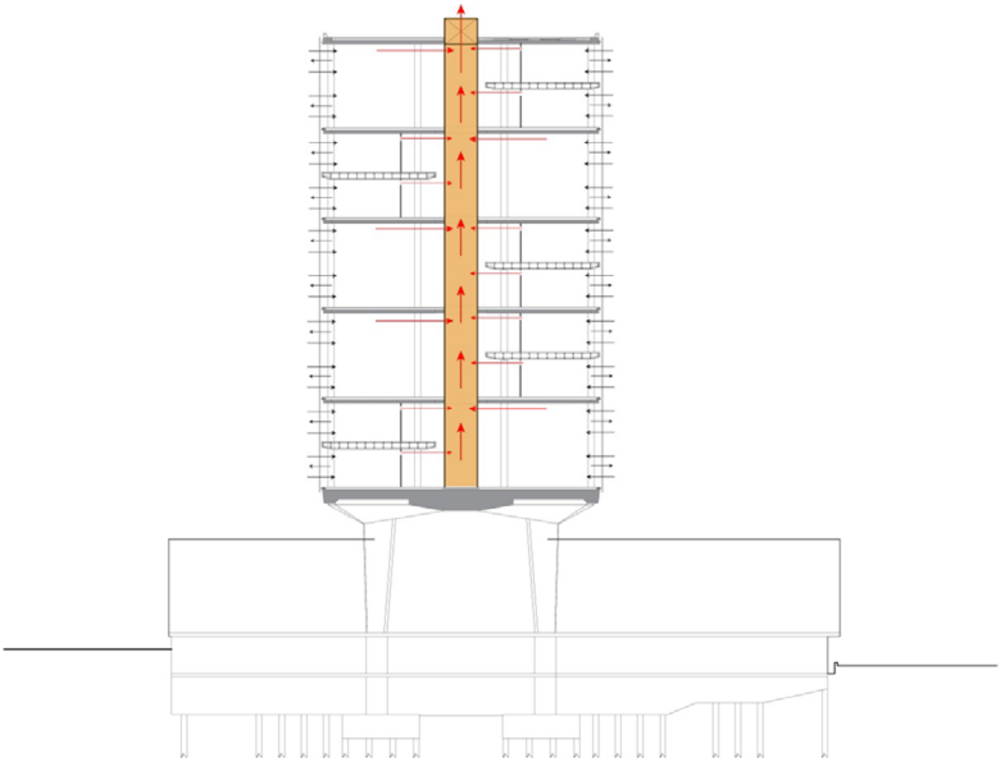


Figure 28. Vertical intersection, ventilation principle on building level

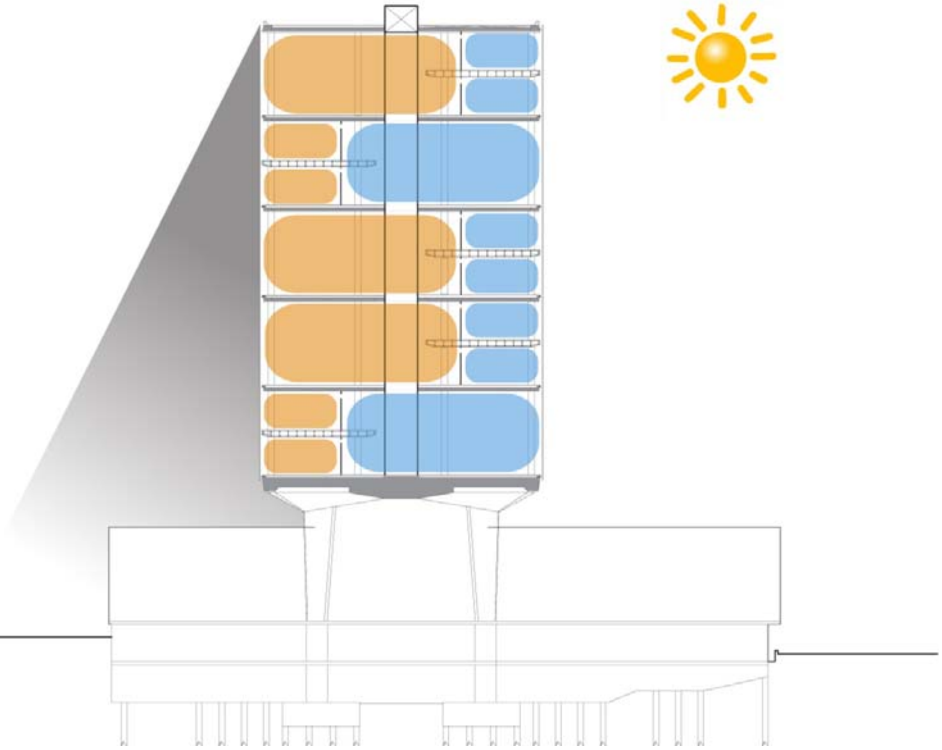


Figure 29. Vertical intersection, zoning principles, mirrored per double floor level

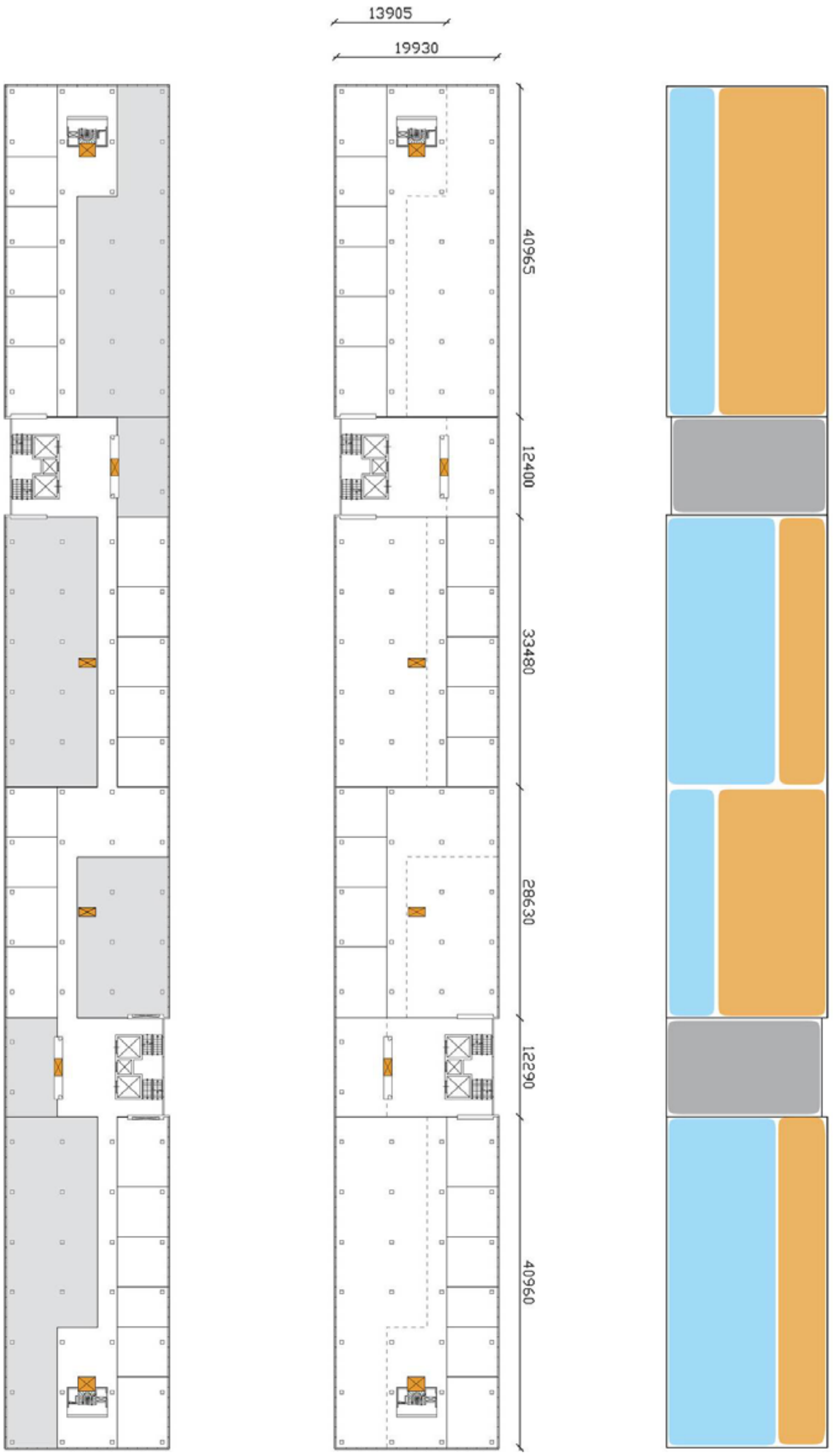
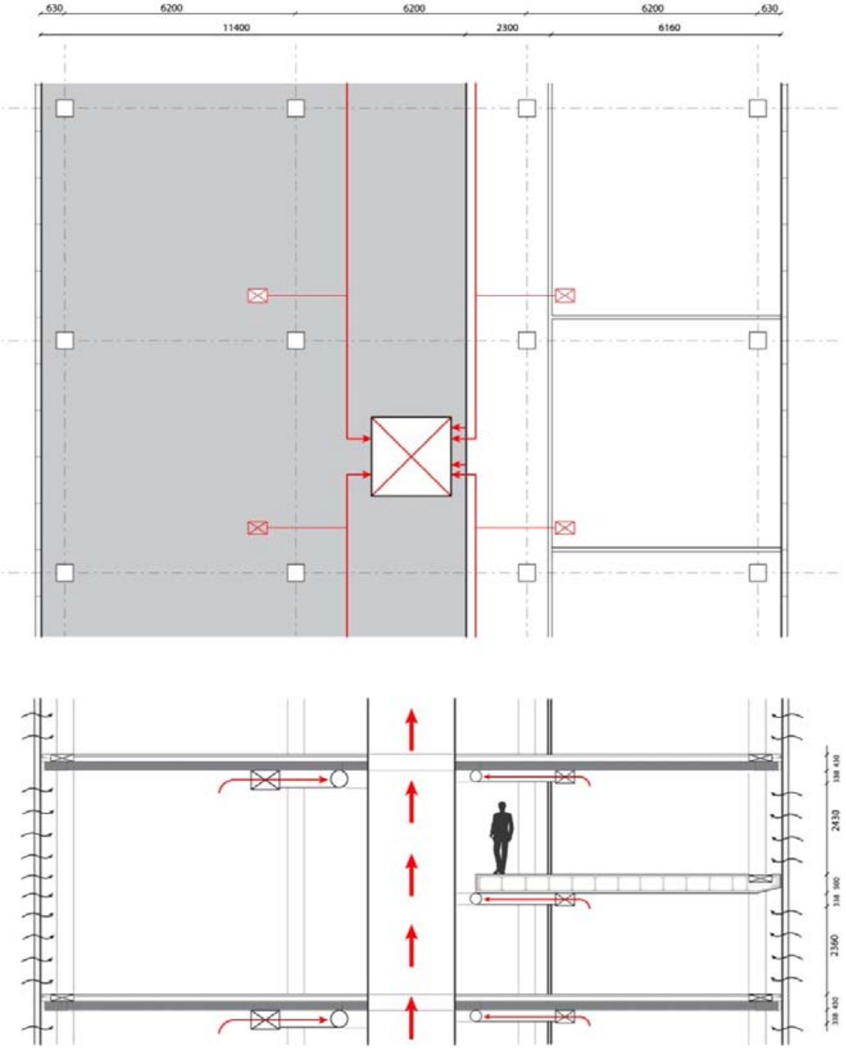


Figure 30. Organisation principle, floor plan. (left: flexible floor; middle: structural floor, right: zoning)



Daytime ventilation (08:00-23:00)

35% **IF: 'free' cooling**	'Frisse Scholen' label **A** **12 $dm^3/s/p$ (= 1,75 $dm^3/s/m^2$)**	+ purge ventilation (via windows) **max. 7,25 $dm^3/s/m^2$**
65% **IF: active cooling/heating**	'Frisse Scholen' label **C** **6 $dm^3/s/p$ (= 0,88 $dm^3/s/m^2$)**	

Night ventilation (23:00-08:00)

100% 'Frisse Scholen' label **A** **(max. 9,0 $dm^3/s/m^2$)**

Figure 31 ventilation principle (top: floor plan, middle: vertical section, below: characteristics)

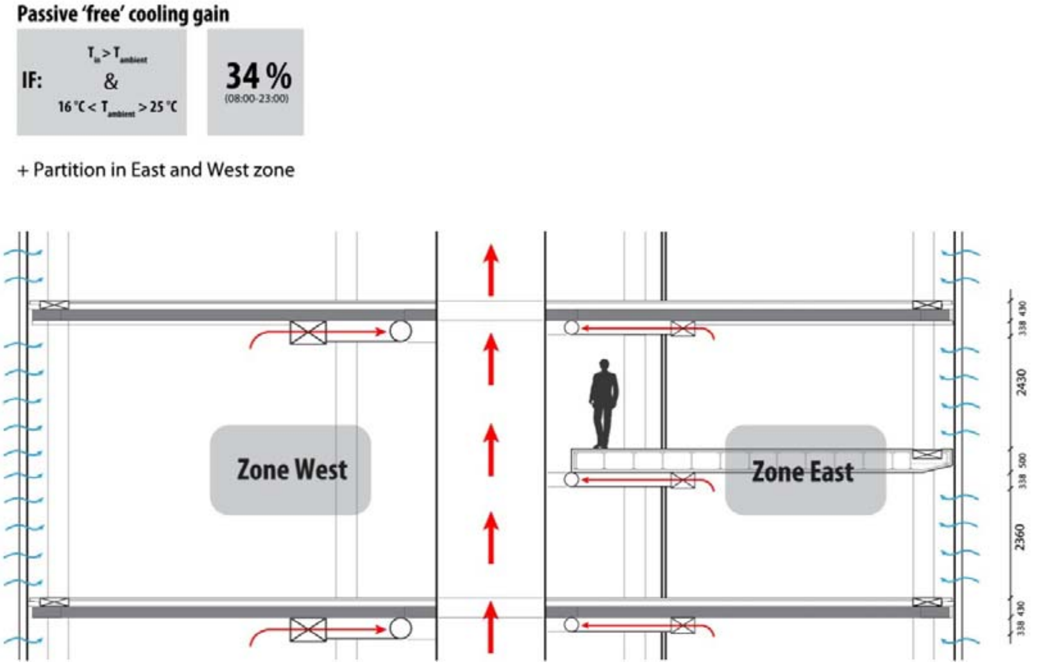


Figure 32. Passive cooling principle

Figure 33. Active cooling and heating principle

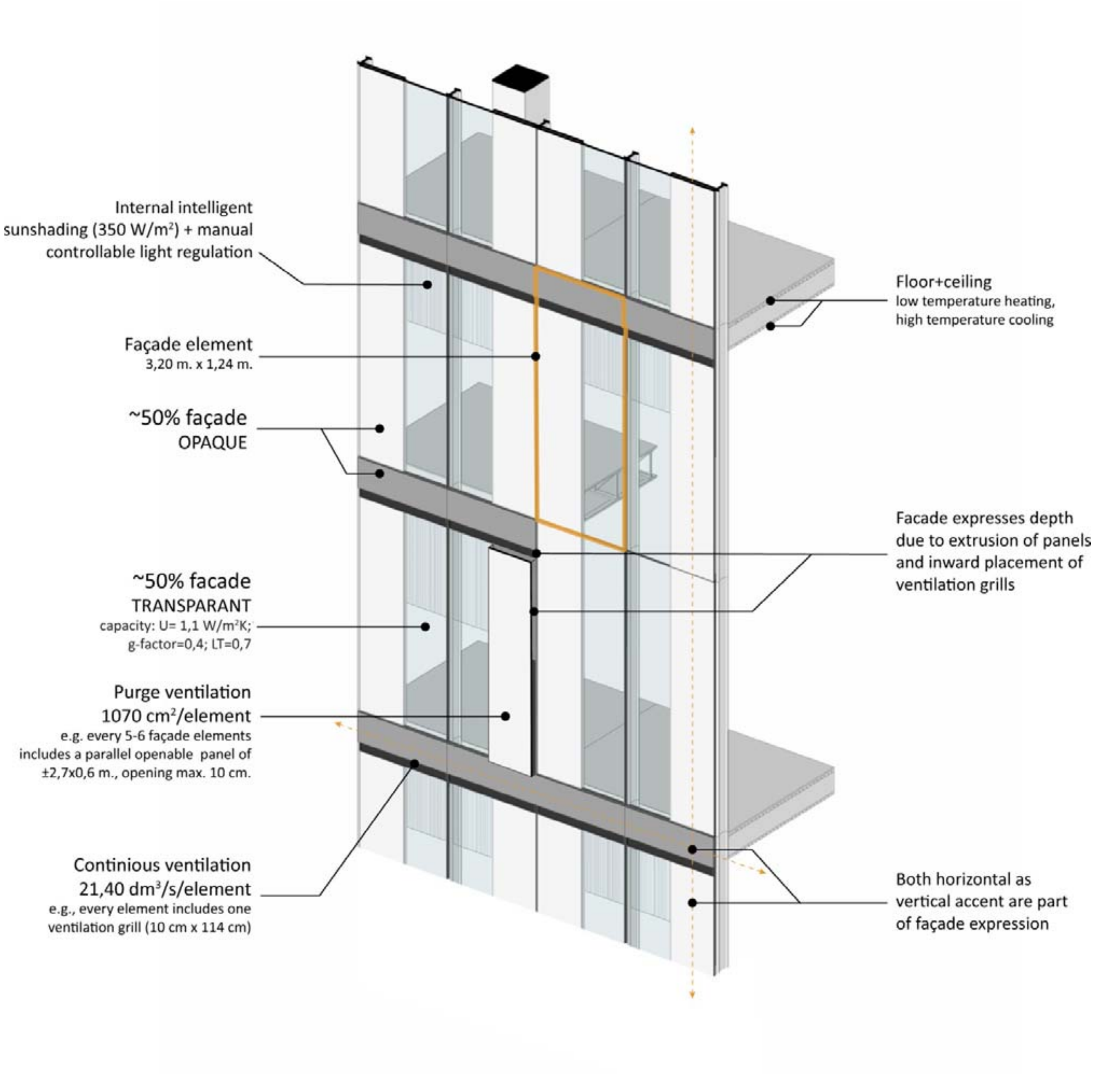
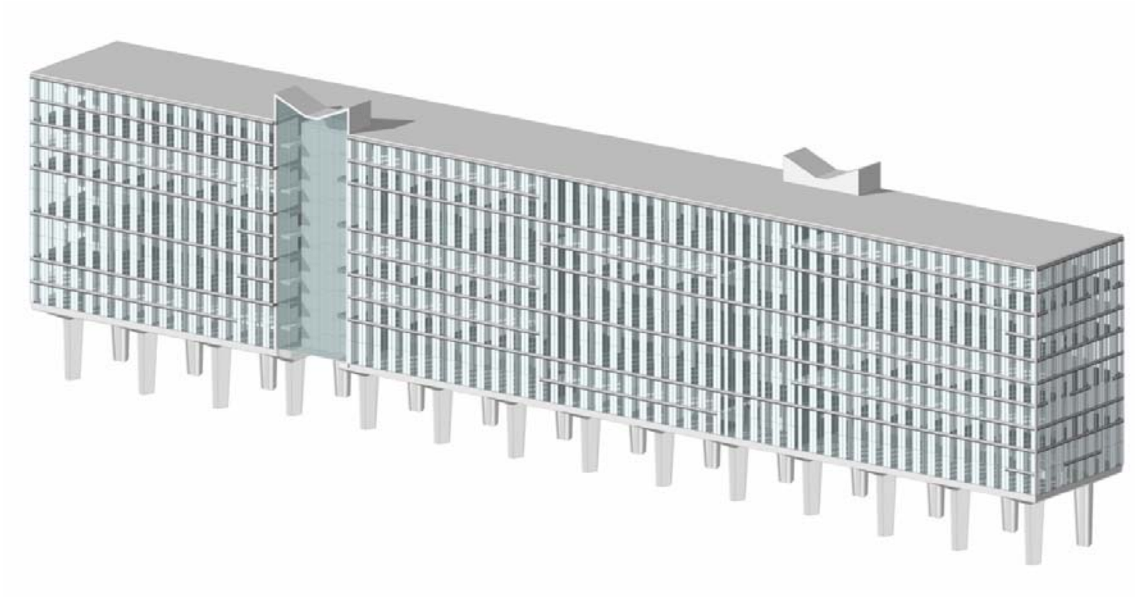


Figure 34. Overview façade principle 'Breathing Façade'



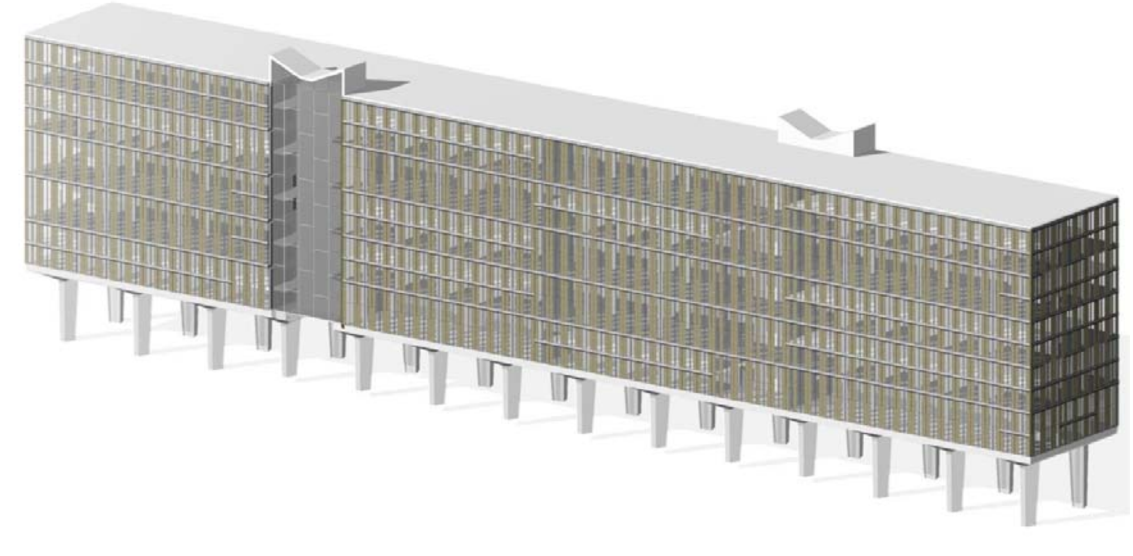


Figure 35. Suggestion façade impression Main building high rise

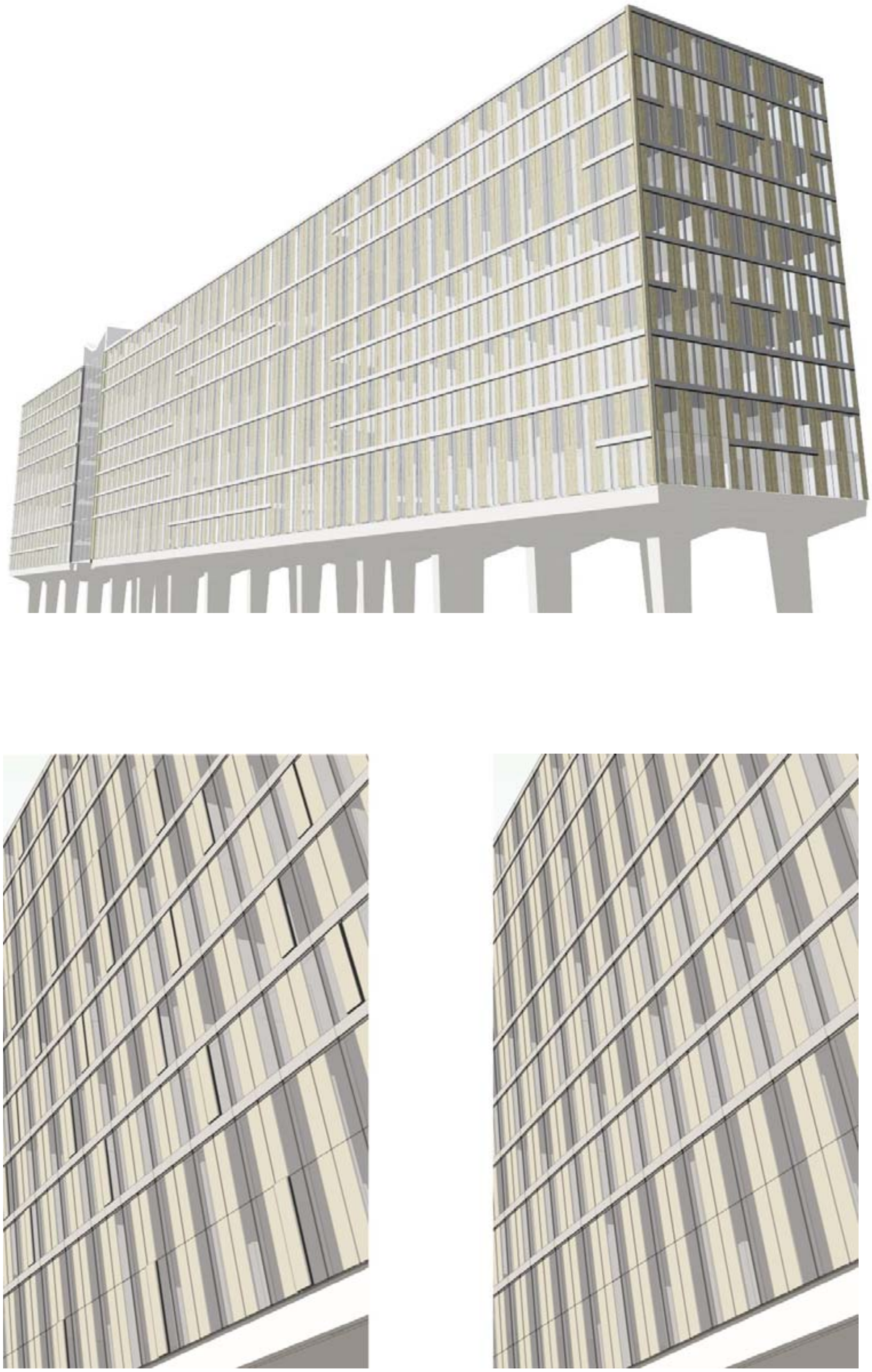


Figure 36. Façade impression, (above: overview; left: façade with extrudes panels ‘active’ ventilation; right: closed façade (only open grills)

Appendix H. Cost indications

Project 3 has a certain total investment, assumed to be € 70 million. As part of a total investment budget, the real estate department will give an assumed indication for the façade budget of 825,00 €/m^2 to be most appropriate. However, Project 3 will be tendered as a Design-Build project, performance is managed by means of output specifications instead of defining specific solution or input. Hence, based on the defined output provided by the TU/e, different design consortia will be asked for an project proposal and will give their interpretation of the best division of total investment that can result in a different budget for the façade design.

Energy costs

In 2012, total energy and water use of the university is €6,3 million. For the year 2013, price for 1 kWh is only €0,079. The prices are given in table 9. Compared to households, offices or facilitating services, the TU/e can use electrical energy at low cost. Due to the amount of energy use, the TU/e is able to wield a low price buying strategy. This gives an significant financial savings, but makes it less attractive to implement renewable energy sources such as PV-panels, since the rate of return is lower due to lower financial savings on energy.

Table 9. Energy prices TU/e

energy price incl. VAT *(BTW)*	0,09104	€/kWh
energy price excl. VAT *(BTW)*	0,07651	€/kWh
energy price incl. *Regulatieve Energie Belasting*, excl. VAT*(BTW)*	0,07961	€/kWh

Maintenance costs

Maintenance, construction and cleaning costs in 2012 are €11.0 million. Maintenance costs are different for each building element and will be included to determine the total cost of ownership.

Comfort costs

Savings due to the increase of comfort are indirect, difficult to determine and beyond the scope of this study. However, two aspects can be given as indication:

- Students are the most valuable assets of a university. On average, the Dutch government finances bachelor and master students for € 6.100 per student per year. Moreover, average costs per beta student are even higher, between €8.500 and €10.500 , based on a study performed in 2003 and more recent estimations;

- As aforementioned, total expenses on the personnel of the TU/e, mainly supporting staff and researchers, over 2012 is near € 200 million, accounting for 64% of total budget. Energy accounts for 2%, € 6.3 million/year. Main purpose of staff and researchers is to facilitate education and perform research;

- TU/e personnel absenteeism due to sickness is 2,1% of total calendar days in 2012, accounting for 7,7 days/person and a total loss €4.2 million euros on personnel expenses. Decreasing personnel absenteeism by 1% would save €42.000/year;

- Most of all, increasing effectiveness of students, staff and researchers will shorten total study time of students, research output of researchers and more productive work output of personnel. The complexity is too large to determine the effect of a more productive work environment. If a 1% increase in productivity facilitated by the façade design would mean a 1% saving on expenses on personnel, it already accounts for a saving of €2 million euro/year;

Appendix I. Mindmap design components Building design

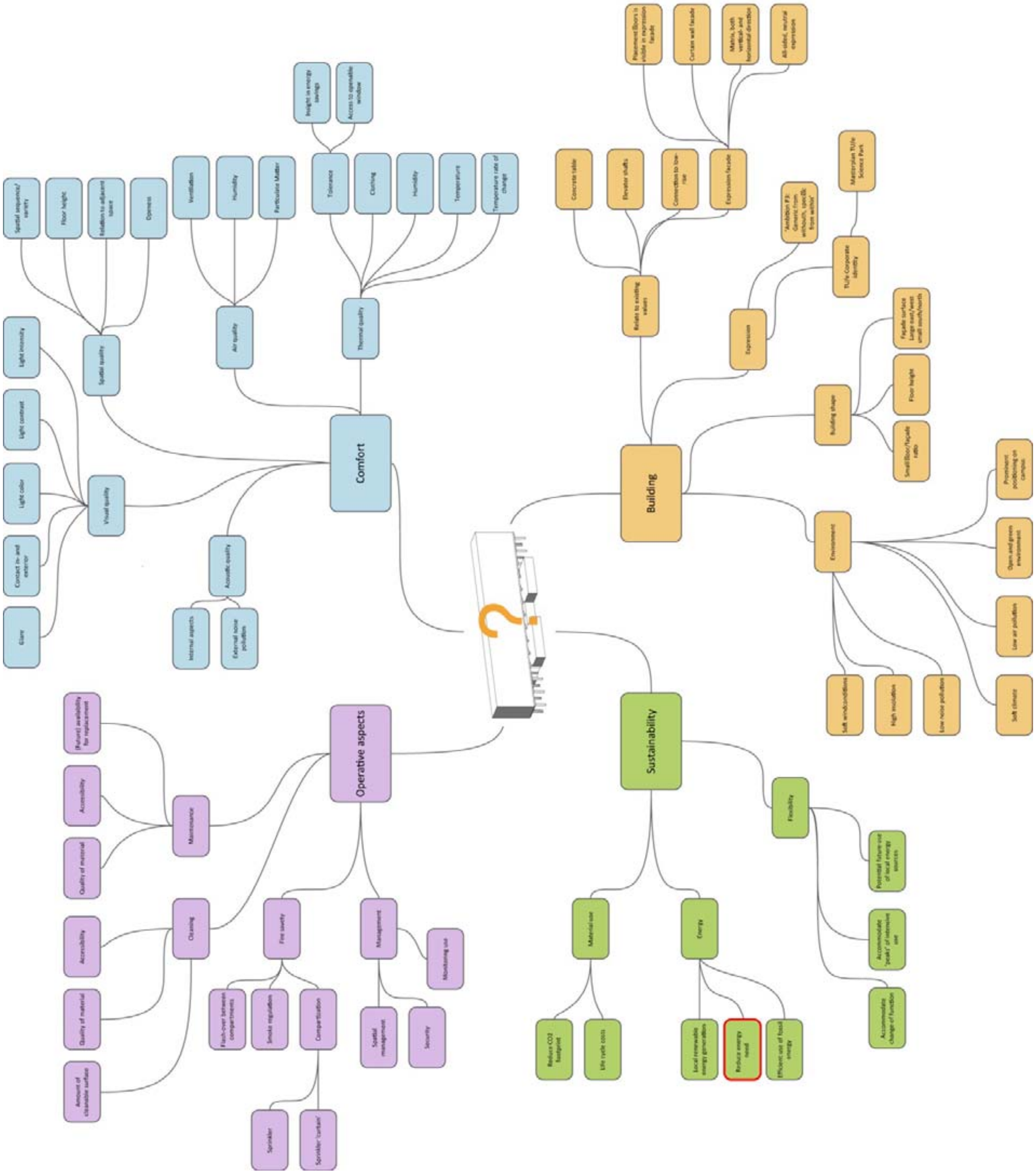


Figure 37. Mindmap of design aspects related to building object, comfort, operative aspects and sustainability

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EINDHOVEN UNIVERSITY OF TECHNOLOGY

Stan Ackermans Institute

SMART ENERGY BUILDINGS & CITIES

SMART FAÇADE CONCEPT FOR THE RENOVATION OF THE TU/e MAIN BUILDING

PART II - TECHNICAL REPORT

By

K.(Krijn) Hombrink, MSc

A dissertation submitted in partial fulfillment of
the requirements for the degree of
Professional Doctorate of Engineering

Eindhoven, the Netherlands

January 2014

This thesis has been established in collaboration with:

TU/e Technische Universiteit Eindhoven University of Technology
Department of the Built Environment

TU/e Technische Universiteit Eindhoven University of Technology
Real Estate Management

eit Knowledge & Innovation Community
KIC InnoEnergy

3TU.School for Technological Design STAN ACKERMANS INSTITUTE

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Abstract of a dissertation at the Eindhoven University of Technology.

Dissertation accomplished in the Post-Ms program Smart Energy Buildings & Cities.

ABSTRACT

The company assignment proposes a new facade concept,referred to as *Breathing façade*., for the renovation of the Main Building of Eindhoven University of Technology (TU/e), referred to as Project 3 of Masterplan Campus 2020. The design concept describes and prioritizes which assets should and shouldn't be included in the façade design to generate the highest value for the TU/e regarding the development of Project 3. The Breathing Façade is a concept which describes the most suitable design for the facade. However, the performance of the façade is related to the building organisation and applied installation concept. Hence, complementary to the façade concept, the study proposes a building organization- and installation concept. The overall concept proposes a light-flooded volume, open up to the environment and communicative with its surroundings. A relative simple façade design, with an intelligent controllable natural ventilation capacity, would ensure a high amount of fresh air and daylight admittance, while ensuring an efficient cooling of the building. Foremost, the proposed design concept distinguishes itself from alternatives in its ability to facilitate an increased study and work efficiency, which are the core-business of the university. Hence, the Breathing façade can elevate the renovation of the Main Building to a statement for the TU/e as a whole, to potential investors and future students, by providing the best learning environment possible. The proposed façade concept is the result of a one year, intensive study. Although the relevant information has been gathered in detail and with great care, the scope of the project makes simplifications and assumptions a necessity. The concept proposes a promising perspective on the renovation of the Main Building and provides an innovative design concept which is contrasting to recent building projects on the TU/e campus. As a result, the *Breathing façade* concept proposes a sustainable design attitude that answers to the ambitions of Project 3 and forms a solid foundation for the renovation of the Main Building.

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Chapter 1: Project introduction

The company assignment ‘Smart Renovation of the TU/e Main Building’ is fulfilled in the second year of the Professional Doctorate in Engineering (PDEng) program Smart Energy Buildings & Cities and is commissioned by the Real Estate Department of Eindhoven University of Technology. The company assignment is carried out in the context of Project 3 of Masterplan Campus 2020.

Eindhoven University of Technology is one of the three technical universities in the Netherlands. It is located on a green campus, positioned in the center of Eindhoven in the middle of the Brainport region. With the implementation of Strategic Vision 2020, the university aspires to enhance its international position to within the top-100 universities. Main aim is to increase the size and quality of education and research. To fulfill stated ambitions, the campus will be transformed according to the Masterplan Campus 2020: Under supervision of TU/e Real Estate Management, multiple building projects are rolled out to reshape the university campus into a high-grade science park, an attractive environment where, in addition to the university, international institutes, student housing facilities, incubators and industrial partners are established.

Masterplan Campus 2020 comprises the outline of the new accommodation plans of the Technical University of Eindhoven and was approved by the Executive Board in 2006. The plans include a fundamental modernization of the building stock of the university. With this new plan a compact campus will be realized. All departments will be housed around a green, car free zone, the so-called ‘Green Strip’. This results in the relocation of seven departments and central student facilities. Masterplan Campus 2020 consists of four large, independent projects which will be carried out in a pre-arranged order. The last project will be completed in 2020. [1]

Project 3 of Masterplan Campus 2020 consists of the thorough renovation of the Main Building (1963), and will be tendered as Design & Build project. The colossal building will be completely stripped, refurbished and provided with a new façade. The Main Building will house both departments of Industrial Design (ID) and Industrial Engineering & Innovation Sciences (IE & IS), as well as several supporting services of the TU/e. The current occupation will be moved out of the Main Building from end of 2014. The renovation, starting in 2015, can be performed in an almost vacant building. Project 3 is expected to be completed in 2017.

The Main Building consists of a high-rise, positioned on a large concrete table, and a low rise, consisting of four boxes positioned under the table. Key to the success of Project 3 is the development of a complete new facade for the high-rise. The façade has a large influence on the overall capability of the building to facilitate stated targets and ambitions of Project 3. The design of a façade is a complex problem and with multiple components: The façade design has to fulfil interrelated performance criteria in long-term perspective, as to facilitate building users, enhance the corporate identity, relate to cultural historical values, guarantee a high level of sustainability and insure low total costs of ownership.

The company assignment is performed in an early stage of the development of Project 3. Prior to tendering of Project 3, significant decisions can and have to be made to ensure highest value of the building design. In the timespan of a year, interrelated design aspects are defined, studied and prioritized. Result of the company assignment will be a design concept which functions as guideline for Real Estate Department for the development of Project 3, in order to develop the Main Building which facilitates the TU/e in a most suitable way.

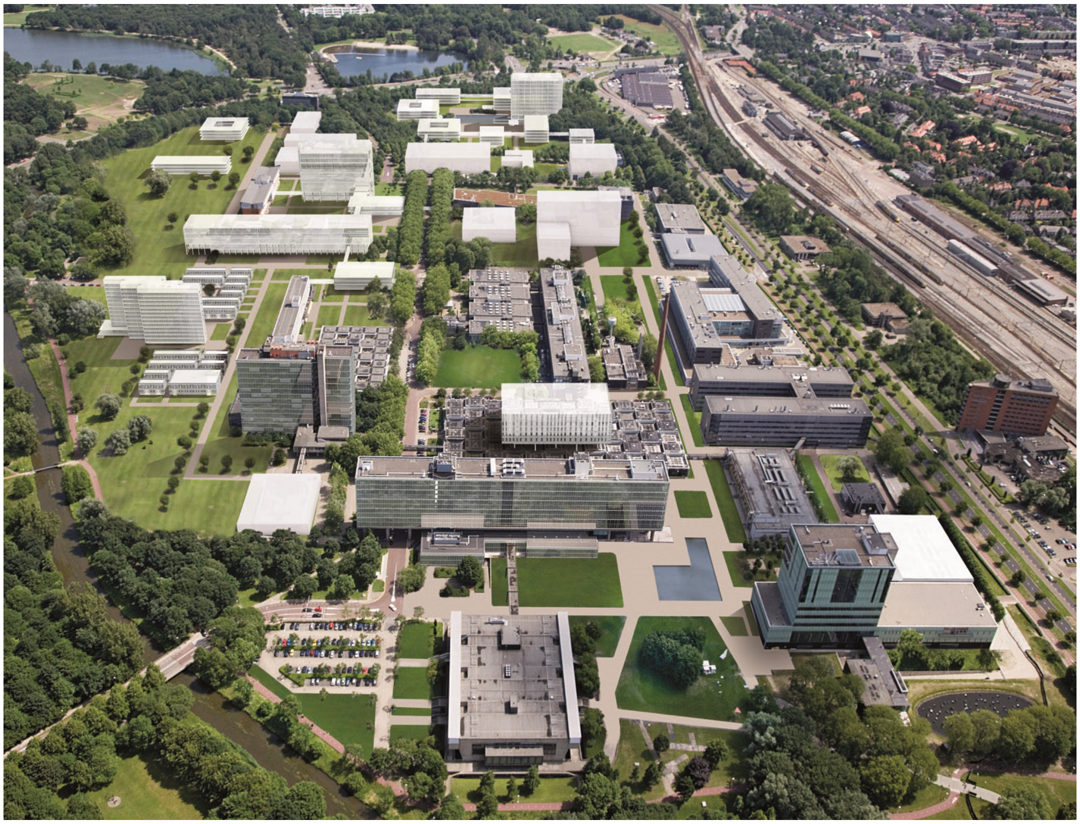


Figure 1.1. Impression Campus 2020, source: Masterplan TU/e Science park

Project introductie

De bedrijfsopdracht 'Smart Redesign of the TU/e Main Building' wordt uitgevoerd in het tweede jaar van het Professional Doctorate in Engineering (PDeng) programma Smart Energy Buildings & Cities, in opdracht van de Technische Universiteit Eindhoven, Dienst Huisvesting. De bedrijfsopdracht is een ontwerpende studie naar de mogelijkheden voor een energie efficiënte gevel voor het nieuwe Hoofdgebouw van de TU/e en draagt bij aan de uitvoering van Project 3 van het Masterplan Campus 2020.

Het Masterplan Campus 2020 omvat de hoofdlijnen van de nieuwe huisvestingplannen van de Technische Universiteit Eindhoven en is door het College van Bestuur vastgesteld in 2006. De plannen behelzen een grondige modernisering van het gebouwencomplex van de universiteit. Met het nieuwe masterplan realiseert de TU/e een compacte campus. Alle faculteiten worden gehuisvest rondom een groen, autovrij gebied, de zogenaamde 'Groene Loper'. Dit heeft ten gevolge dat zeven faculteiten en centrale studievoorzieningen een nieuwe huisvesting krijgen. Het Masterplan Campus 2020 bestaat uit 4 grote, onafhankelijke projecten die in een afgesproken volgorde worden uitgevoerd. Het laatste project wordt voltooid in 2020.

Opdrachtgever is Dienst Huisvesting (DH), één van de centrale diensten van de TU/e en is verantwoordelijk voor de totale vastgoedontwikkeling, het parkmanagement en de 75 hectare terreinen van TU/e Science Park. Voor de TU/e zelf verzorgt zij het projectmanagement en het beheer van alle gebouwen, installaties en infrastructuur van de compacte campus. Dienst Huisvesting heeft een adviserende rol naar het College van Bestuur, de faculteiten en de diensten op huisvestingsgebied. Er is er sprake van een klant/opdrachtgeverrelatie voor huisvestingsprojecten. Dienst Huisvesting telt ongeveer 40 medewerkers.

Project 3 van Masterplan Campus 2020 omvat de grondige renovatie van het Hoofdgebouw. Dit gebouw zal in verregaande mate worden gestript en opnieuw ingericht. Het hoofdgebouw krijgt onder meer een geheel nieuwe gevel. De nieuwe bewoners van het Hoofdgebouw zijn de faculteiten Industrial Design (ID) en Industrial Engineering & Innovation Sciences (IE & IS). Ook de ondersteunende diensten worden ondergebracht in het vernieuwde hoofdgebouw. De huidige bezetting zal vanaf 2012 uit de bovenbouw van het Hoofdgebouw worden verplaatst. In 2015 zal de renovatie in een nagenoeg leeg gebouw plaatsvinden. De renovatie van het hoofdgebouw wordt ongeveer in 2017 afgerond.

Het hoofdgebouw bestaat uit een hoogbouw, gepositioneerd op een grote betonnen tafel, en een laagbouw, bestaande uit vier dozen onder deze tafel. Bepalend voor het succes van Project 3 is de ontwikkelingen van een geheel nieuwe gevel voor de hoogbouw. De gevel heeft grote invloed op de mate waarin het gehele gebouw vastgestelde doelstellingen en ambities kan faciliteren. Het ontwerp van de gevel is een complex probleem, gelieerd aan meerdere, onderling gerelateerde, componenten: de gevelontwerp moet een prettige werk en studieruimte faciliteren, de bedrijfsidentiteit van de TU/e versterken, zich tot cultuur- en historische waarden relateren, een hoog niveau van duurzaamheid borgen en lage totale kosten verzekeren.

De bedrijfsopdracht is uitgevoerd voor de aanbesteding van Project 3. In dit vroege stadium kunnen en moeten belangrijke beslissingen worden genomen, om zo tot de hoogst mogelijke waarde van het gebouwontwerp te komen. In het tijdsbestek van een jaar worden onderling verbonden ontwerpaspecten gedefinieerd, onderzocht en geprioriteerd. Resultaat van de *bedrijfsopdracht is een ontwerpconcept welke als richtlijn dient voor Dienst Huisvesting bij de ontwikkeling van Project 3, om zo het hoofdgebouw op de meest waardevolle wijze te renoveren.*

Figure 1.2. Main Building at the heart of the TU/e campus

Chapter 2: Project plan

2.1 Project client

Project client is TU/e Real Estate Management, one of the central services of TU/e. They are responsible for the entire real estate development and park management of the 75 hectares of land owned by the TU/e. Real Estate Management caters for the project management and management of all buildings, installations and infrastructure of the campus. Moreover, Real Estate Management acts as advisor to the Executive Board, the departments and housing services. Real Estate Management has some 40 employees. [2] The TU/e Real Estate Management is principal of Project 3 of Campus 2020. To ensure the ambitions and performance criteria of Project 3, prior knowledge of relevant building aspects and design opportunities is needed. The TU/e Real Estate Management commissions the SEBC company assignment in order to get knowledge which supports decision making in the design process of Project 3.

2.2 Project motivation

2.2.1 Window of opportunity

Since the establishment of the university, the Main Building has always been an important icon of TU/e. However, over the years, this prominent positioned building has lost most of its programmatic importance and can't meet today's standards in facilitating activities for staff, researchers and students. Moreover, operational costs are high, considering that there are no energy consuming laboratories or test facilities placed in the building. [3] Despite its outdated appearance, existing qualities were recognized which resulted in Project 3, a comprehensive renovation of the building: starting by stripping the building to its concrete core, the TU/e aims to give the building back its former position and purpose, translated to meet contemporary standards.

Key to the success of Project 3 is the development of a complete new facade for the high-rise. With the renovation of the Main Building, the role of the façade has changed. Regarding comfort and energy efficiency, the facade needs to regulate influences between interior and exterior climates. With the current design, the Main Building's curtain wall is separated from the building construction, leaving the façade as a thin, almost non-materialized layer, bearing nothing but its own weight. The original façade is designed for optimal transparency and flexibility. Despite studies of building-physical aspects [4], this façade design resulted in a high need for active cooling during the summer and heating in winter. Unlike today's design attitude, this lack of performance was not seen as an important deficiency. The expected comfort level was relative low and, with fossil energy use not being an issue, building installations would actively maintain the indoor climate. The original façade design has a poor capacity as regulator between the interior- and exterior climate. An example of a good regulator is the wooden façade of traditional farm, made of local, insulating wood and multiple removable single pane windows with shutters, this type of façade is designed to perform in all four seasons (figure 2.1) The overall capability of the building to facilitate stated targets and ambitions of Project 3 is highly dependent on the new façade design. Therefore, the potential performance of the façade concept is studied prior to the design process of Project 3.

2.2.2. Relevancy of a pre-design study

The design of a façade is a complex problem with multiple components: The façade design has to fulfil interrelated performance criteria in long-term perspective, as to facilitate building users, enhance the corporate identity, relate to cultural historical values, guarantee sustainability and insure low total costs of ownership. An overview of relevant design components are shown in figure 2.2 and figure 2.3. Many of these components are in mutual contradiction. To give an indication:

- A high transparency of the façade will most likely increase the cooling load, while improving the quality of light admittance. A trade-off in openness has to be determined;

- Another consideration might be to integrate installations in the façade, in order to preserve the already limited existing floor height. However, this might give difficulties for future adaptations of the façade, reducing the flexibility of the design;

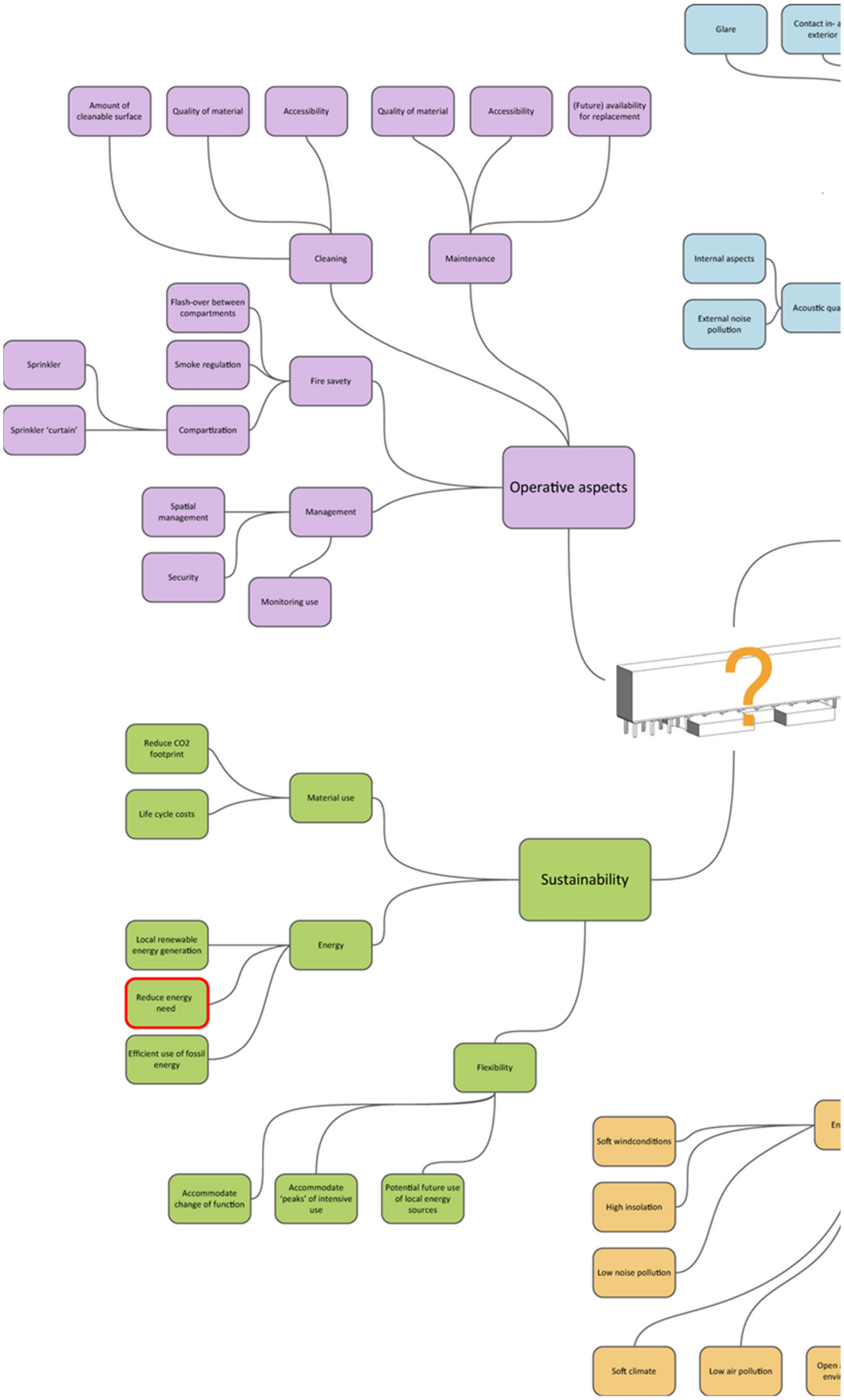
- With the renovation of the Main Building, a higher and more integral performance is expected from the façade design. In contrast with the original design, the façade should be a good regulator between in- and outdoor climate. However, the existing expression of this outdated façade design forms the basis for the appearance of the Main Building, which has become an icon with cultural-historical relevance and should be respected in the new design. This 'character' originates from a façade concept which is based on, by far, lower performance criteria than which are required for the new façade design to meet the high ambition level of sustainability;

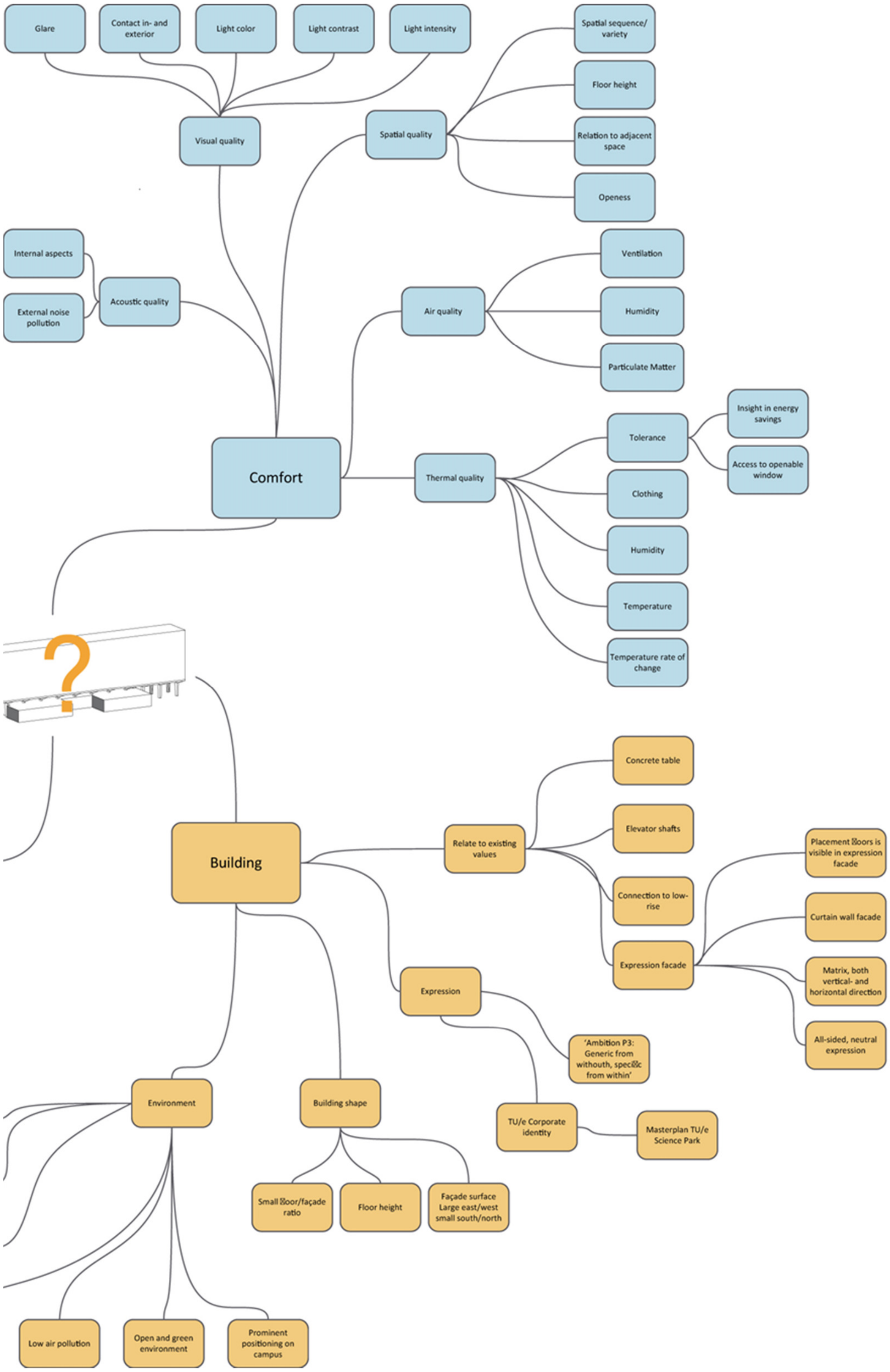
- Moreover, energy savings might contradict with experienced comfort or total cost of ownership because of the initial expenses are too high.

Combining these seemingly contradicting principles requires a deep understanding of all relevant aspects and the mutual relation between these aspects. The company assignment has been performed in an early stage of the development of Project 3. Prior to tendering, significant decisions have to be made to ensure highest potential value. In the timespan of a year, interrelated design aspects have been defined, studied and prioritized. Result of the company assignment will be a design concept which supports decision making by Real Estate Department during the tendering and design process of Project 3.

Figure 2.1. Façade of an old farmhouse with box windows

Figure 2.2. Interrelated design aspects related to façade design


Glare
Contact in- a
exterior
Amount of cleanable surface
Quality of material
Accessibility
Quality of material
Accessibility
(Future) availability for replacement
Cleaning
Maintenance
Internal aspects
External noise pollution
Acoustic qua
Flash-over between compartments
Smoke regulation
Fire savety
Sprinkler
Sprinkler 'curtain'
Compartization
Operative aspects
Spatial management
Management
Security
Monitoring use
?
Reduce CO2 footprint
Life cycle costs
Material use
Sustainability
Local renewable energy generation
Energy
Reduce energy need
Efficient use of fossil energy
Flexibility
Accommodate change of function
Accommodate 'peaks' of intensive use
Potential future use of local energy sources
En
Soft windconditions
High insolation
Low noise pollution
Soft climate
Low air pollution
Open
envi


Glare
Contact in- and exterior
Light color
Light contrast
Light intensity
Visual quality
Spatial quality
Spatial sequence/ variety
Floor height
Relation to adjacent space
Openess
Internal aspects
External noise pollution
Acoustic quality
Air quality
Ventilation
Humidity
Particulate Matter
Comfort
Thermal quality
Tolerance
Insight in energy savings
Access to openable window
Clothing
Humidity
Temperature
Temperature rate of change
?
Building
Relate to existing values
Concrete table
Elevator shafts
Connection to low-rise
Expression facade
Placement floors is visible in expression facade
Curtain wall facade
Matrix, both vertical- and horizontal direction
All-sided, neutral expression
Expression
'Ambition P3: Generic from withouth, specific from within'
TU/e Corporate identity
Masterplan TU/e Science Park
Environment
Building shape
Small floor/façade ratio
Floor height
Façade surface Large east/west small south/north
Low air pollution
Open and green environment
Prominent positioning on campus

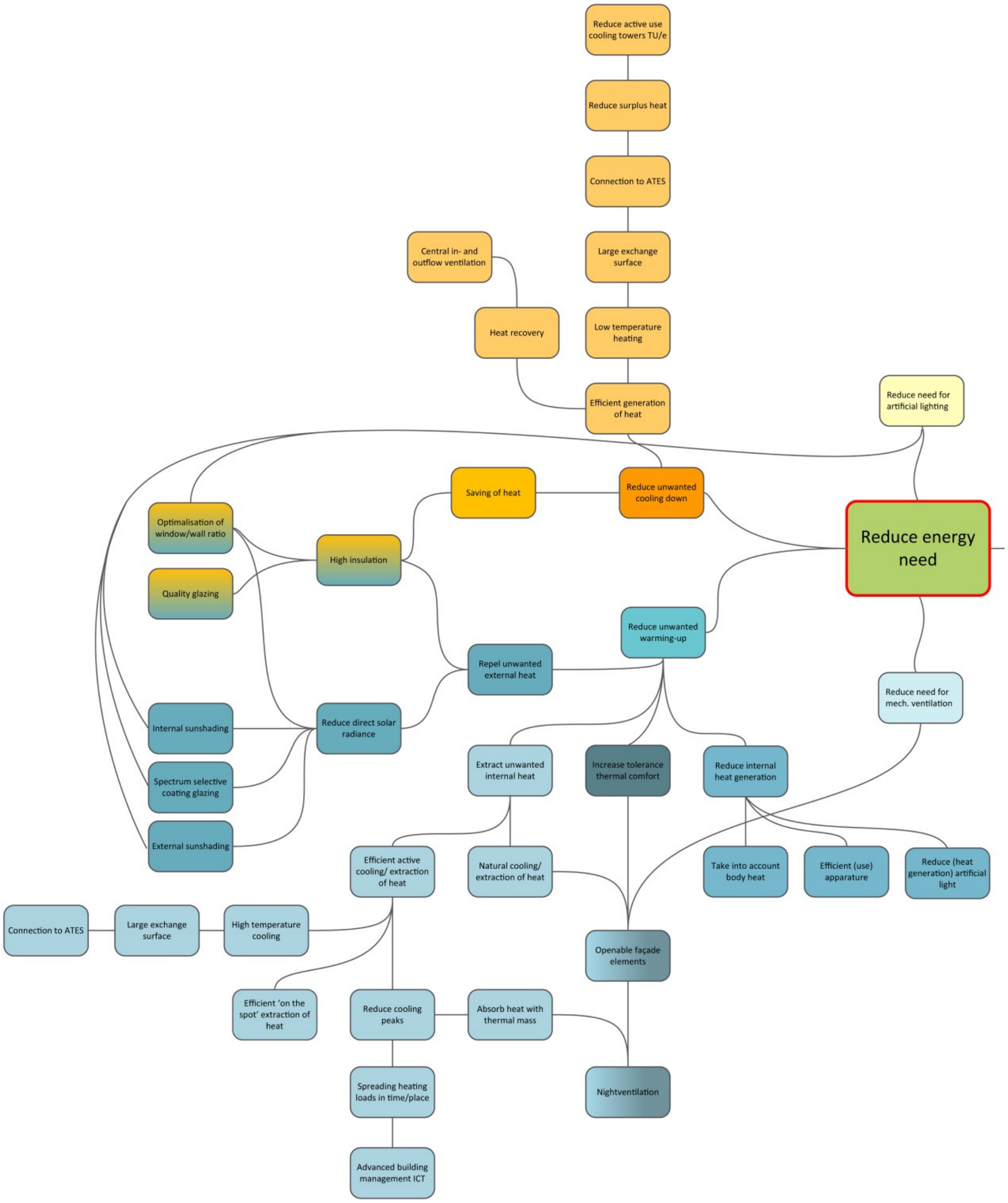


Figure 2.3. Interrelated design aspects related to energy efficiency of the façade design

2.3 Main objective

The main objective of the company assignment is to write a recommendation on the façade design, defined as a façade concept, for the high rise of the Main Building. The objectives are:

1. To provide insight in the performance of different partial design solutions for the Main Building;
2. To prioritize different partial design solutions based on integral performance;
3. To define opportunities and threads for the renovation of Main Building;
4. To design a façade concept for the high rise of the Main Building;
5. To implement the research outcome in the project process of Project 3.

2.4 Deliverables and scope of research

The final product will consist of:

- Presentation on the project results;
- Technical report which comprehends an extensive and concise documentation of performed research;
- Corporate report which described the value of proposed façade concept;
- Digital documentation of project information

2.5 Product scope

The scope of developed façade concept is:

1. The concept is applicable for the façade of the high rise of the Main Building (figure 2.4.);
2. The performance of the façade concept is based on interrelated aspects of user value, sustainability, total cost of ownership and architectural quality
3. The outcome of object analysis beneficial for complete building renovation of the Main Building high rise;

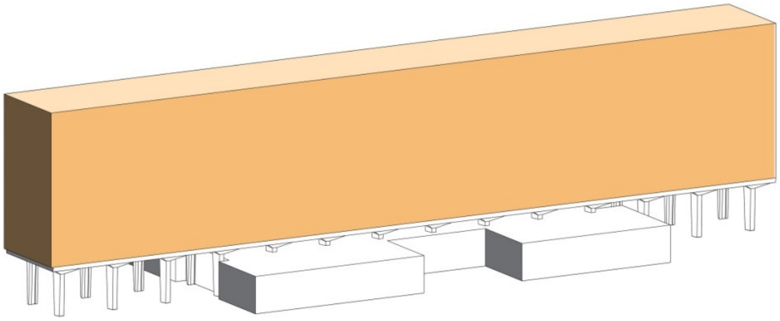


Figure 2.4. Main Building high rise (orange)

Chapter 3: Project approach

3.1 Project criteria

The company assignment is one of the required activities for earning a Professional Doctorate in Engineering. As a general aim, the assignment provides technical solutions for products, processes and systems based on functional requirements as well as on business/market requirements, within the context of a general societal character (attention for environment, reuse, and so on). This is to be achieved by means of a methodological approach with the following characteristics:

1. Goals formulated by industry should be made concrete in a measurable and verifiable specification, the so-called program of demands or requirements;

2. The concept of the product, process, or system, is designed using and integrating, in principle, existing knowledge and techniques from engineering sciences as well as from the disciplines associated with the problem domain;

3. Concept is validated with respect to the requirements and then made explicit after consultation with the customer.

3.2 Project methodology

Main purpose of the company assignment is to increase knowledge and insight to support decision making processes on practical and unique problems of the project commissioner. The developed theory serves the practice-oriented problem. A broader, more generic, application of the theory can be a secondary objective. The research will use existing theory and empirical verified insights to develop a theory of practice, tailor-made for the unique problem. This practice oriented research will be performed with the methodology of the *regulative cycle*, as shown in figure 3.1. This methodology differs from empirical driven research, which is commonly performed with the methodology of the empirical cycle, for several reasons:

- Firstly, the research addresses an individual, unique problem instead of a generic, universal problem;
- Secondly, the research aim is to define a certain proceeding or operation that supports the realisation of a desired situation, instead of validating or rejecting a hypothesis in order to predict certain behaviour or characteristics;
- As a third aspect, the practice oriented research is based on stated norms and/or values.

These norms and values form an important cornerstone for all steps of the regulative cycle; the problem is defined as a deviation on these stated norms and/or values; the design solution aims for these norms and/or values and the evaluation compares the result with the stated norms and/or values.

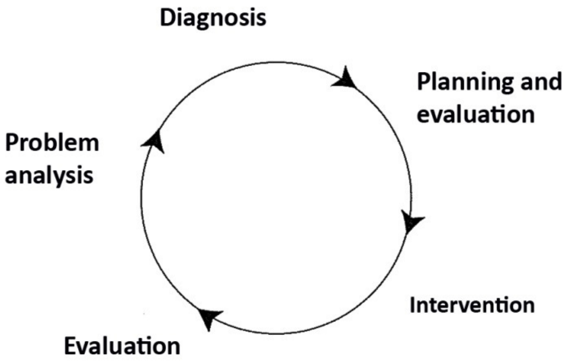


Figure 3.1 Regulative cycle

The practice oriented research will be performed according to the five phases of the regulative cycle, adapted on a technical oriented problem. The phases are briefly summarized below:

1. Problem analysis, defining the problem

One or more problems experienced by the problem owner form the starting point of the practice oriented research. Often the problem is not specific enough and needs refining. A first survey is executed, exploring the specific field of work, interviewing different experts and stakeholders and analysis constrains, to redefine the problem and if necessary, adjust the problem statement according to new insights. Prioritizing and relating problem aspects will be performed according to defined performance criteria, as will be explained in chapter 4.

2. Diagnosis

An analysis of the initial problem situation is performed, mapping causality, relation and consistency of problem aspects. The kernel problem, minor problems, side-effects and causalities are being defined.

3. Planning and evaluation

After problem analysis, the planning and evaluation criteria will be formulated which describes aim, approach and objectives. Alterable and not alterable aspects are distinguished and certain constrains and preconditions are being defined. Developed interventions are described and evaluated on effectiveness and feasibility.

4. Intervention

In this phase, the intervention, or proposed design concept, will be refined, re-evaluated and further developed based on new deepened insights obtained with more intensive analytic tools. This process follows a typical design cycle, being non-linear, reacting and using (expert's) reflection on generated insights and design studies.

5. Evaluation

The intervention will be evaluated on the defined evaluation criteria. Because of the practical nature of the problem, the intervention, or design concept, will be evaluated from a holistic perspective, mapping negative and positive side-effects. The intervention will be presented to relevant stakeholders and experts, defining recommendations and conclusions, putting the final intervention in perspective.

3.3 Project scheme and planning

The project has been performed in phases, as shown in figure 3.2.

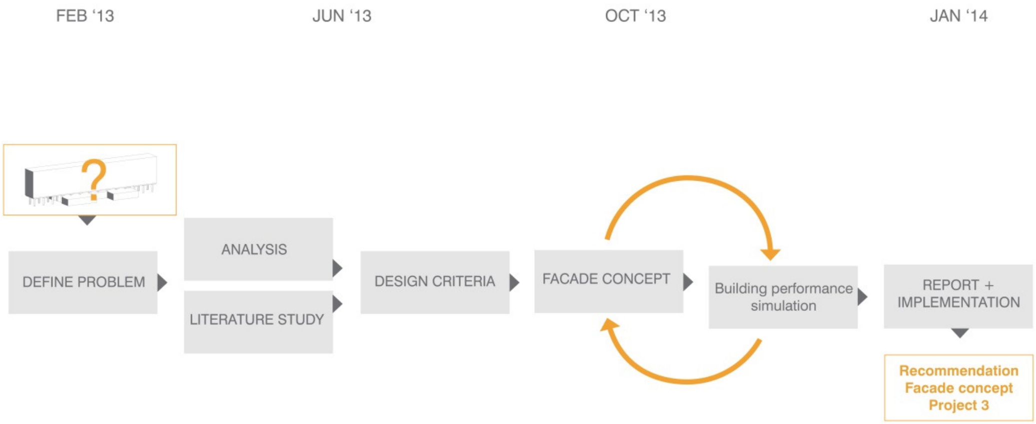


Figure 3.2. Overview project phases

A more detailed project scheme and planning can be found in appendix A and B

Chapter 4: Façade performance criteria

4.1 Integral performance

A building interacts with its surroundings and the façade is its regulator. On the interior, the façade needs to provide shelter, reduce dependency on fossil energy use and ensure a pleasant and healthy work environment. On the exterior, the façade should only let through desired climate influences, make up for the building's appearance and express the corporate identity of its users.

The façade is a component of a building, a tool to ensure the functioning of the building. The building primary facilitates the TU/e in its core business: research and education. Both tangible and intangible values provided by the façade design have to be considered in this perspective. The value of the façade concept is related to four performance criteria:

- *User value* – A high quality environment provided by the design concept supports intangible values as comfort, productivity and less absenteeism of students, staff and researchers. The façade performance is related to provided building physical and architectural qualities;

- *Expression* – The Main Building is of historical and cultural relevance to which the façade concept needs to relate. Moreover, the Main Building is the flagship of the TU/e, an icon which is noticeable immediately when visiting the campus. Enhancing the corporate image of the university results in higher student subscriptions and international attractive environment for top-researchers;

- *Total cost of ownership* - Tangible values of investment costs, maintenance costs and energy savings are considered over time;

- *Sustainability* - The TU/e is obliged to enhance their sustainable performance, regarding material, water and energy use on the campus. Water use is not significant, leaving material and energy efficiency as tangible performance criteria for the façade concept.

4.2 User value

4.2.1. Motivation

As primary function, a building facilitates its users. It is the platform on which the core business of the university, being research and education, thrives. As aforementioned, if a façade could influence a better and more effective working and learning environment even slightly, the (financial) impact could be far greater than when the façade saves half on potential energy use (sustainable design attitude, chapter 2.5, p.14). Major problem to make a balanced trade-off is the difficulty to quantify an increased quality of a space. However, increasing amount of studies state a certain relation between increasing comfort standards and its quantifiable influence on a more healthier, effective work environment. In this chapter, a short literature study on the effect of different sorts of comfort on building users is performed.

The scope of the literature survey is specified for the influence of the façade for the Main Building. Since there is only a low amount of external noise pollution, the façade has no major influence on internal acoustic comfort. This study focuses on the influence of the façade design on provided spatial, visual and thermal comfort and the effect of the quality of indoor air.

4.2.2. Spatial comfort

The quality of the indoor space is of major influence on how one would perceive the space as pleasant or not. A certain openness and division of space, a diversity in scale of sequenced spaces and open floor height are important factors. For example, the construction of the high rise, varying with the placement of flexible floors, allows a diversity in scale of adjacent spaces. The façade could strengthen the difference in scale, with large scale openings adjacent to large scale ateliers and smaller, more refined, openings adjacent to smaller offices. Furthermore, the guideline for comfort criteria, as formulated in the concept of *Frisse Scholen*, states a minimum floor height for group spaces of 2,8 m. for label C and 3,5 for label A. [5] when flexible floors are used, the high rise construction only allows an open floor height of 2,7m. To ensure a high spatial quality, the limited available floor height should be kept to a maximum.

4.2.3. Visual comfort

As explained in chapter 5.1, a quarter of the total electrical energy use of the TU/e campus is used for artificial lighting. In addition, as stated in chapter 5.2., the shape and construction of the high rise has the potential to allow a high amount of daylight entrance, reaching up to 50% of total floor space. Up to a certain amount, increasing daylight entrance not only saves energy on artificial lighting, but, foremost, it has a very positive effect on user comfort.

However, increasing transparent façade surface increasing the admittance of solar radiance and often decrease the total insulation value, which can have a negative effect on energy consumption, increasing cooling and/or heating load. Therefore, a balance in façade openness (window to wall ratio, or 'WWR') needs to be found when designing the façade. As indication for façade openness, a study performed for the location of the Main Building suggests a different openness by orientation. This study compares energy savings with visual comfort criteria (contrast, illuminance, glare), as shown in figure 4.1. Outcome of this study suggests an openness of:

- 50-70% for north oriented facades;

- 50-60% for east and west oriented facades;

- and 60% openness for south facing facades.

The suggested openness is relative high when compared to the openness of the Meta Forum (approximately 25-30%) or often suggested guidelines, which often suggest an openness of 30-40%. This can be explained due to that the study sets high visual comfort standards (for example, over 50% of daytime hours an illuminance of 500 lx is reached). [6]

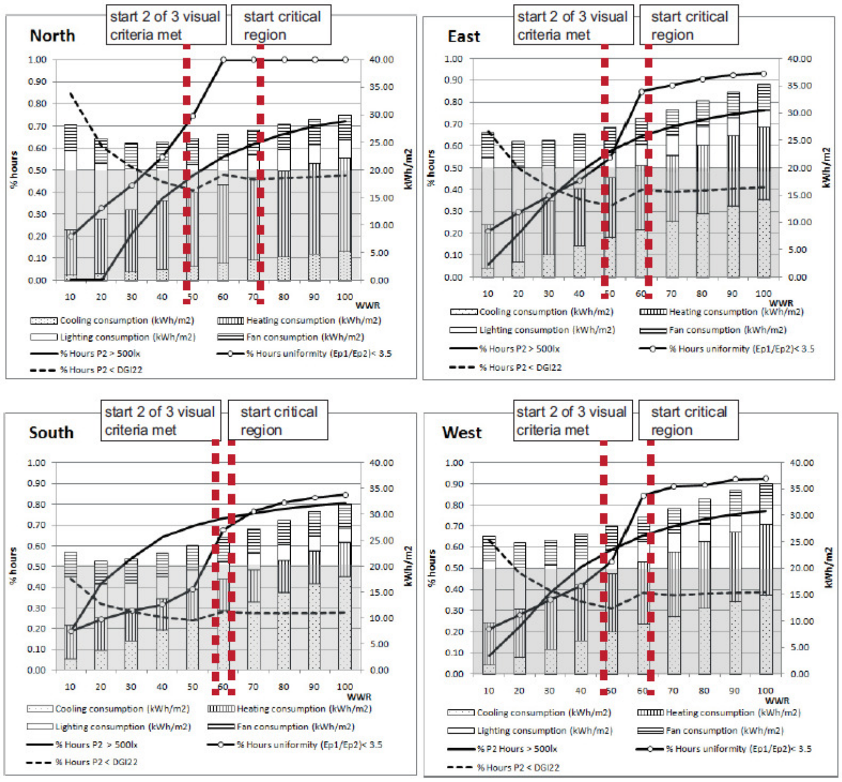


Figure 4.1 Openness per orientation (source: [6])

In addition to facade openness, there are different indications to determine visual comfort. One guideline to determine the amount of daylight entrance is the daylight factor (D):

> *Internal illuminance [lx] on a horizontal pane (height 0,85 m.)/external illuminance [lx] near façade with an overcast sky) * 100%*

As indication, an illuminance of 2500 lx, in the case of a full overcast sky, is reached about 90% of the daytime hours per year. An illuminance of 300 lx of a desk is regarded as minimum value for a daylight-oriented workspace and at least 75 lx is regarded as threshold for switching on artificial light. A daylight factor of 3% allows an internal illuminance of 75 lx for 90% o and 300 lx for 50% of daytime hours. [7]

A daylight factor of 1% is regarded as a minimum. For an office space, a daylight factor of approximately 3% is regarded as a daylight-oriented workplace. In daylight oriented workplaces, the daylight autonomy must be at least 70%, meaning that on a minimum of 70% of working hours available daylight levels are sufficient. A daylight level of 3% can only be reached to a depth approximately equal to the height of the room. Daylight autonomy is the proportion of annual hours of use in which sufficient amounts of daylight are available and artificial lights do not have to be switched on. With a daylight factor of 3%, a daylight autonomy of approximately 40% could be reached for over 50% of total floor space in the high rise. [7] Increasing the daylight factor would be less efficient in increasing daylight autonomy and would result in an increased thermal energy load, especially additional heat gain during summer period. This relation is shown in figure 4.2.

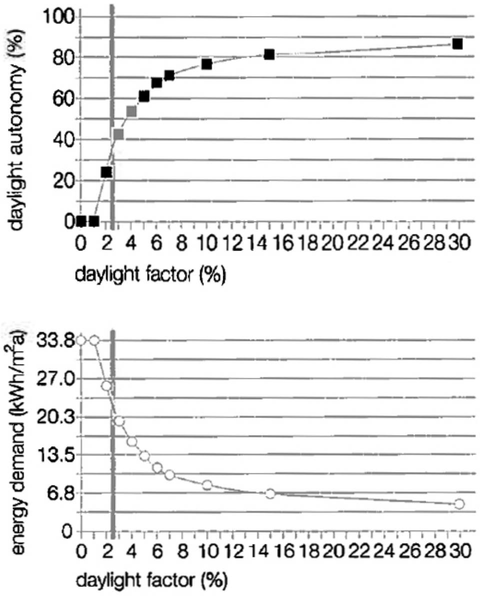


Figure 4.2 Influence of daylight factor (source: [7])

4.2.3.1 Contact with exterior

The Main Building is centrally positioned on the campus. Contact with exterior is an important quality for building users, it supports the relation between the campus and building users. Moreover, a skyline visible from the workplace is another important factor which suggest high openings in the façade.

4.2.3.2. Colour of daylight entrance

Due to different types of coatings and foils on or behind glazing, the colour of daylight may be altered and turn greenish, bluish or greyish. Not directly visible when inside and no other reference of 'normal' daylight colour is available, but certainly has an effect when long term usage of adjacent space. Therefore, when performance is equal, the less coloured glazing is always preferred.

4.2.3.3. Light control device

In addition to the amount of illuminance, contrast and glare are other important factors which can be measures. This study will not focus on these criteria other than the conclusion that in any case, a manual controllable light repelling device should be included in the façade design. As shown in a study performed by TNO [8], this daylight control device should be another device than the sun repelling device. Glare or high light contrasts can occur on bright winter days and can cause visual comfort problems, but warmth of the solar radiance is still desired and could save energy use.

4.2.4. Thermal comfort

An important difference can be made between thermal sensation , a subjective evaluation of experienced temperature, and thermal comfort, assessing the subjective evaluation of experienced temperature. In other words, one could experience warmth (thermal sensation) but assess this same warmth as comfortable or discomfortable. This is exactly the difference between a space conditioned using mechanical ventilation and a space conditioned using natural ventilation. In the latter, one would have a higher tolerance and sooner accept a higher indoor temperature, mainly because the user is in relation with outdoor climate.

- Thermal sensation: 'a conscious feeling commonly graded into the categories cold, cool, slightly cool, neutral, slightly warm, warm, and hot; it requires subjective evaluation'.
- Thermal comfort: 'that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation'.

Moreover, the human body is designed for fluctuation of temperature, both thermoregulation, reacting on heat changes, and thermal sensation, how one experiences temperature, make thermal comfort, how a building user will experience and tolerate indoor temperature. With other words, if a building would be cold in the morning, for example using night time cooling, and warmer during the afternoon, caused by internal and external heat gains. This fluctuation would improve thermal comfort.

4.2.4.1 Thermal setpoints

The guidelines provided by the highest label of *Frisse Scholen* suggests , for heating season, a fluctuation allowance of between 19 °C and 25 °C. In cooling season, a difference is made between active and passive cooling systems. When actively, mechanically cooled, temperature may only fluctuate between 23,5 and 25,5 °C. With passive cooling, such as natural ventilation, operative temperature may fluctuate between 0,33*ambient temperature +18,8 °C ± 2 °C. This could mean that when outside temperature is 27 °C, indoor temperature is allowed to be between 25,7 °C and 29,7 °C. This temperature is still regarded as label A of *Frisse Scholen*, providing high comfort guidelines, and can potentially save energy on cooling.

4.2.4.2. Downdraught

Workplaces close to large façade openings can experience thermal discomfort caused by downdraught and cold radiation. A high insulation level of glazing, with low e-coatings can reduce this effect greatly. Triple glazing, climate facades or auxiliary heating near the facades can reduces these effects. Moreover, uninterrupted vertical lengths of approximately 2,8 m. for glazing cause problems with downdraught and should be avoided. Larger lengths could be reduced by the addition of a shelf or other element to the façade design.

4.2.4.3. Effect of thermal comfort:

A short literature survey gives an indication of the effect of thermal comfort:

- Preller (1990): possibility of open able windows and possibility of personal control of thermal indoor climate result in a 34% less short term sickness absenteeism; [9]
- Wyon (1996): individual control of indoor temperature (± 3 °C) results a 99% user satisfaction regarding indoor temperature; [10]
- Oseland (1999): Individual influence over temperature in combination with fresh air supply results in an increase of work productivity of 2,8 to 9%; [11]

- Wyon (2000) Personal temperature control causes a productivity increases with 4-6%, in comparison with the same work environment with no personal control; [12]
- Clements-Croom (2000): personal control of indoor temperature (± 3 °C) increases productivity with 5-15%. [13]

Personal control is regarded to be effective for spaces for individuals or small groups. The Main Building high rise will mostly accommodate ateliers and open office work-concepts, in which self-control is regarded as a less evident necessity. Moreover, a fluctuating temperature, as shown in figure 4.3., provides a higher comfort compared to a fixed set point. Thermal comfort is related to experience cold radiance and downdraught caused by large glazed surfaces or/and glazing with poor insulation and no low-emissivity coatings.

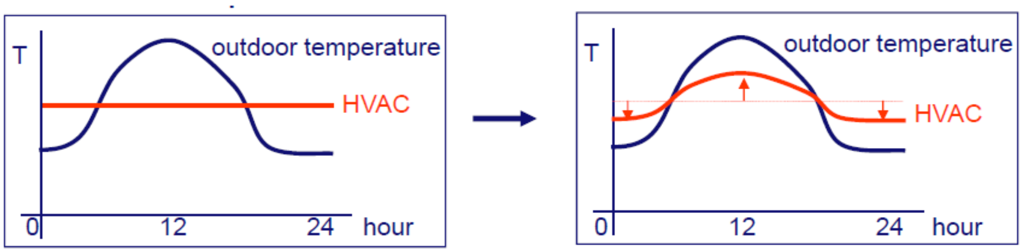


Figure 4.3 + figure 4.4. Allowable temperature fluctuations based on thermoregulative principles and dynamic

4.2.5. Air quality

The quality of internal air has a long term effect on health and productivity. It affects the capability of students to learn and perform on tests. [14] Ventilating indoor air ensures the quality of air. Quality of air is influenced by unwanted odors, moist and most determinative, the contained particles of carbon dioxide, which is denoted in ppm. (parts per million). In general, the quality of outside air in the Netherlands is around 400 ppm. (0.00040 $m^3_{CO_2}/m_{air}^3$). Project 3 aims for an indoor air quality of 800 ppm., which is since 2012 standard in the Netherlands for schools. [14] 800 ppm. is set as maximum for *Frisse Scholen* label A, a lower concentration of CO^2 particles is regarded as preferable.

Moreover, in order to have a high level of air quality, referred to as *Frisse Scholen* label A, states:

- A ventilation rate of 1,75 $l/s/m^2$ during office hours (08:00-23:00);

- In addition the façade should be able to facilitate an occasional ventilation purge of maximum 9,0 $l/s/m^2$. This can be used for night cooling as well (23:00—08:00).

4.2.5.1. Effect of high air quality

A short literature survey gives an indication of the effect of a high interior air quality:

- Oseland (1999): increase of fresh air supply in office results in an increase of productivity of 3%; [11]

- Milton et al. (2000) increase of fresh air supply from 12 to 24 dm3/s/person results in 35% less sickness absenteeism. Moreover, addition of air moistening results in a negative effect, increasing sickness absenteeism; [15]
- Kroner et al (2000): personal control of temperature, air exchange rate and fresh air supply results in an increase of work productivity of 12,5%. [16]

4.2.6. Conclusion

As outcome of the analysis, the façade design should facilitate a dynamic indoor temperature, a high amount of daylight admittance and the ability of natural ventilation to enhance indoor air quality. Moreover, the façade should enable building users an experienced contact with external environment. Regarding user value, the following criteria function as guideline for the façade design.

Spatial comfort:

- A certain amount of experienced openness of interior space is desired;
- Limited floor height should be kept open to a maximum, if possible 2,7 m. height;
- Sequence and variety of spatial scale is desired.

Visual comfort:

- The shape of the Main Building is ideal for providing a high amount of daylight autonomous workspaces. 50% of total floor space can be lighted by daylight 40% of daytime hours, expressed by a daylight factor of 3%. To reach this amount of daylight illuminance, the full façade height should be open;
- In addition, a balance in energy efficiency and visual comfort (glare, illuminance and contrast) is sought, resulting in a WWR indication which differs per orientation. Based on high visual comfort standards an openness of 50-70% for north, 50-60% for east and west and 60% for south facing facades in indicated. Larger openings will be decreasingly effective and cause increasingly higher energy losses;
- The façade should allow contact between in- and exterior and a visible skyline from most workplaces. This results in high, vertical openings;
- Daylight entrance should be clear and when different options exists, least coloured due coatings and foils;
- In addition to possible sunshading, daylight control devices, such as manual controllable screens, should always be included in façade design.

Thermal comfort:

- Passive cooling, such as visible natural ventilation, allows higher tolerance of indoor temperatures;

- A controlled, tempered, thermal fluctuation provides higher thermal comfort when compared to fixed set point. Allowing thermal fluctuation supports passive cooling and night time ventilation concepts, which always cause thermal fluctuations;

- Independent of the need for thermal energy savings, high insulation level of glazing are needed to avoid cold radiation and downdrafts.

Quality of interior air:

- An interior air quality of 800 ppm. should be considered as minimum for an educational building, such as the Main Building;

- Regarding façade design, the façade should facilitate the capacity of ventilation as described by *Frisse Scholen*, label A (1,75 l/s/m^2 ventilation and 9,0 l/s/m^2 purge ventilation and night cooling);

- An increase in quality of internal air affects the productivity, health and learning capabilities of building users.

Figure 4.5. Quality of indoor air should be as if one would be working outside

4.3 Architectural expression

Due to its central position on campus, The Main Building has a dominant influence on the overall image of the TU/e. The expression of the high rise of the Main Building should relate to both the corporate identity of the TU/e and the cultural and historical values of the building:

4.3.1. Masterplan TU/e Science Park

With the future building projects of Campus 2020 in mind, a more expressive and shaping general plan is formulated, *Masterplan TU/e Science Park*. [17, p. 61] This plan provides urban and architectural rules and counts as a broad and leading document for future building projects on the campus. The provided design rules aim for a uniform and distinguished identity of the campus. 'The explicit choice of the Masterplan is that new architecture on the campus should not contrast with the distinctive, existing, architecture (…) instead —in a contemporary manner it should connect. By doing so, the TU/e Sciencepark will present itself architecturally as one evolutionary unity.' [18] In addition, the plan states a technical expression of sustainability. 'The high-tech appearance is not just a decor, but the technique should actually be in service of sustainability. This way the building façades on the TU/e Science Park form one recognizable billboard for the existing expertise on the campus.' [18, p. 69] The Masterplan TU/e Science Park provides clear design rules for upcoming building projects of Campus 2020, including project 3. An impression is shown in figure 4.6.

Figure 4.6. Impression Campus 2020, source: Masterplan TU/e Science park

4.3.2. Cultural and historical values

The Main Building is the most prominent building, and with a gross floor area of 44.606 m^2, by far the largest building on the campus. Centrally placed, its appearance is the first impression on visitors when entering the campus. Moreover, the building forms the center in a network of university buildings. Connected by walking bridges, students and employees will almost always cross the main hall of the Main Building on their route. The Main Building is seen as an icon of Functionalism in Eindhoven. Designed by the architecture bureau of Van Embden, named OD205, the building is a true example of modern building techniques and innovative vision of its time. Due to the planned renovation, the Real Estate Department commissioned a culture historical study of the Main Building in 2011. [19] The study showed the relevance of the Main Building as an important icon of functionalism, for the city of Eindhoven and of course for the campus itself. The survey describes the architectural, culture- and historical values of several aspects and components of the Main Building. Several characteristics and qualities were identified. These described values serve as an important guideline for the design of Project 3.

Figure 4.7. Photo of the Main Building, date unknown (source:OD205 architectuur)

4.4 Total cost of ownership

4.4.1. Target and ambitions TU/e Real Estate Management

An important objective of TU/e Real Estate Management is to facilitate and maintain the built environment, in which TU/e can operate its core business: education and research. With the transformation of the campus into TU/e Science Park, opportunities arise to renew the university's portfolio both technically and functionally, in order to strengthen its financial base for the future. A comparative study between Dutch universities shows that the TU/e has relative high energy and water use (23.2%) related to total costs of ownership. A lower operative cost can be achieved by reducing the total energy use and total used building space (UFA m^2). Main objective of TU/e Real Estate Management is to reduce the total costs of ownership of the TU/e campus and its buildings, including the Main Building.

4.4.2. Energy savings in a broader perspective

An energy efficient façade can both lower the energy needs and operating costs of a building. Lowering cooling and/or heating loads of interior climate, reducing the need of artificial lighting and less dependency on mechanical ventilation can result in significant savings over time. However, the design of an energy efficient façade for the Main Building has to be considered in a broader context. A façade primary functions to accommodate a pleasant and qualitative indoor environment for the building's occupants. Moreover, it forms the expression of a building to its surroundings (the TU/e campus) and, in the case of the Main Building, has to express the corporate identity of the building user. The core businesses of TU/e are research and education. The buildings on the campus have to accommodate these activities. More than 63% of total expenses, which count for more than € 200 million each year, is spend on supporting staff, researchers and students to perform core business related activities. [20, p. 78] Moreover, a significant part of student scholarships is funded by the national government. To put matter in perspective, only 2%, (€ 6.3 million/year) of total expenses is spent on energy and water use. See figure 4.8 for a more detailed breakdown. The ratio between both assets (energy: users) is 1:32. Hence, increasing the effectiveness of staff and student endeavors by 1% could be considered equal to an energy saving of 32%.

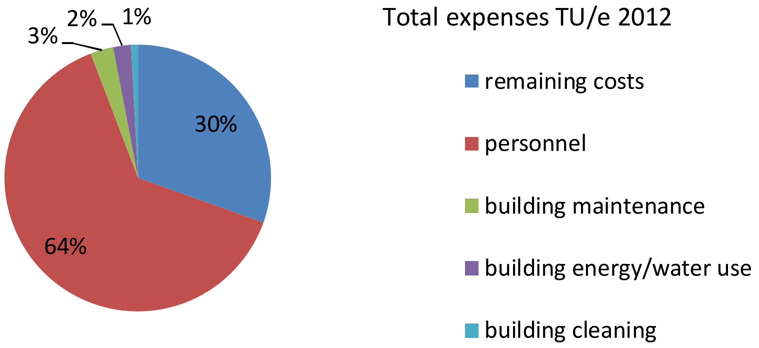


Figure 4.8 Annual expenses TU/e (source: [20])

4.4.3. Value over time

The façade could be seen as an investment over time. Cost savings have to be considered over the total lifecycle costs. Energy savings are directly related to cost savings and are measurable over time. For example, the investment in a better insulation capacity of a façade saves on energy use, and this effect can be measured directly when the building is in operation. However, supporting a more healthy and productive work and study environment is more difficult to measure, and effects are only noticeable over time. For example, the effect of a higher attendance in flexible workspaces or a higher productivity at the end of a working day has a great effect on supporting the core process of education and research, but the effect is more difficult to measure and/or distinct but might be far greater than the savings on cooling and/or heating of the interior space. Moreover, on a even larger timescale, the façade design can have an even more significant effect on the health of building users. Especially if building users use a space for many hours during a day, the quality of air, contact with exterior climate and the overall quality of space can have a great effect on stress-factors and other health aspects. The relation between the impact and directness of effect of different design aspects is shown in figure 4.9.

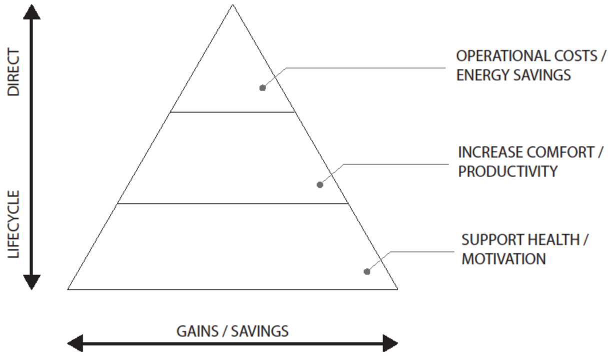


Figure 4.9 Influence of energy savings and improving user value

4.4.4. Cost indications

Project 3 has a certain total investment, assumed to be € 70 million. As part of a total investment budget, the real estate department will give an assumed indication for the façade budget of 825,00 €/m^2 to be most appropriate. However, Project 3 will be tendered as a Design-Build project, performance is managed by means of output specifications instead of defining specific solution or input. Hence, based on the defined output provided by the TU/e, different design consortia will be asked for a project proposal and will give their interpretation of the best division of total investment that can result in a different budget for the façade design.

4.4.4.1. Energy costs

For the year 2013, price for 1 kWh is only €0,0765. The prices are given in table4.1. Compared to households, offices or facilitating services, the TU/e can use electrical energy at a low cost. Due to the amount of energy use, the TU/e is able to wield a low price buying strategy. This gives a significant return on investment, but makes it less attractive to implement renewable energy sources such as PV-panels, since the rate of return is lower due to lower financial savings on energy. The amount of thermal energy savings of different partial solutions is determined by the outcome of a verified model performance study. The thermal energy savings are converted to electrical energy savings, assuming a certain efficiency related to the ATES system on the campus, which will generate the demanded cold and heat for the Main Building. Finally, the electrical energy (kWh) is converted to financial savings.

Table 4.1: Energy prices TU/e

energy price incl. VAT *(BTW)*	0,09104	€/kWh
energy price excl. VAT *(BTW)*	0,07651	€/kWh
energy price incl. *Regulatieve Energie Belasting*, excl. VAT*(BTW)*	0,07961	€/kWh

4.4.4.2. Maintenance costs

Maintenance, construction and cleaning costs in 2012 are €11.0 million. Maintenance costs are different for each building element and will be included to determine the total cost of ownership.

4.4.4.3. Comfort costs

Savings due to the increase of comfort are indirect, difficult to determine and beyond the scope of this study. However, two aspects can be given as indication:

- Students are the most valuable assets of a university. On average, the Dutch government finances bachelor and master students for € 6.100 per student per year. Moreover, average costs per beta student are even higher, between €8.500 and €10.500 , based on a study performed in 2003 [21, p. 79] and more recent estimations; [22]

- As aforementioned, total expenses on the personnel of the TU/e, mainly supporting staff and researchers, over 2012 is near € 200 million, accounting for 64% of total budget. Energy accounts for 2%, € 6.3 million/year. Main purpose of staff and researchers is to facilitate education and perform research;

- TU/e personnel absenteeism due to sickness is 2,1% of total calendar days in 2012 [20, p. 60], accounting for 7,7 days/person and a total loss €4.2 million euros on personnel expenses. Decreasing personnel absenteeism by 1% would save €42.000/year;

- Most of all, increasing effectiveness of students, staff and researchers will shorten total study time of students, research output of researchers and more productive work output of personnel. The complexity is too large to determine the effect of a more productive work environment. If a 1% increase in productivity facilitated by the façade design would mean a 1% saving on expenses on personnel, it already accounts for a saving of €2 million euro/year;

4.5 Sustainability

Sustainability is a broad term which can be interpreted in many different ways. Sustainability, related to the design of the façade, is determined by energy efficiency, material use and flexibility of the façade design.

4.5.1. Energy use in the built environment

The integration of renewable energy technologies in the built environment is a valuable option to reduce energy consumption, in particular GHG emissions. The built environment has a large share in the overall energy load. About 37% of final energy consumption in Europe is taken by the building sector, both housing and serving facilities. [23, p. 166]Over the last decade, a gradual shift has taken place toward the use of renewable energy sources, such as solar energy, wind power and bio energy. In the last decade, the share of renewable energy sources has doubled to 11.6%. [23, p. 168] In order to strengthen the transition to a sustainable built environment, the European Commission is directing the improvement of sustainable energy use and supports low-carbon policy (such as the Energy Performance of Buildings Directive (EPBD), 2010). The 2020 target aims to increase the overall share of renewable energy sources in Europe (of total energy use) to 20%. [23, p. 168] To achieve this aim, the EPBD requests for nearly-zero energy buildings, taking into account the possible positive impact of renewable energy technologies. Zero energy means that any energy required for the operation of the building will have to be compensated by the equivalent amount of energy supplied back to the grid by the building. The returned energy is generated from renewable sources. Numerous innovations and technologies for the built environment offer opportunities to reduce the energy consumption, control the energy demand/supply balance through intelligent management and renewable energy. Even so, low-energy buildings can only become reality when the design process takes into account energy flows from passive solar and landscape design and is able to integrate new technologies with architectural design. The high investment costs involved, the lack of information on energy-efficient solutions at all levels and scarce availability of solutions to specific conditions, are considered as the major barriers to the implementation of energy-efficiency measures in building projects [23, p. 169]. Moreover, the low number of new buildings compared to the existing building stock is the reason that the potential energy savings are not leading to the desired overall energy savings. The operational energy load in residential or commercial buildings to be renovated should be the first aspect to be taken into account when considering the improvement of the energy performance of building stocks.

4.5.2. Changing trend in energy consumption in built environment

At present, roughly two-thirds of the energy consumption in buildings is used for space conditioning (temperature and ventilation) while the remaining one third is mostly electricity used for installations and appliances [23]. Figure 4.10 illustrates this development. The trend is that by energy saving, the use of thermal energy is decreasing, while at the same time electricity consumption is increasing, making the need evident for more efficient energy consuming devices. Renewable Energy will hold a more important share in the final energy supply. The 2010 data provided by the evaluation of the National Renewable Energy Action Plan reports give an estimated share of 11.6 %; this corresponds to a doubling over 10 years, whereas the 2020 target gives an overall share in Europe of 20%.

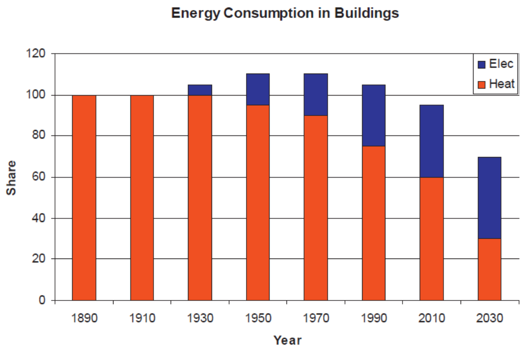


Figure 4.10 Energy consumption trend (source: Bloem, 2011 in [23])

4.5.3. Targets and ambitions TU/e campus

As one of the major universities in the Netherlands, the TU/e has accepted an agreement (MJA-3) to aim for a total energy reduction of 30% in the period of 2005-2020. As stated in the yearly energy report, this means that for electricity only, TU/e's total load needs to be reduced from the current 42.000 MWh/y to 30.000.MWh/y by 2020 [24]. In addition to energy reduction, the TU/e has the ambition to implement more distributed energy resources (DER), to increase local energy generation and energy neutrality in 2020 [25]. To strengthen ambitions, in 2011 the board of the TU/e has granted the *Energiebeleidsverklaring* which strengthens the progress towards a more sustainable campus. Energy has become one of the three Strategic Areas of the *Strategie 2020*. [26] With the modernization of the TU/e campus as determined in Campus 2020, innovative energy-efficient measures can be introduced to reduce the total energy load. In addition, the TU/e is currently implementing the Living Lab concept, a new vision on the sustainable transformation of the campus into the *City of*

Tomorrow. [27] An important aspect is the integration of research and education with the buildings on the campus, to stimulate sustainable innovations and to make them more visible and part of the university's image. The Living Lab recommendation is explained in more detail in the succeeding document *Naar de City of Tomorrow* [28]. The Living Lab concept can be seen as a fulfillment of the *Strategie 2020* and gives a recommendation on the *Campus 2020* and future projects.

4.5.4. Project 3 ambition level sustainability

Part of the ambitions for Project 3 are the high ambition levels regarding sustainability. Being the third project in a row for Masterplan Campus 2020, expectations and ambitions for the project outcome are higher than they have ever been for the TU/e. As an ambition regarding energy use, energy neutrality was stated as a starting point for the project. The question rises how to interpret this term and how significant a tunnel focus on energy can be. With the development of Project 3 a more broad scope on sustainability is formulated, including building related 'ecological' aspects and 'social-economic' related aspects. [29, p. 20] Improving the energy efficiency of the building will be considered in this broad perspective.
The Greencalc (4.0) A+ label, MIG score of 330-490, as shown in figure 4.11., is used in Project 3 as target for the desired ambition level of sustainability. A MIG score of 100 is related to the average performance of the same type of building back in 1990.The MIG score is related to water, energy and material use of the building. Related to façade design, energy and material use are important performance criteria.

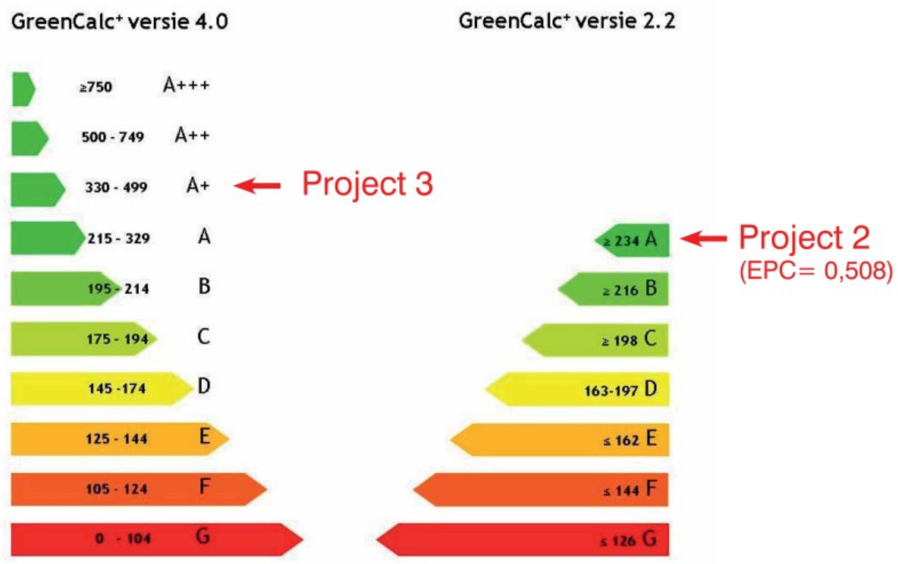


Figure 4.11. Ambition level sustainability Project 3

4.6 Conclusion performance criteria

The company assignment will study the design possibilities of the façade which match with the ambitions and constraints of Project 3. Based on the outcome of the object analysis, different façade solutions are defined and compared on performance. The ambitions and constraints are explained in different performance criteria, as described in this chapter. The performance criteria are interrelated. Moreover, not all performance criteria can be expressed with tangible values, making it more difficult to determine total performance of façade solutions.

- Comfort includes the ability of the façade to facilitate building users a pleasant, healthy and productive work and study environment. This performance criterium is most important and related to the core business of the university. However, performance is less tangible and the effect is more difficult to determine;

- Architecture is related to the ability of the façade to relate to the current building design and express the desired corporate identity of the TU/e. Moreover, the Main Building has cultural and historical relevance to which the new architecture needs to relate;

- Sustainability is a broad term which can have many meanings. Regarding the performance of the façade design, it is related to energy efficiency, material use and robustness. Robustness can be explained as the ability to handle changes and steadiness of value over time;

- Costs include the total cost of ownership. Investment costs, energy savings and maintenance costs are considered regarding the performance of the façade.

Chapter 5: Object analysis

5.1. Environment analysis

5.1.1.Motivation

Current façade is almost not related to ambient environment. It's design is equal for each orientation and has almost no function in regulating outdoor influences on indoor climate. To design a building less dependent on mechanical climate conditioning (heating, cooling and ventilating), the new facades should relate to ambient environment .

5.1.2.Location

The Main Building is positioned centrally on the TU/e campus. The campus in enclosed by the inner ring road of Eindhoven (*Onze Lieve Vrouwestraat and Insulindelaan*), and the main roads *John F. Kennedylaan* and *Professor Doctor Dorgelolaan*. The campus is a green island in the centre of Eindhoven, with treelines and the riverbed of the river *Dommel* separate the campus from adjacent urban fuss. Only the south boarder is defined by adjacent buildings. Two out of three primary entrances to the campus guide visitors, via a so-called *bajonetaansluiting*, to the primary east-west oriented axis of the campus, *de Zaale.* This aspect of the urban design stages the entrance in such a way that the high rise of the Main Building presents itself as a first beacon of recognition to campus visitors. The high rise of the Main Building is therefore important for the over-all impression of the campus.

The campus is a green and open environment, a detailed composition of green- and open spaces. The spatial quality of the campus is described and forms an key aspect of the Masterplan TU/e Sciencepark [18, p. 36]: 'the TU/e Sciencepark will be a citypark. Namely, a green environment with a public character.' In contrast with neighbouring urban environment, campus buildings are positioned freely in the landscape, often all-sides oriented with an open vision on its environment. The high rise of the Main Building is tilted above ground level by the support of a monumental concrete table. The low rise, which exists of a quadrant of four boxes, is shoved under the table. The high rise of the Main Building, together with the high rise of Vertigo and Potentiaal, forms the backbone of the campus. In addition, the Main Building is the connecting steppingstone between the central library (Metaforum) and the main lecture rooms and canteen (Auditorium). The Main Building high rise is a dominant and connecting building on the campus.

5.1.3.Orientation

The Main Building is orthogonally positioned exactly towards the cardinal directions (N, E, S, W). With a changing sun orientation during the day and seasons, together with the daily changing activities and indoor climate-demands during the day, the design of each façade should be done in relation to these parameters.

5.1.4. Air quality and sound pollution

Despite the inner city location near the city centre, train track and inner ring road, the TU/ campus has almost no nuisance due to traffic or other activities. [30] The broad line of trees and/or buildings near the boarders block sound sufficiently. In addition, the air quality measured centrally on the campus is sufficient as well. [31]

5.1.5.Wind characteristics

Wind can be an important design aspect for high rise buildings. Wind has the potential to generate energy or reduce energy needs, for example when used to generate underpressure for building ventilation. Moreover, wind can cause trouble. The possibility to open windows, generation of noise or damaging of external sunscreen devices are related to the behaviour of wind.

As defined by the *KNMI* (Royal Dutch Meteorological Institute), Eindhoven is positioned in a soft, land inward, wind climate. [32, p. 100]. Eindhoven has an annual average wind speed of 4,5 m/s. As an example, Schiphol, near the coastline, has an average wind speed of 5,4 m/s, as shown in figure 5.1.. During midday in cooling season, form May till September, average wind speed is slightly higher, approximately 5,0 m/s, as shown in figure 5.2.. In addition to averages, the amount of wind gusts, caused sudden acceleration of wind speed is important. Figure 5.3. shows a low amount of gusts with a low wind speed compared to other locations in the Netherlands. Eindhoven, due to a low wind speed and low amount of gusts, has a mild wind climate.

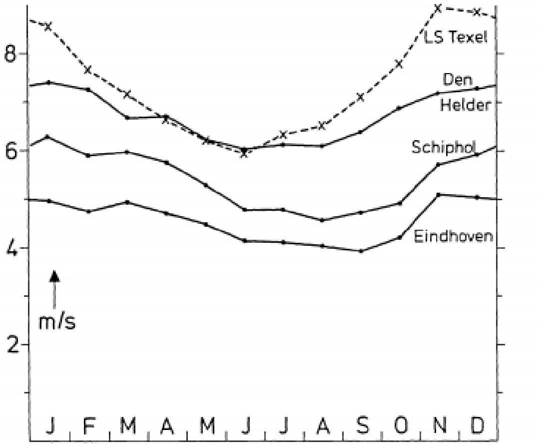


Figure 5.1 Annual average wind speed. (source: KNMI [32])

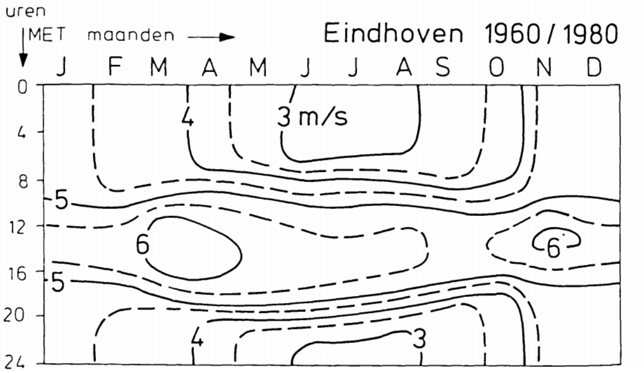


Figure 5.2 Daily average per month for wind speed in Eindhoven (source KNMI [32])

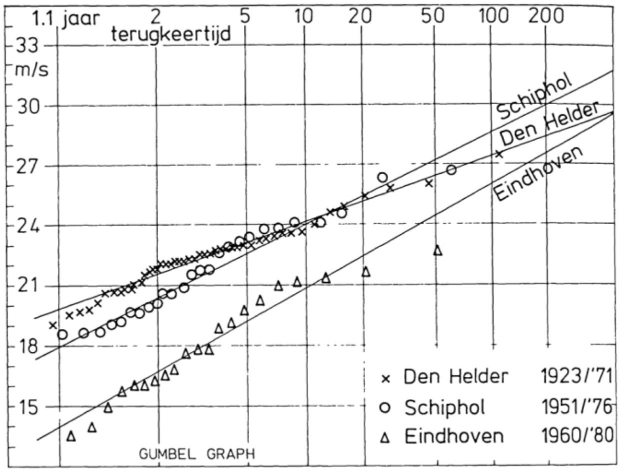


Figure 5.3 Annual averages speed and frequency of wind gusts (source KNMI [32])

When comparing measurements of wind speed at the edge of the city of Eindhoven (10 m. height, as shown in figure 5.4.) and wind speed on the university campus (figure 5.5, 44,6 m. height), average wind speed, despite the increase of height, are far lower at the TU/e campus. This is mainly caused be the inner city positioning of the campus where roughness, caused by treelines and buildings, reduces wind speed. The TU/e campus receives most wind from a south-west direction. Most common are wind speeds of around 3-6 m/s (as measured on 44,6 m. height). Maximum measured average wind speed is 11-12 m/s. Sudden gusts can have a higher wind speed. The south and west façade will most often be the windward side. East and North façade are most often leeward side, as can be seen in figure 5.6 and 5.7.,. Highest wind speeds are measured around noon, especially in the months March, April, November and December.

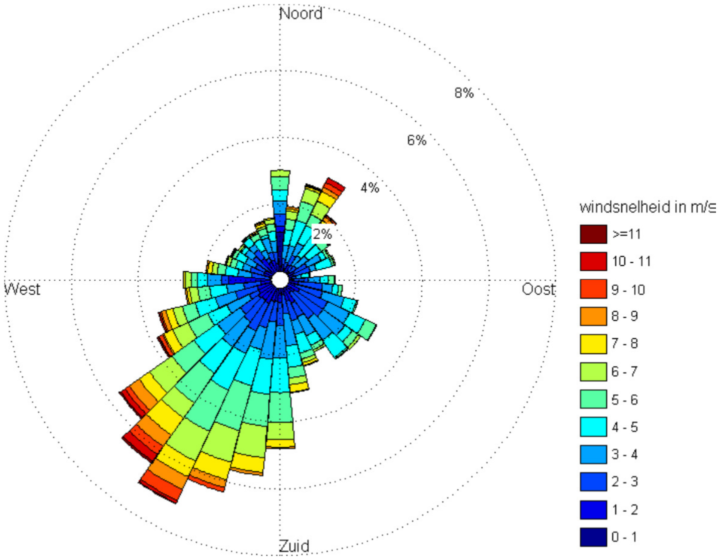


Figure 5.4. Wind speed averages of KNMI weather station (height 10 m.) over period of 01-08-2009/ 02-02-2010.

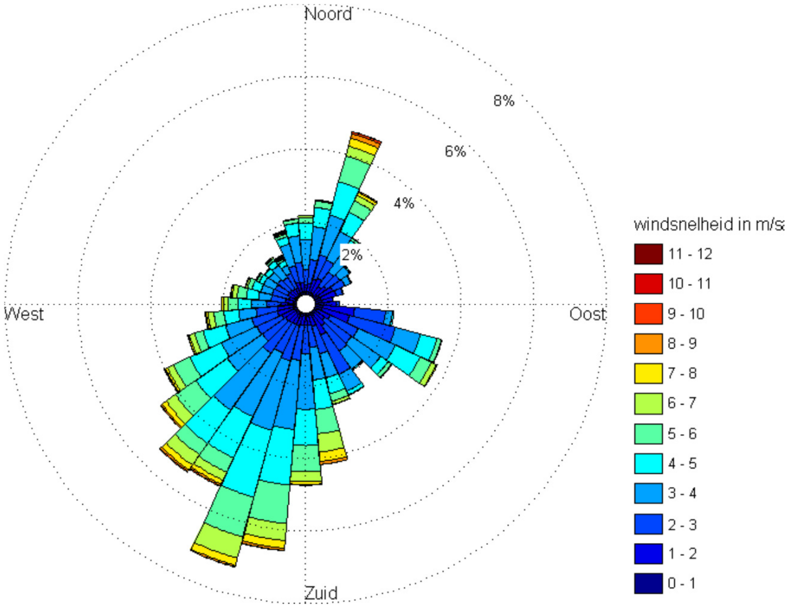


Figure 5.5: Windspeed averages of TU/e weather station (height 44 m.) over period of 01-08-2009/02-02-2010.

5.1.6. Wind acceleration

The combination of altering building heights and shapes and adjacent open spaces on the campus, can result in large differences in wind pressure and related speed. By means of a certified CFD (Computational fluid dynamics) model, wind characteristics for wind from an west- and south direction were studied. [33]. Highest wind pressures on het facade are measured on 2/3 height (± 30 m. height) of the high rise, as shown in figure 5.7. At this height, wind is either pushed up- or downwards, parallel to the façade. A horizontal section (figure 5.7.) shows that the north-west corner of the building encounters the highest wind pressure and draught.

With wind coming from a south-west direction, a strong acceleration of wind speed is generated. Experienced wind speed at ground level are equal to the wind speed at 40-50 m. height. This is mainly caused by the smooth façade, in combination with the tilted volume, which allows a 'shortcut' and pulls wind under the Main building high rise. For more information on this subject, a study commissioned by Real Estate Management on wind comfort on ground level of the TU/e campus is referred to [34] .

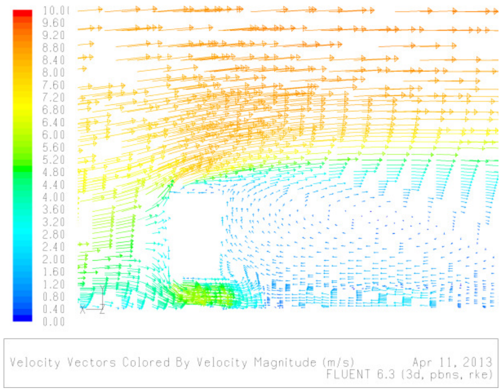


Figure 5.6: vertical section CFD model Main Building(source: [33])

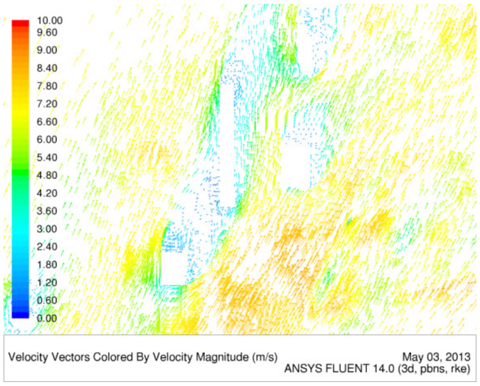


Figure 5.7 Horizontal section (height 30 m.) CFD model Main Building (source: [33])

5.1.7. Campus energy generation and use

The campus has a specific energy use. Building related energy use, energy that is needed to accommodate building operation, can be divided in heating, cooling, lighting and ventilation. Other types of energy use are more 'occupant dependant, in other words 'process related' energy loads, such as laptops, elevators and other apparatus. A clear separation is increasingly difficult to make: for example, artificial lighting is, especially when linked to presence detection, directly related to occupancy and could therefore be regarded as process related energy use as well.

5.1.7.1. Energy use

The TU/e campus uses both natural gas as electricity for building operation. Currently, the TU/e has an aquifer thermal energy storage system (ATES) in operation. The ATES system will be connected to new and renovated buildings, decreasing the use of natural gas for primary heating indoor climate. The vision posed by 'City of Tomorrow' urge a further implementation of renewable energy technology on the campus. [28, p. 33] An extreme implementation of the idea is shown in figure 5.8. Currently there are promising initiatives developing for renewable local energy generation systems, such as a combined heat and power installation (CHP) for biological waste or experimental solar energy fields. For this study, only the operational ATES system is taken into account.

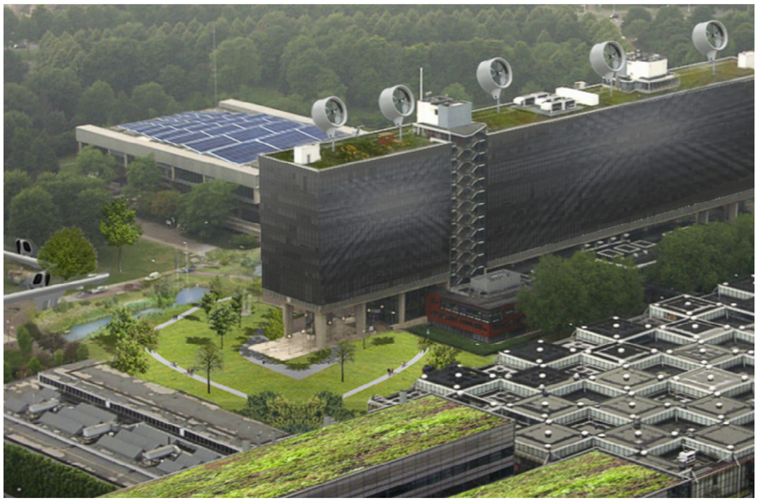


Figure 5.8: 'Impression' Main Building by Urgenda for integration of renewable energy technology ([27])

The TU/e campus has a specific energy use pattern. The buildings on the campus have a relatively high basic need for electrical energy, resulting in a night-time energy use of 55-60% compared to daytime energy use. [24, p. 27] This high basic load is partly caused by clean rooms and laboratories, whose strict climatic needs have to be conditioned constantly. In addition, occupant behaviour, building design and relative simple control systems contribute to the high basic load. A more efficient building design and intelligent monitoring and control device of building installations would lower the electrical basic load. Moreover, especially on warmer days (above 25 °C), the TU/e buildings have an high peak load, over 10.000 kW/hour, as can be seen in figure 5.9. [24, p. 27] This is for a large part caused by a high dependency on cooling and ventilation when outdoor (ambient) temperature is high.

To get a better insight in the energy use of the TU/e campus, electrical energy use is categorised in six categories. As shown in figure 5.10, artificial lighting (25%), ventilation (25%), cooling (10%) and heating (electrical energy needed for ATES system (‘WKO’), 2%) make the total building related energy use, which is 62% of total electrical energy use. 38% of total electrical energy use is regarded as process-related. The TU/e has a high basic load of electrical energy use, which can be easily seen during weekends and Christmas holidays, when almost no one is working in the buildings and therefore occupant-related energy sources are brought down to a minimum.

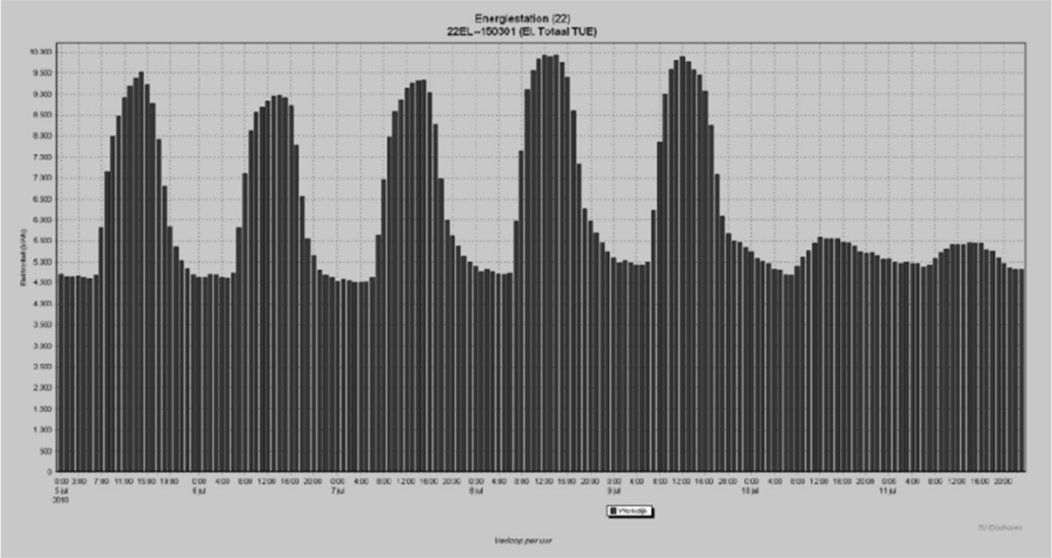


Figure 5.9 Typical weekly energy use of buildings on the TU/e campus (source [24])

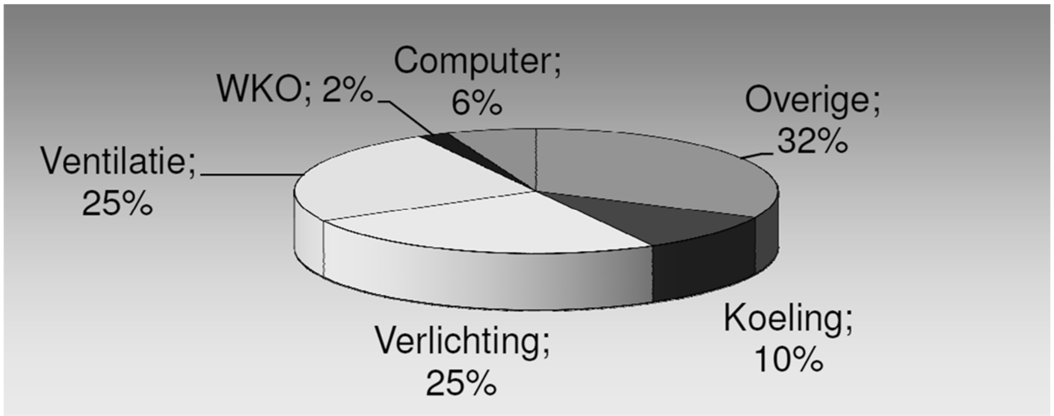


Figure 5.10: Breakdown annual electricity use on the TU/e campus [24]

5.1.7.2. Aquifer thermal energy storage (ATES) system

The TU/e has a large Aquifer Thermal Energy Storage (ATES) installed. This mainly underground installation is connected to a large amount of buildings on the campus. The underground system is shown in figure 5.11. Currently, 12 of the 46 buildings are connected (Sportcentre, Auditorium, Vertigo, Matrix, Helix, Cyclotron, N-laag, Spectrum, W hoog, W laag, Laplace and Kennispoort). The Main Building will be connected as well. The ATES installation provides a high amount of sustainable energy and contributes to the sustainable targets of the TU/e. Currently, the system is out of balance because of higher cooling demand in summer than heating demand in winter. To give some feeling of size, in 2010 the ATES installation delivers 10,04 GWh on heat and 8,124 GWh on cooling. [24, p. 21]**.** The ATES system is not in balance due to that the connected buildings use far more cooling than heating: the generated cooling is used fully in the cooling season. About half of the generated heat is used for heating of the connected buildings during the heating season. The other half of the heat is 'thrown away' through the use of cooling towers on the campus. The operation of the cooling towers cost the TU/e 600-800 MWh a year (2010, total use of WKO system is 916 MWh electrical energy).

The use of the ATES installation will increase. With the realization of Campus 2020, it is expected that the warmth and cold usage is doubled. New and renovated buildings will be connected to the ATES. Upcomming building projects of Masteplan campus 2020 are planned to be connected and N-laag will be demolished. In general, new and renovated buildings will be conditioned with low temperature heating and high temperature cooling generated by the ATES and will not have a natural gas connection anymore. [24, p. 10] Even more, buildings of so called third parties will be using the ATES more in the future, which results in an even higher usage. [35] [36]. Current system capacity limits are not met yet. Total transported water volume by the ATES in 2010 was 2,94 mil. m^3, while total capacity allowed is 6,5 mil. m^3.

As aforementioned, only half of the current installed water flow capacity of the ATES is currently used by the connected buildings. By enlarging the system, the TU/e aims to increase the share of sustainable energy generation on the campus. The current ATES cooling and heating is equivalent to the savings of ± 370.000 m^3 natural gas and 1863 MWh electricity. In order to make efficiently use of the installed capacity, the heat and cold usage should be brought into balance. With the completion of new and renovation projects, the TU/e will connect more buildings on the ATES system. Currently, the TU/e Real Estate Department tries to restore the thermal balance by making sure newly connected buildings or refurbishing buildings that are already connected, have an equal annual heat and cold usage on their own as well.

The TU/e campus is a specific multifunctional environment, a combination of different institutes and type of functions. It can be seen as a green island that aims to keep its energy generation and usage within its borders. Among others, this implies that the ATES should be balanced by dividing generation and loads within the campus. Combining the loads of different programmatic type of buildings on the campus can provide some balance. The planned living quarter can partly use the surplus heat that is produced by department buildings or offices in the business district. However, the TU/e campus cannot be compared with more conventional multifunctional environments. The main difference are the fundamental research activities, one of the universities core competences. Large scale test installations in different laboratories will always be an essential part of the TU/e. These installations need an consistent high amount of cooling, which result in a 'core business related' imbalance in the cooling and heating installation. Balancing the building installations cannot cope with this imbalance caused by the laboratory installations.

The ATES provides a large share of the needed cooling on the campus. Only very little tap water is used for cooling. The remaining cooling load is done electrically. 10% of the total electrical energy load (total electricity load 2010 40.267,600 MWh [24]) is used for cooling the built environment, related to climate influences. Next to this cooling for 'conventional' buildings, a large part of the cooling load is due to the laboratories and test installations. To give an estimation: the TU/e has a large base load which is caused by the four major lab buildings on the campus. Together these four laboratories use 19 mil. kWh, which is over 1/3 of total electricity load. [24, p. 27] These laboratories need a constant, 24 hour, climate conditioning. This conditioning forms a large share of the base load and is normal for a technical research institute like the TU/e.

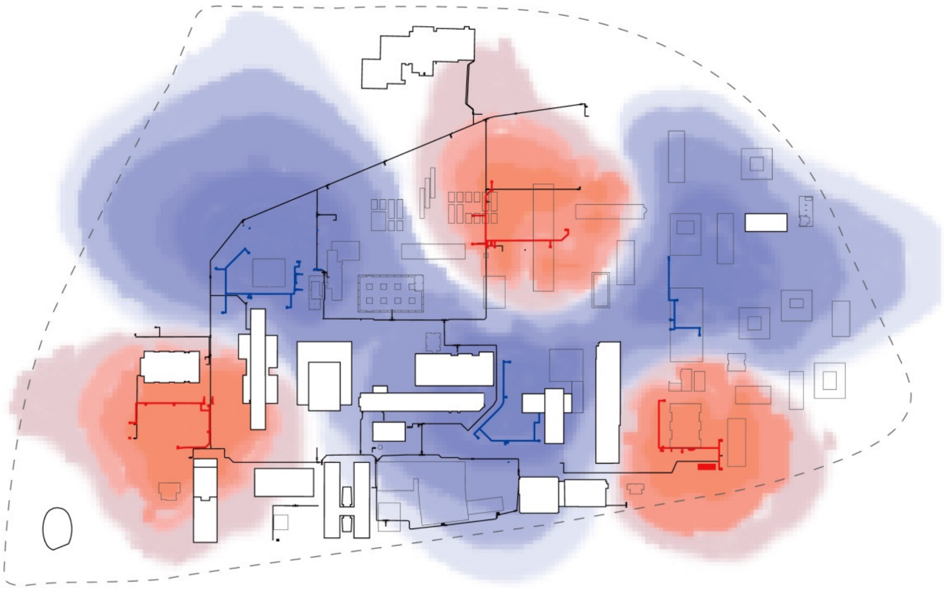


Figure 5.11. Aquifer thermal energy storage system, heat and cold sources on campus

5.1.8. Insolation

5.1.8.1. Motivation

An important aspect for the design of the facade is the regulation of admitted solar radiance. The desired amount of solar radiation admitted to the building over time is a trade-off between transparency and opaqueness of the façade. A high openness increases visual comfort and can be desired for architectural and cultural reasons. Major negative effect would be the increase of undesired solar radiance admittance, increasing cooling load and causing thermal discomfort. Insolation of a building differs per location, shape, façade orientation and over time. The insolation is studied to determine how the façade performance will be influenced by insolation.

5.1.8.2. Insolation characteristics

Dutch climate has a peak in insolation around June. Figure 5.12 shows the average global solar radiance on a horizontal surface during the year. Because of the higher insolation together with an increase of temperature, the period of May, June, July and August is referred to as cooling season.

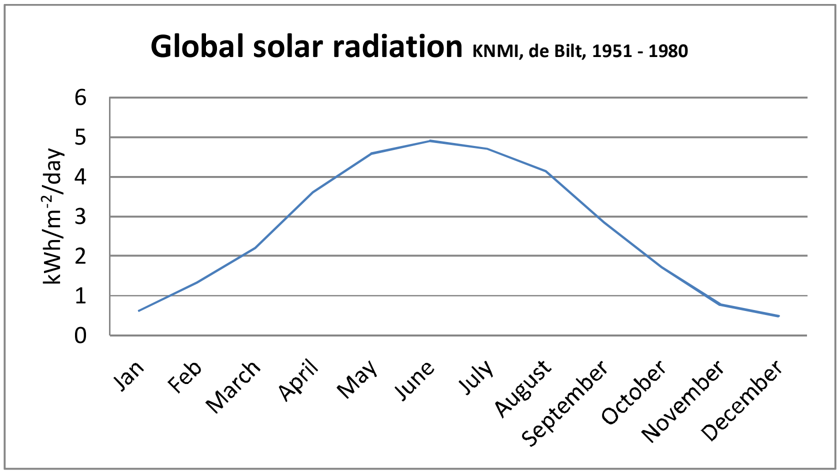


Figure 5.12 Global solar radiation

Global solar radiation is the combination of direct and diffuse radiation. Diffuse radiation is the indirect, scattered radiance deflected via the atmosphere, ground and the environment and is mainly caused by a (partly) overcast sky. Both types radiate solar energy but are very different in characteristics:

- Direct radiation is more easily redirected and concentrated (ideal for all types of active solar technology). To relieve heating systems in winter, sunlight should be let into buildings. In summer, excessive direct daylight entering a building will lead to overheating and require heat protection measures. Direct radiance causes glare and large light contrasts.

- Diffuse radiation occurs with a cloud cover, partial cloud cover, or when the sky is blue. It is considered comfortable for general visual tasks and is ideal from bringing daylight into interior spaces. [7, p. 19]

Diffuse radiation results out of scattering of direct sunlight on miniscule particles and gasses, During cooling season, over 60% of total daytime, when the sun is above the horizon, there is an overcast sky, as shown in figure 5.13. When looking at working hours (08:00-18:00) only, this ratio is slight different (57% diffuse radiation, 43% direct radiation in June, as shown in figure 5.14.This means that energy gain on a horizontal surface is for more than half caused by indirect solar radiance and direct solar radiation is only perceived less than half of daytime. Between 11:00-15:00 in June, more than 50% of global radiation (45% diffuse radiation, 55% direct radiation) is emitted by the sun.

Therefore, devices that use or repel direct radiance only are therefore effective less than 60% of total daytime. This should be taken into consideration when comparing different devices (For example, coatings or foils can repel global radiation where window setbacks or fixed lamellae are only effective against direct sun radiance). The façade design should be able to repel direct radiation as much as possible and control the amount of diffuse radiation.

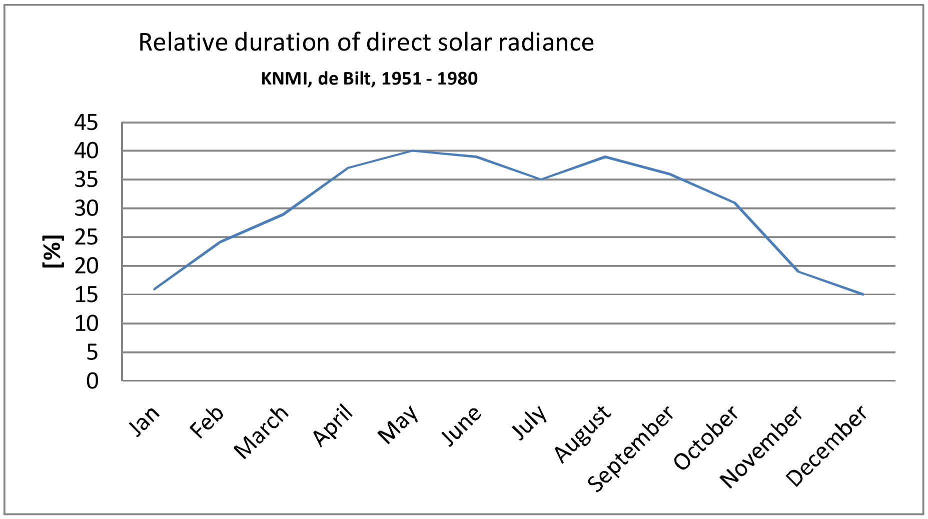


Figure 5.13 Relative duration of direct solar radiance

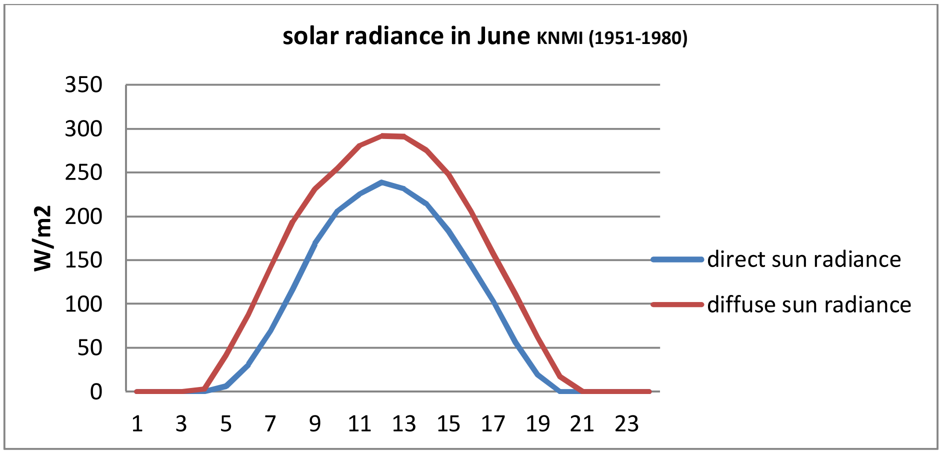


Figure 5.14 Ratio direct and indirect solar radiance

5.1.8.3. Insolation and façade orientation

The position of the Main Building towards the sun is dynamic, therefore the direction and intensity of direct solar radiation is constantly changing. Based on a yearly cycle, the distance between earth surface and the sun is changing, altering the perceived intensity of solar radiation. Based on a daily cycle, the altitude of the sun changes, resulting in a different inclination of perceived solar radiation during the day. These two cycles have a great effect on the amount and angle of radiance that is received.

Solar radiation is highest when the direction is perpendicular to the receiving surface. When the sun has an inclination of 90°, which only can occur on the equator, the distance through the atmosphere is shortest and the received solar radiation by a horizontal surface is optimal, resulting in the highest amount of solar radiation. When regarding vertical surfaces, such as a façade, the distance through the atmosphere is still shortest at highest inclination, but the angle between the arrays and the receiving surface is very small, as shown in figure 5.15, resulting in a lower solar radiation. In the Netherlands, far from the equator, the sun altitude is low. In summer, the altitude of the sun can be up to 61,5°, where in midseason a maximum of 38° can be expected. Therefore, during summer period, as shown in figure 5.16, a façade facing west or east receives a higher amount of solar radiation compared to a façade facing south. Moreover, due to the lower angle of incidence, repelling the direct radiance repels more diffuse radiation which results in a reduced daylight entrance, and blocks a larger part of view as well.

5.1.8.4. Insolation of the Main Building high rise

The high rise of the Main Building is positioned in an open environment, elevated by the concrete table. Therefore, as shown in a insolation study in appendix C, the Main Building receives almost no shadow cast from surrounding buildings or objects. The inclination angle changes during the day and during the year, as shown in figure 5.20. Around 15:00, the solar radiation perceived in June is at an angle of incidence of 53° and horizontal angel of 40°. The amount of solar radiation received by the Main Building facades per façade orientation is shown in figure 5.18. Both east and west facades receive the highest insolation. North receives the lowest amount of solar radiation, but due to the amount of diffuse radiation and the direct radiation in summer evenings and mornings, this amount is still relevant. South receives most insolation on annual basis especially during mid- and winter season. During cooling season, interior spaces adjacent to the west façade are expected to receive the highest cooling load due to a combination of highest amount of solar radiation and air temperature.

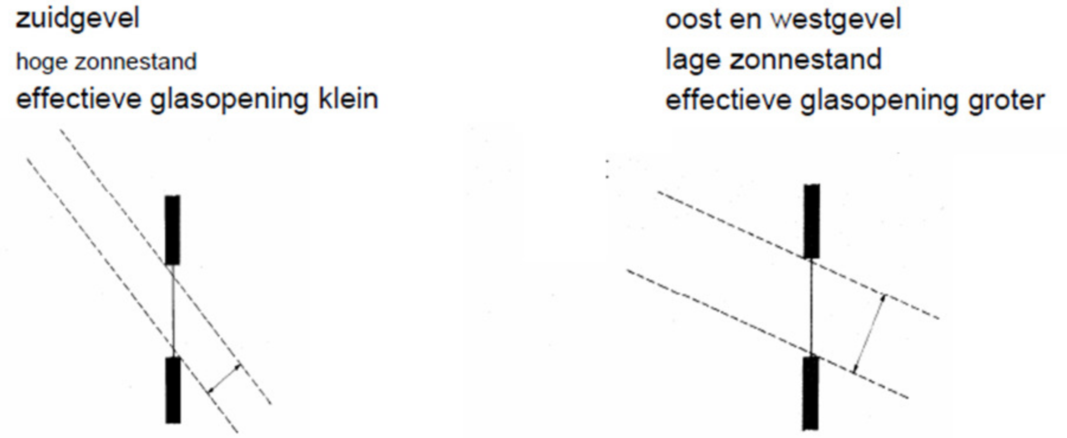


Figure 5.15: relation between insolation and façade orientation. (source: [37])

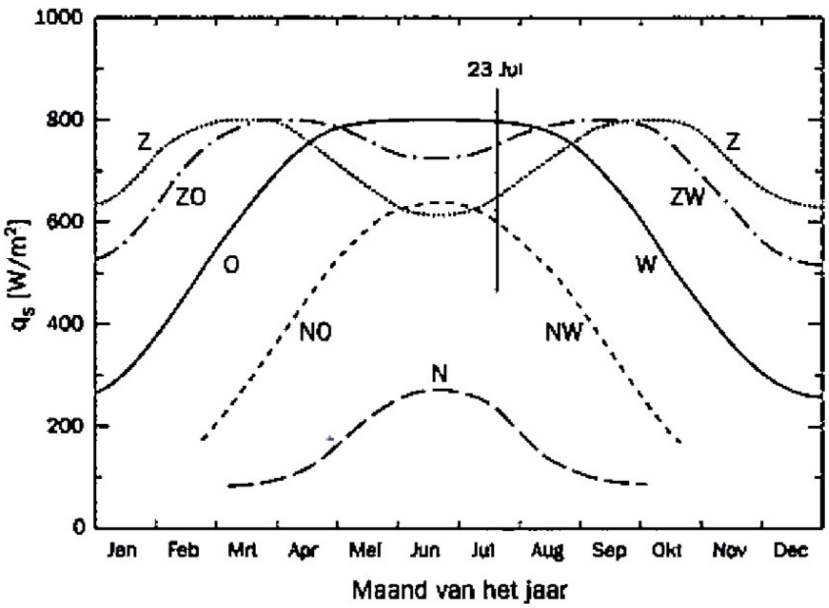


Figure 5.16 Average insolation per facade orientation

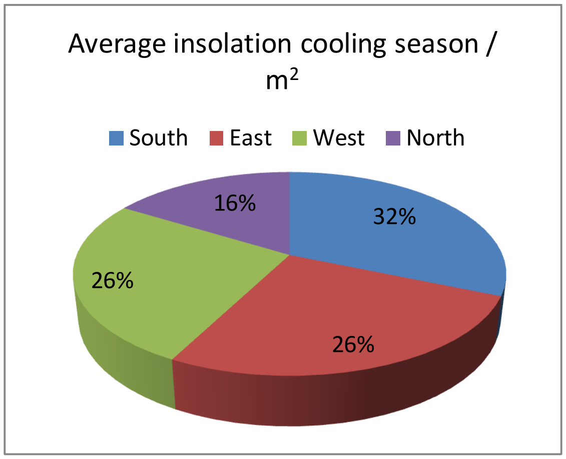


Figure 5.17 average global solar radiation

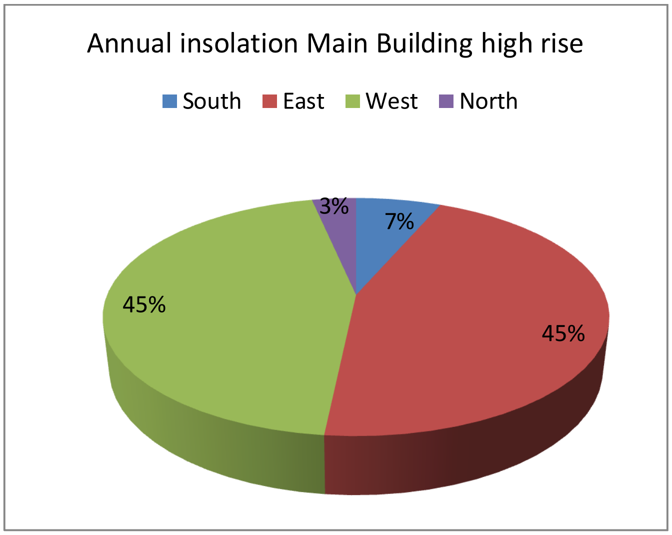


Figure 5.18 Ratio received global solar radiation by the Main Building

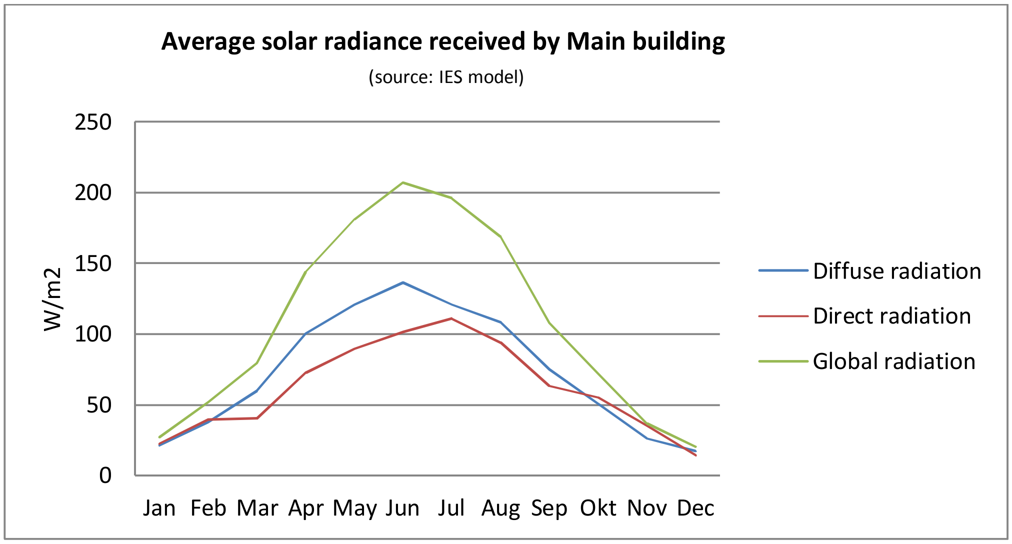


Figure 5.19 Solar radiance received by Main Building (source: model study)

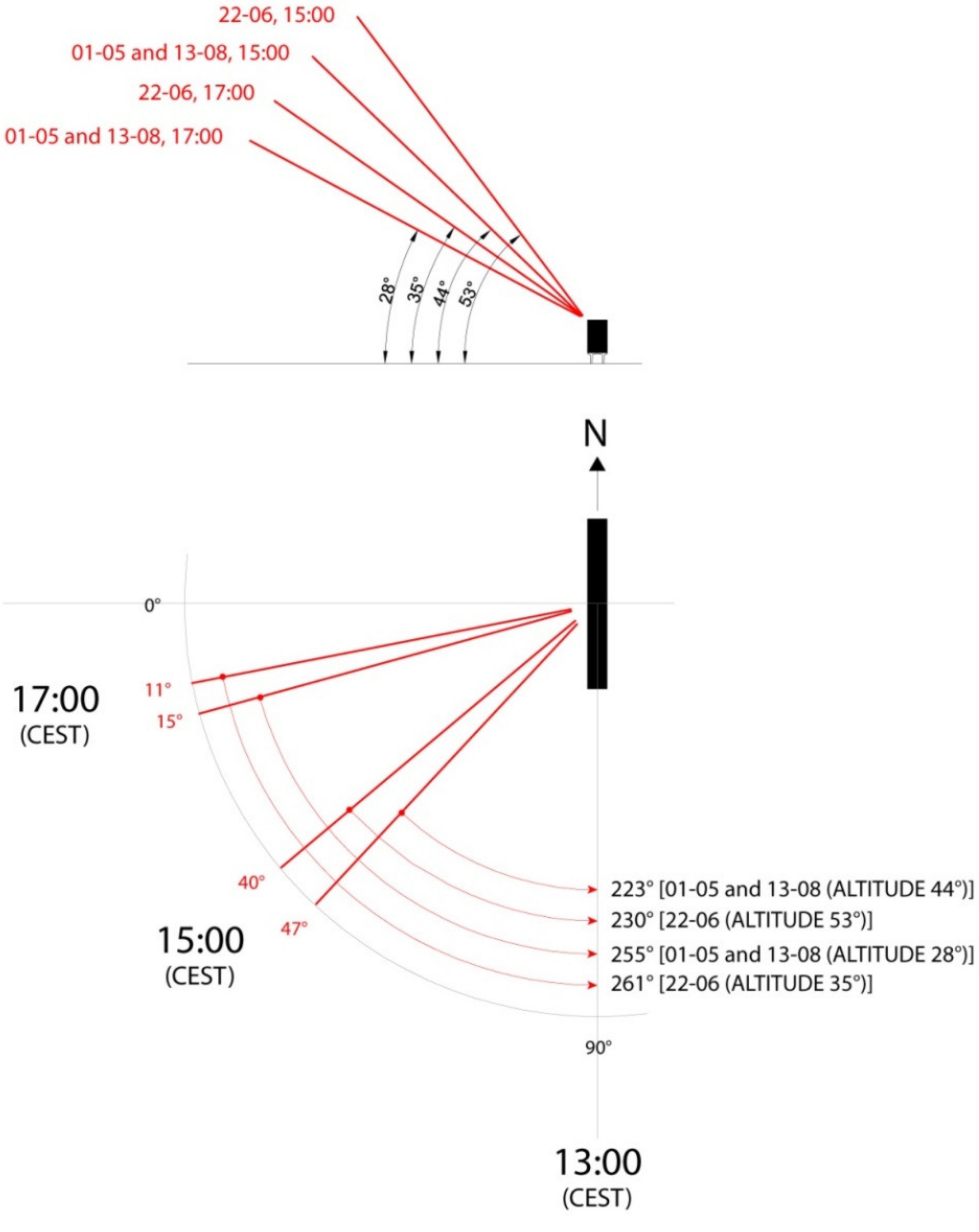


Figure 5.20: Angle of incidence

5.1.8.5. Summary on insolation characteristics

The insolation characteristics for the Main Building are studied. Relevant aspects for the façade design are:

- Insolation of the Main Building will be highest during the period of May-September, referred to as cooling season;
- The Main Building will receive more diffuse than direct radiation, which has to be taken into consideration regarding the effectiveness of solar radiation repelling and/or collecting devices related to the façade design;
- The Main Building receives almost no shadow cast from its surroundings. East and west facades receive almost equal insolation per square meter during cooling season (figure 5.18) compared to the south oriented façade;
- Due to the slender building shape, the highest direct solar radiation during cooling season is received on west and east façade (figure 5.16);
- Furthermore, the low inclination makes it more difficult to repel direct solar radiation on east and west, without blocking the view and repelling diffuse radiation [38];
- From the perspective of repelling solar radiation during cooling season, due to the building shape and orientation, the Main Building design is far from optimal. It functions as a large 'solar collector', reducing the expected cooling load will be a major challenge for the façade design.

5.1.9. Temperature

The average ambient temperature can be considered for a full day or a working day. Average temperatures can be seen in table 5.1. Average monthly temperature differ between 3 to 20 **°C.** During warmer period of the year, from may till September, more than 42% of a working day, temperature fluctuates between 16 **°C** and 21 **°C,** ideal for natural ventilation and cooling.

Table 5.1. Average temperature (source: KNMI)

Period of time		$T_{average}$ [°C]	T > 21 °C (%)	T < 16 °C (%)	16 °C < T > 21 °C (%)
full year	24 hours	10,84	7,98	75,34	16,67
	08:00-18:00	13,15	15,92	61,73	22,35
May - Sept	24 hours	16,57	18,11	47,47	34,42
	08:00-18:00	19,67	35,81	21,84	42,35
June	24 hours	17,13			
	08:00-18:00	20,28			
December	24 hours	3,67			
	08:00-18:00	4,48			

5.1.10. Conclusion

The Main Building is located in an environment with distinctive characteristics. The façade design should relate to these qualities and/or threads.

- Despite the inner city location, near the train station and an intensively used ring-road, the environment of the TU/e campus has a good air quality and almost no noise pollution;

- Moreover, the Main Building is exposed to a friendly wind climate;
- and the university has a structural imbalance in the thermal energy use, having a large surplus of heat;
- The building is prominently and freely positioned in a green park landscape, free from cast shadow and fully exposed to the sun;
- Due to its shape and orientation, the Main Building high rise is near optimal in collecting heat during warmer months and difficult to repel direct solar radiance.

5.2 Mass study

5.2.1. Motivation

The study focusses on the high rise of the Main Building. Understanding the distinctive shape, size and object restraints are object of this chapter. The façade needs to relate to the object mass.

5.2.2. Object description

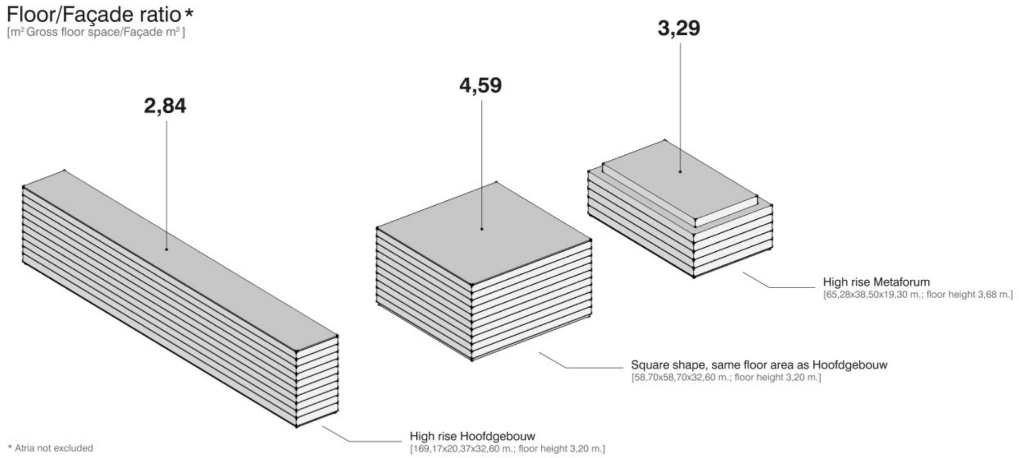
The Main Building consists of a eleven stories high rise, including the *TUreluur* skybox on roof level, resting on two rows of seven large monumental columns (*piloti*), tilted over an autonomous low rise, consisting of first and second floor, and two underground floors as basement. Due to the appearance and spatial organization of the building, a distinction can be made between the lower and upper part, which rests on a load bearing concrete table. [19, p. 45]The upper part has the shape of a disc, about 170 length, 20 m. broadness and 32,50 m. height and consists of ten floors. During the years it has always housed different (parts of) faculties and served mostly educational purposes. The floors are vertically accessible by two elevators with staircases which give access to a centrally placed corridor. On each floor there are a large number of small offices and a few large, double height ateliers. For a more detailed description, see the cultural historical report on the Main Building. [19, p. 45]

Because of the aforementioned disc shape of the high rise, the building has a relative large contact surface between in- and exterior climate, as shown in figure 5.21 and table 5.2. The interaction with external climate is therefore potentially greater compared to the situation with compact buildings, such as the high rise of the Metaforum, which is almost square-shaped. When interaction with external climate is desired, for light entrance or letting in fresh air, the Main Building shape is potentially positive. When interaction is causing higher cooling/heating loads due to extreme external temperature, a more compact shape is potentially more efficient.

Table 5.2: Dimensions Main Building per floorlevel

Dimensions Main Building	Gross floor surface (m2)	Length (m	Width (m)	Height (m)	Façade surface (m2)	Façade/floor ratio
High rise Main Building	3445,9929	169,17	20,37	2,70	1023,50	0,30
Square shaped volume	3445,9929	58,70	58,70	2,70	634,00	0,18

Figure 5.21: Floor-facade ratio



5.2.4. Floor size

With a possible gross floor size of over 50.000 m^2, the Main Building is one of the largest buildings in Eindhoven. As aforementioned, the building could be divided in a low- and high-rise. This study focusses on the high rise and the dimensions and size of the high rise only. For a full breakdown of available floor size and spatial requirements of the future program of P3, see appendix D. As will be further explained in chapter 5.3.2., the high rise is composed of a combination of structural, permanent, floors and flexible, replaceable floors. If one considers only the permanent, structural floors, 19.653 m^2 is the minimum gross floor size (*BVO*). When considering a complete occupied building with full flexible floor placement, 34.971 m^2 . When considering the optimal situation for light entrance, which is approximately answering as well to programmatic needs of Project 3, 50% of flexible floors will be used, resulting in a total available gross floor size of 26.396 m^2.

Structural floors have a gross floor size of 3.430 m^2 each. Flexible floors have a fixed, concrete floor slab near the staircases and vary between 367 to 3.430 $m^{2,}$ where currently most floors are around 2.200 m^2 in gross floor size, where 1715 m^2 (50%) would be considered ideal for this study. Due to the thin, lengthy floor plan, large part of floor surface is currently used for transport and corridors, resulting in a high building factor (gross floor index/usable floor surface) of around 1,56. Due to the long and thin building shape, the high rise has a large façade surface area of 12.356 m^2 (west and east both 5514 m2; north and east both 664 m2). Currently, the façade window-wall ratio (WWR) is 52% (52% window, 48% opaque) for each orientation.

5.2.5. Conclusion

The Main Building consists of a low rise and a high rise. This study focusses on the high rise, a distinctive long but small volume, resting on the monumental concrete table. Due to its shape, the high rise has a relative large façade surface (12.356 m^2), which makes the interaction between in- and external climate high. This is positive when external climate is 'friendly' but can have a negative effect when external climate is too warm or cold, where a more compact building shape would be efficient. The high rise has a changeable total gross floor size due to the option of replacement of flexible floors. Ideal, with around 50% placement of flexible floors, an gross floor size of 26.396 m^2 would be achieved.

5.3 Building construction

5.3.1. Motivation

The Main Building will be renovated with the existing concrete construction. The construction offers opportunities and sets constraints to possible design solutions. The design of the façade is related to the possible installation concept of the building. Therefore, it is a major importance what the primary building construction allows regarding possible building installation concepts, in order to include or exclude integration of possible installation in the façade. The existing construction is described based on observation, historical photos and drawings and the analysis performed by students. [39]

5.3.2. Building construction

The existing construction of the high rise starts at second floor level and is supported by the large concrete table. The building construction consists of a grid of beams (385x1200, so-called *hoedliggers*) and columns (450X450). Floors are alternately structural, made of spanning concrete floor elements (so-called *cusveller ribvloeren,* 170 mm. thickness), and flexible, constructed of lattice beams (*vakwerkliggers*) or wooden framework. Both structural floors as flexible floors have a 504 mm. thickness. Normative are the more heavy dimensioned layers (500x1200 mm.) with a larger thickness at the most middle tier near the staircases. Underside of each structural floor is levelled, upper sides of each structural floor has differences in height and need to be levelled. The structural principle is shown in figure 5.22.

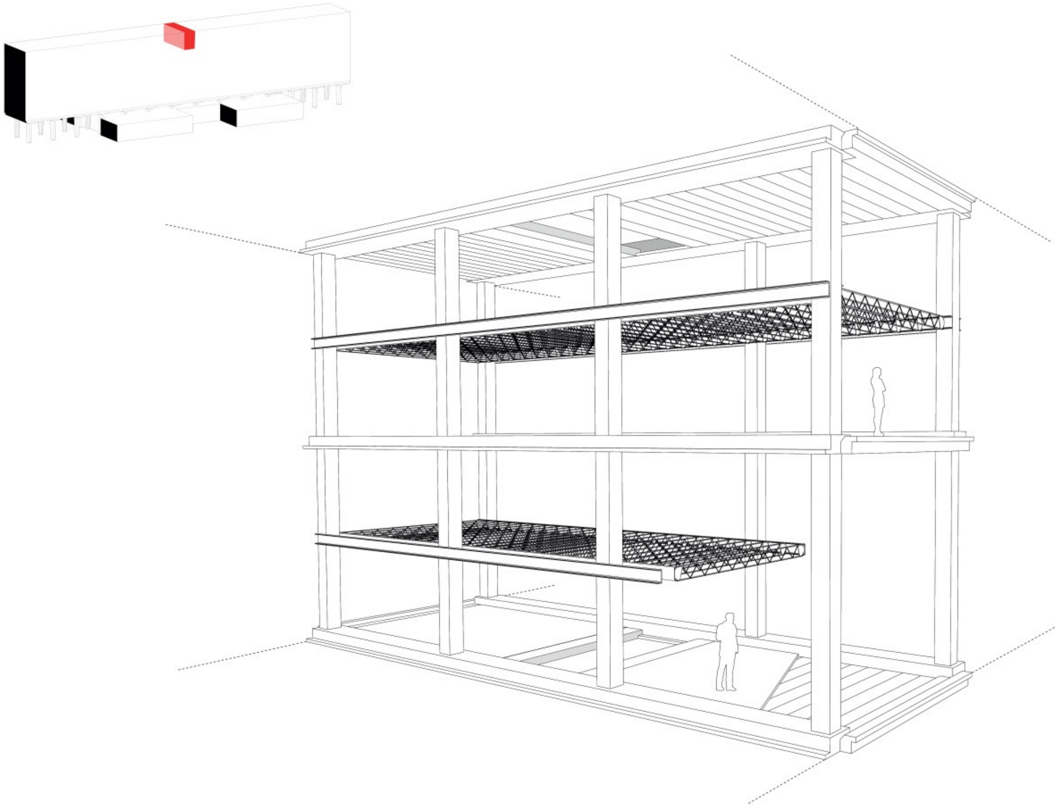


Figure 5.22: structural principle Main Building high rise (source [39]):

Each structural floor has an opening in the middle tier and the adjacent beams have holes to allow limited space for horizontal piping and small ducts. The flexible floors are completely removable due to the use of bolted joints, expect for the the middle tier near the elevator shafts, where for structural reasons, concrete beams (500x1200) are placed with concrete floor elements equal to structural floors (170 mm. thickness).

5.3.3. Existing shafts

In addition to the row of openings in the middle tier of each structural floor, the building construction has five vertical shafts: Near each main staircase (7,5 m2) and one in the middle (5,3 m2), which was used for the housing of large objects (so-called *doorgeefluik*) and one near each fire escape staircase at both ends (6,0 m2) placement is described in figure 5.30. These existing vertical openings could function as installation shafts. Original construction drawings can be found in appendix N.

5.3.4. Floor height

Determinative for the possible free floor height are the beams located near the elevator shafts which are largest dimensioned. If flexible floors are placed, a free floor height of 2700 mm. remains. If flexible floors would be taken out, a free floor height of 5904 mm. between both structural floors remains (2x2700+504 mm.). Possible installation ducts and pipes have to be placed within this height. A conventional solution, with air ducts covered by a lowered ceiling, needs about 500 mm. in height, reducing free floor height to 2200 mm., which is more than the minimal requirement of renovated buildings is 2100 mm. in floor height, but is still very low and greatly reduces spatial quality. An alternative placement of installations should be designed in order to preserve the maximum available free floor height. (A combination of) possible solutions are given below:

1. Integrated in structural floors and separated air ducts (existing situation)

The middle tier of structural floors in combination with the holes in the structural beams is used for electricity, ICT and mechanical installations. Since available openings are too small for ventilation ducts, a separated placement is needed. Moreover, openings are small according to modern standards and it is questionable if modern cabling and piping will fit. Characteristics of this partial solutions is given in table 5.3.:

Table 5.3: SWOT analysis partial solution 1

Solution 1. Integrated in structural floors +separated air ducts (existing situation)	**Helpful**	**Harmful**
Internal	*- limited installations need to be placed in open space;* *- Using existing situation, less effort;*	*- Air ventilation still needs to be placed elsewhere in open space;*
External	*- If an alternative can be found for ventilation, the open space is free of HVAC installations;*	*- Not enough space in beams to fit installation;*

2. *Vertical placement*

Installation is primary organized using multiple vertical shafts, using existing openings in the structural floors. Same as a tree, the installations running through the vertical shafts could have horizontal branches to facilitate adjacent spaces and spaces positioned further away, near the façade.

Ventilation ducts could be installed in these large dimensioned shafts. To create an airflow, naturally generated draught could be used. Natural draught occurs due to natural thermal current over a large heights or due to forced airflows which generate a negative pressure at upper level, for instance caused by the venturi-effect or 'Ventec' roof systems. [40] Possible solutions are currently under development [41]. Applications related to mentioned ventilation principles can provide an effective solution but need further research. Auxiliary mechanical ventilation is needed to ensure the desired in/outflow. Characteristics of this partial solutions is given in table 5.4.:

Table 5.4: SWOT analysis partial solution 2

Option 2. Vertical organization	Helpful	Harmful
Internal	- limited installations need to be placed in open space. Keeping maximum floor height; - Using existing openings in construction.	*- Still subdivision per floor needed;*
External	*- Natural draught due to 'chimney' effect or venture effect can reduce energy load for outward ventilation*	*- How to subdivide installations per floor when floors are divided in smaller rooms*

3. Integration of installations with flexible floors

When flexible floors are in place, the piping and wiring of installations are largely integrated with the floors, leaving available floor height open. The flexible floors are mostly hollow, constructed of lattice beams or other perforated, material saving, types of beams. Available free space could be used to integrate installations. [42] Moreover, the head-ends of the floors could be used as a railing for installations. When flexible floors are not present, the installations could be placed in the open space, since floor height is not an issue when double floor height is available. Main disadvantage is the limited flexibility of flexible floors. However, the value of flexibility is questionable, past use of the Main Building has shown only additions have taken place, removal of floors did not occur. A constraint to a full horizontal placement of installations in the flexible floors is the available open space in the concrete beams placed in the middle tier of the flexible floors. A placement of the installations in the tier near the façade, in opposite of the staircase, could provide an solution. Characteristics of this partial solution is shown in table 5.5.:

Table 5.5: SWOT analysis partial solution 3

Option 3. Horizontal placement integrated in, and at head ends + flexible floors	**Helpful**	**Harmful**
Internal	*- Keeping maximum floor height;* *- Placement of installations in openable floors gives a good accessibility of installations;*	*- full horizontal placement is constrained by limited openings in beams;* *- less flexible due to integration of installations;*
External	*- Both under and upper floor can be served with same installation line.*	*- every 2nd floor cannot be fully used because need for set-back to place installation;*

4. Integration of ventilation installations with Facade

Instead of placing installations in the building, installations, or ventilation only, could be integrated with the facade design. For instance, a double layer façade could provide natural ventilation which could be used as inflow. An alternative could be an mechanical, decentral system, integrating fan coil units in the façade or near the head-ends of the floors. An example of this installation concept can be found in the façade of the RADIX building (Wageningen, DP6 architectuurt studio) Electricity, ICT and mechanical installations could be installed in the open spaces between floor slabs, as described in solution 1. External placement of installations integrated with the façade could be part of the building's expression. Characteristics of this partial solutions is given in table 5.6.:

Table 5.6: SWOT analysis partial solution 4

Option 4. Installation integrated in facade	**Helpful**	**Harmful**
Internal	*- building is completely free of HVAC installations, gives full flexibility and floor height;*	*- Expensive and complex solution, riskfull;*
External	*- Decentralized installation service, improving user comfort;* *- Pre-fab façade elements incl. installations are possible;*	*- Installations have a lower life expectancy than façade. Will have an effect on future renovations;*

5.3.5. Possible daylight entrance

The high rise of the Main Building, with its system of removable flexible floors, is originally designed for an optimal daylight entrance [4, p. 4].The building is open to all sides. The possible depth of daylight entrance is twice the floor height with an angle of incidence of (30°). This 'rule of thumb' is based on diffuse daylight entrance, which is most common in local environment, as described in chapter 5.1.8., and therefore applicable for all orientations. As first indication, it is easily possible to allow daylight entrance for 50% of total floor space, as shown in figure 5.23. Horizontally, an angle of 45° should be take into account to estimate the shadow cast of columns and other closed parts of the façade.

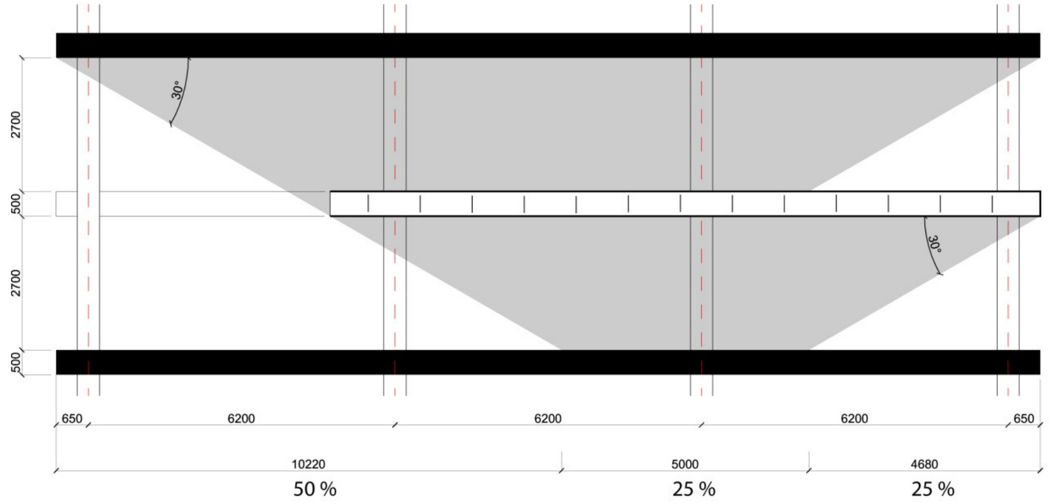


Figure 5.23: Principle of light entrance in high rise

5.3.6. Conclusion

The structure of the Main Building provides constraints and opportunities for the façade design. Relevant aspects are:

- When both structural- and flexible floors are placed, the free floor height is limited to a maximum of 2,7 m. placement of installations, most relevant ventilations ducts, can reduce floor height to 2,1-2,2 meter height., greatly reducing spatial quality. This solution is not preferable . Hence, an alternative placement of ducts or avoiding the need for ducts is needed.

- Existing vertical openings can be used as installation shafts, possible facilitating floors from five 'core' shafts.

- building construction provides the opportunity for a large amount of daylight penetration. A placement of 50% of possible flexible floors allows a high amount of daylight admittance, by which 50% of total floor surface can be reached.

- Underside of structural floors are fully 'flat', upper side of structural floors have difference in height of 115 mm., due to the use of beams with different dimensions, and need to be levelled.

5.4 Current façade design

5.4.1. Motivation

The expression of the original façade of the high rise is an important and dominant aspect of the current design. Although the current façade is based on outdated design criteria (the façade has a very limited role in regulating the internal climate) and its performance does not meet today's standards regarding energy efficiency, the current façade is an important part of the architectural and cultural historical expression. The new façade needs to relate to the original design.

5.4.2. The existing façade of the high-rise

The façade of the high rise is a prominent and dominating aspect of the building. Due to the slender, elementary shape of the high rise, its façade has a large and constant surface. As a starting condition for Project 3, the existing façade of the high rise will be completely removed. Keeping (parts) of the existing façade can be an opportunity to save valuable material and/or the architectural appearance. However, due to presence of asbestos in the façade and in a the interior, preserving parts of the façade is costly and inefficient. [43, p. 17] Moreover, it is very arguable that renovating the façade on site, originating from late '50, will answer to demanded capacities of the future façade, where a high quality insulation, air tightness and low maintenance costs are almost precondition to meet the target ambitions of project 3.

As stated in the cultural-historical survey, preserving the architectural quality of the building refers to strengthening the character of the façade in relation to the building's architecture, and not an one-on-one preservation of the existing façade. 'Articulation of the façade contributes to experiencing (the building's) architecture. An example can be strengthening the tall appearance of the high rise by strengthening the vertical character of the façade'. [19, p. 70] As part of the company assignment, new façade design possibilities for the high rise will be considered in the perspective of cultural-historical and architectural values of current design.

The Main Building is currently equipped with a curtain wall façade. Based on the principle of a curtain wall façade, it is consists out of an aluminium framework with double glazing, connected to steal IPE profiles which are hung at the structural concrete floors of the high rise. For a more detailed description of the current façade design, see the work of Atelier HG 2.0. [39, p. 48] The original type of façade is still best suited construction principle for multiple reasons:

1. Current dimensioning, based on a modular size of 1,24 m., is an important aesthetical aspect of the building and the corporate identity of the TU/e. The new façade should relate, not mimic, to this dimensioning. A curtain wall façade system allows the separation of the Main Building construction from the façade construction, which gives more freedom in dimensioning the façade. Hence, it allows open junctions with slender framework at the façade's corners which is an important aesthetical aspect of the buildings articulation.

2. A curtain wall façade principle is based on tensile stress, reducing material needed to transfer structural loads. Therefore, curtain wall principle allows a minimum dimensioning and use of material. The Main Building's construction not only allows a limited amount of weight, as will be explained in chapter 5.4.4., moreover, it will positively contribute to the desired *Greencalc*-score as mentioned in chapter 4.5.4..

3. A curtain wall façade allows a high (flexibility in) transparency. Due to allowance of a slender dimensioning of the framework, a high transparency and daylight admittance can be achieved. When desired, it can be almost completely opaque, open and/or transparent. Based on different orientation or adjacent programmatic function, this allows different configurations of these design aspects within the same dimensioning and appearance of the façade.

4. A curtain wall façade suits best according to relevant constraints: As described in the cultural and historical analysis, the construction principle of a curtain wall façade, separating building elements, supports the almost monumental status of the Main Building [19, p. 73], being an local icon of functionalism Main Building. Moreover, the *Masterplan TU/e Science park* states ‘a transparent curtain wall with a high-tech appearance’ as a design criteria. [18, p. 68]. Original façade is shown in figure 5.24

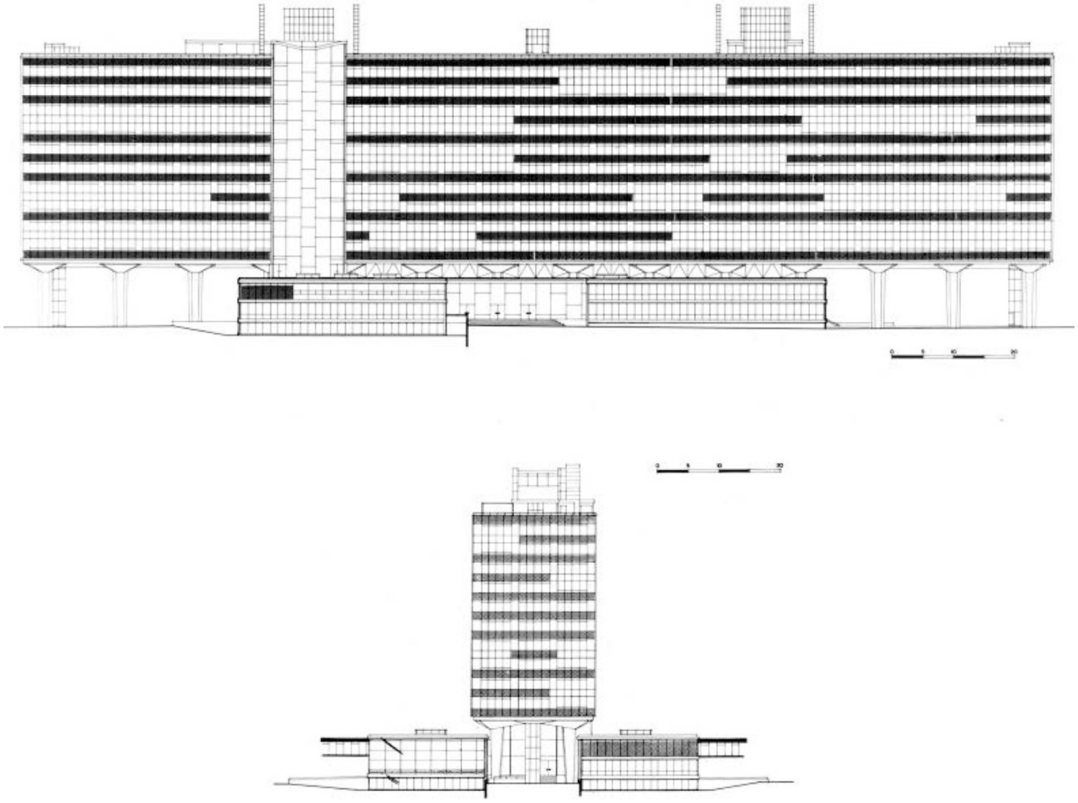


Figure 5.24. Design existing façade (source: OD205, 1957)

5.4.3. Façade dimensioning

The existing façade is shown in figure 5.25. As aforementioned, the Main Building design is based on a modular size of 1,24 m. The floor plan is based on a mesh of columns (0,45 x 0,45 m.) with intermediate distance of 6,20 m. Length between the heart of the columns and floor overhang is 0,65 m. Columns are not extrapolated in the façade expression. Floors are expressed in the façade by placement of apron walls, forming horizontal strips. The combination of vertical lines, 1,24 m. width and horizontal strips make a neutral mesh, not expressing a dominant vertical or horizontal primary direction.

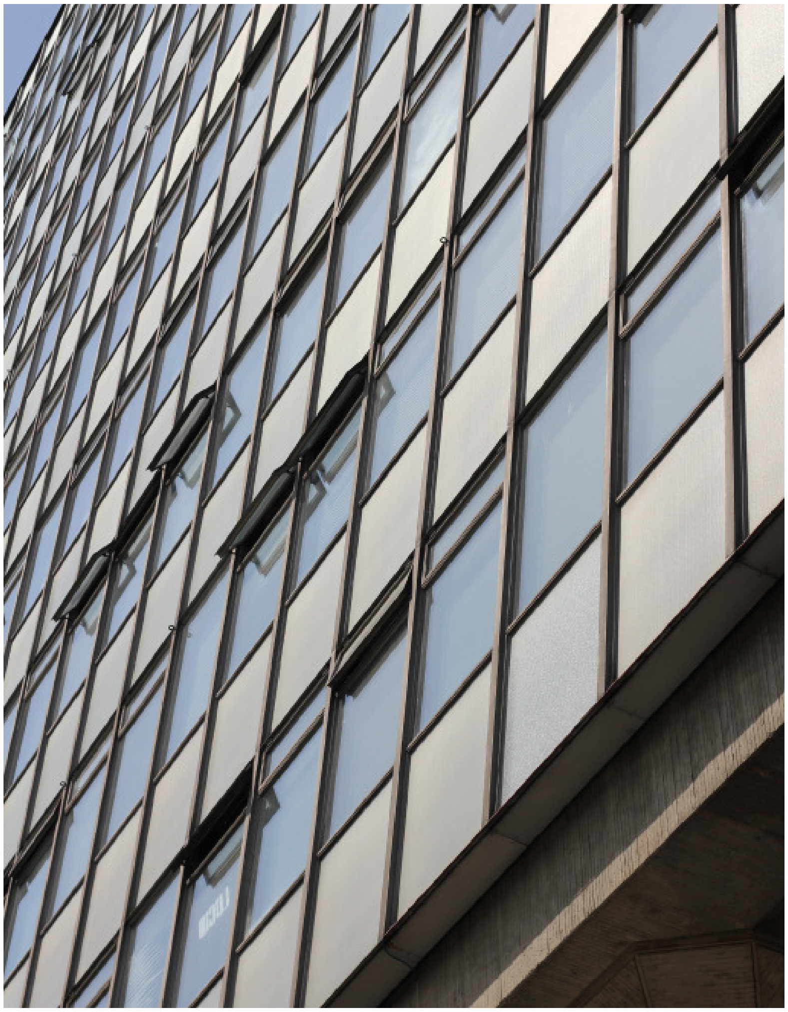


Figure 5.25. Current façade high rise

5.4.4. Façade weight allowance

Current façade weight is related to the primary building construction allowance. For architectural and financial reasons, a slim dimensioning was aspired. The original reports state a maximum weight allowance for the façade of 70,0 kg/m^2, including safety margins [4]. To give an indication: two layers of 6 mm. thick glazing, including a IPE 160 profile weights 43 kg/m^2. For a breakdown of the structural calculations, see appendix F. The limiting factor is the column dimensioning of 0,45x0,45 and the dimensioning of the concrete table columns. It is possible that by reducing weight allowance of , for example the current floor weight allowance of 500 kg/m^2, a higher weight for the façade can be achieved. Further researched should be conducted to fully exploit possibilities.

5.4.5. Conclusion

The curtain wall principle is still regarded as the best suiting façade construction principle. The façade should relate to the original dimensioning and neutral mesh of with no (too) dominant vertical or horizontal expression. Original calculations show that current design is stooled on 70 kg/m^2, a slim and light weight construction that allowed a lighter primary construction dimensioning. This limited weight allowance is a constraint for the new façade design, especially when considering a double façade principle with large overhang and/or triple glazing.

5.5 Solar energy generation capacity of the facade

5.5.1. Motivation

For aforementioned reasons, the university aims to increase its energy neutrality in 2020. In addition to decreasing the energy load of the campus, new means to implement distributed energy resources (DER), such as solar energy systems, are needed to achieve this ambition. A promising technology to might be solar energy systems. As stated in the Urgenda report 'City of tomorrow ', large horizontal area is needed to generate considerable amount of solar energy. [28, p. 34] Since the usable surface area is limited to mostly roofs and some scarce plots of ground, the possibility to implement solar panels on facades becomes a 'second best' option.

With Project 3, the possibility of implementing solar energy systems, most common are photovoltaic (PV) panels. Other promising solar technologies are under development. For this study, PV panels with a module efficiency of 15% were chosen because of their wide implementation and availability in the market. Furthermore, an energy conversion efficiency of 81,2% is estimated due to other losses (cabling, conversion, and so on) in the complete system.

Tilted above ground level by an monumental 'concrete table', the high rise forms a very regular and flat shape hardly distorted by any shadow from its surroundings. Only the east side is cast in shadows by the adjacent Metaforum building. The high rise orthogonal shape 32,595 (h) x 20,37 (b) x 169,173 (l) is perfectly oriented to the north, should be considered for the implementation of PV panels.

5.5.2. Overview calculation

To give an estimation about the energy generation potential of the high rise facades, an estimation is made, 'non-realistic' assumption of covering the full façade with panels. The breakdown of the calculation can be seen in appendix G and an overview of possible yield is given in table 5.7.

Table 5.7: energy yield and savings due to PV electricity generation for the façade

Façade	**South**	**West**
generation capacity[1] [kWh/m²/y]	98,22	67,27
Total surface area facades [m²]	663,96	5514,10
WWR	*0,6*	*0,5 – 0,6*
PV Panel surface	398,38	3032,75
Total annual yield [MWh/y]	39,13	204,02
Total cost price for TU/e [€/MWh]	76,50	
Savings [€/y]	**2.993,46**	**15.608,88**

The energy yield for the roof is included, as can be seen in table 5.8. The energy yield of the roof depends greatly on the usable surface, furthermore, the effective use of the available surface is reduced because the arrays of panels need some distance from each other in order not to cast any shadows on the next array. The ideal distance ratio between arrays is shown in figure 5.26 [37]. If a higher density of panels should be implemented, efficiency per panel would be less but a higher yield would be achieved:

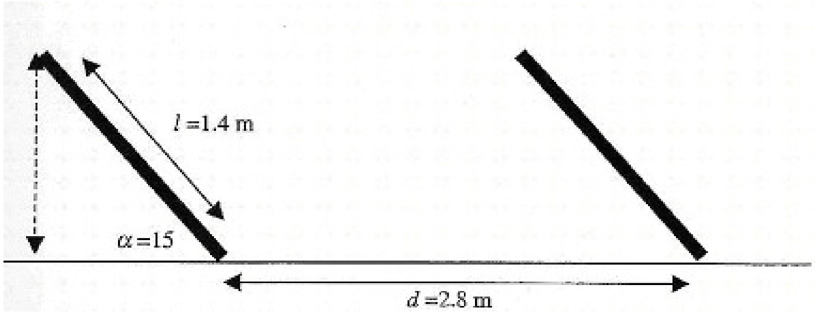


Figure 5.26: distance between two panels

Table 5.8: energy yield and savings due to PV electricity generation for the roof

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[1] Capacity based on amount of insolation according to KNMI climate file 2001-2008

Roof	**[m^2]**
Gross surface	3445,99
Distance to edge for wind turbulence = 1 m	-375,08
Installations space 20% of total roof space	-689,20
Usable space for PV arrays	2381,71
Effective roof usage [%]	*69,12*
Array-distance (d)/ panel length (l) 36° = 3,10	
Panel surface/ effective roof usage ratio [%]	*32,26*
PV panel surface on roof of MB (36°, south)	768,29
Total annual yield [MWh/y]	135,32
Savings ratio [€/m^2/y]	4,35
Savings [€/y]	**10.352,89**

Mainly due to the mutual array distance, the savings ratio for roof panels appears to be lower than the savings ratio for façade-mounted panels. This comparison does not take into account the extra maintenance costs for façade panels and difficulties involved in integrating panels in a high rise façade. In addition, panels on roofs are ventilated well. The ventilation of façade panels is complicated. Well ventilated panels have a higher over-all efficiency. Placed on a horizontal roof, panels are easy accessible and can be placed after building construction.

5.5.3. Methodology

In order to estimate the energy yield for the high rise of the Main Building, several steps have been taken.

As a first step, the insolation is being determined. Insolation is a measure of solar radiation energy received on a given surface area and recorded during a given time. Using the KNMI weather file average over a period of 2001-2008, the insolation on a horizontal surface in the region of Amsterdam is given. To validate the data, the insolation is also being calculated using the simulation tool IES VE.

Secondly, correction factors were determined for different orientations (north, east, south and west) and different array angles (vertical for façade, 36° for optimal angle on the roof) using data from NASA meteorology and the tool PVWatts, developed by The National Renewable Energy Laboratory (NREL), the United States' primary laboratory for renewable energy and energy efficiency research and development.

As a third step, the PV system efficiency was determined. A 15% module efficiency (the amount of energy from the sunlight that is being captured 'inside' the panel) was assumed . Furthermore, an energy conversion efficiency of 81,2% was assumed (caused by aspects such as unexpected shading, electricity conversion, metering, cabling) based on assumptions given in table 5.9..

Table 5.9: PV module efficiency

PV module efficiency:	**15 %**
deviation from STC cond.	4,5%
soiling	2,5%
temp	3,5%
shading	2,0%
mismatching & dc-dc conv.	3,5%
Mpp. mismatch	1,5%
meter	3,0%
Total conversion losses:	**81,2%**

As a fourth step, the surface area theoretical usable for PV panels per orientation was determined. Focusing only on the high rise of the Main Building (32,60 (h) x 20,37 (w) x 169,17 (l)), the window wall ratio (WWR) has to be estimated. Using the outcome of an design optimization study [6] (considering both energy efficiency and visual comfort) the following WWR is assumed as described in table 5.10:

Table 5.10: assumed openness per facade orientation

	South	North	East	West
WWR	0,6	0,5-0,7	0,5-0,6	0,5-0,6

With the openness of the façade estimated, it is assumed that the closed part will be completely covered with PV panels. This assumption is quite optimistic, at least. The annual yield is calculated for all orientations. As can be seen in table 5.11 and for obvious reasons, north orientation provides the lowest yield. However, due to diffuse radiation, energy is still being generated. East and west provide can generate the highest amount of energy. However, as can be seen in the sun study of the Main Building, the east side is shaded for a large amount by the high rise of the Metaforum building. The south and west side are the most interesting sides for sun energy generation.

Table 5.11: PV yield per façade orientation

Façade	South	North	East	West	Total
Generation capacity [kWh/m²/y]	98,22	42,03	68,07	67,27	208,31
Total surface [m²]	663,96	663,96	5514,10	5514,10	12356,11
Usable surface [m²]	398,38	398,38	3032,75	3032,75	6862,26
Energy yield [MWh/y]	39,13	16,74	206,43	204,02	466,32
Savings [€/y][2]	2993,46	1280,92	15793,01	15608,88	35676,26
Savings ratio [€/m²/y]	7,51	3,22	5,21	5,15	

5.5.4. Indicators for initial and maintenance costs.

As indication of the efficiency of energy generation by façade integrated PV panels, an investment cost of at least an additional 200 €/m^2 is assumed. [44] This is an positive

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[2] Based on energy cost prices 2012-2013, (76,51 €/MWh), provided by Real Estate Management TU/e

indication and prices can fluctuate greatly over time. As shown in figure 5.27, financial benefits remain negative when considering interest. Maintenance and other operative costs such as cleaning are not included in the calculation. On the other hand, savings could be gained due to the fact that the PV panel can replace, for example, the apron wall (*borstwering*) of the façade. When integrating panels with the façade, complexity of the façade system and difference between lifetime expectancy of integrated elements make additional risks. A future increase in efficiency at lower investment costs is expected. 'With photovoltaic module costs as low as €500/kW and module lifetime up to 30 and even 40 years now in reach, competitiveness is already accomplished in several market segments. Roadmaps and objectives should be revisited because PV now offers a generation of technology which is ready to deliver.' [23, p. 20] When considering a more efficient system for the same cost price, a positive result is gained as shown in figure 5.27.

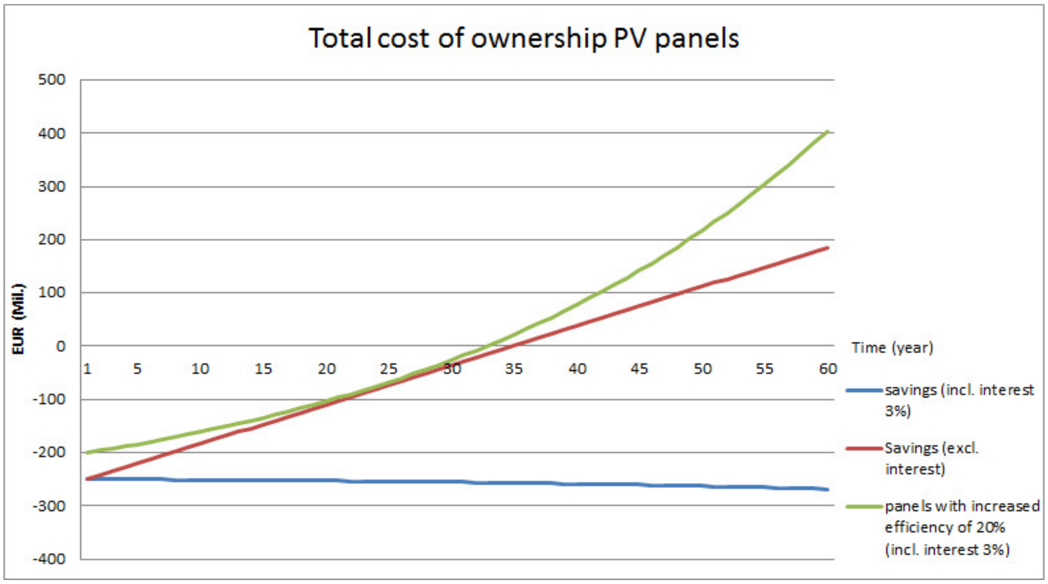

Figure 5.27: Total cost of ownership PV panels mounted on the façade

5.5.5. Conclusion

Solar energy can be used to actively generate energy, which could directly be used for cooling or other building related purposes. Actively generating energy would contribute to the aim for the Main Building and university campus' future goals to become (almost) energy neutral.

The high rise is almost fully exposed to the sun. Due to the lifted position of the Main Building high rise, the volume is almost not obstructed by any (temporary) shadow cast. Moreover, the shape and orientation of the high rise make it an almost perfect solar collector during cooling season. However, market available technology is still at a relative high price and system efficiency low. A brief estimation is made based on measured insolation and the use of average efficient PV panels on both the façade and roof. Energy generation proofed to be relevant, but the required investment should be regarded in perspective of energy saving, alternatives, such as high quality insulating or more expensive glazing. Calculations show that mounting PV panels on the façade or integrate PV panels with the façade are no (financial) attractive solutions yet. However, future developments make façade integrated PV panels more feasible, urging the need for an flexible and adaptable façade design.

5.6 Current energy use

5.6.1. Motivation

To determine energy efficiency of possible facade concepts, insight in current energy use is needed to compare difference in building related energy demand. Data over a period of six operational years (2006-2011) is analysed and interpreted. More specified data analysis can be found in appendix H.

5.6.2. Methodology

TU/e Real Estate Management monitors energy use of buildings on the university campus. Data is collecting using the software tool *Erbis*. The Main Building has not been fully operational since 2012, therefore, data is collected for the period of 1st of January 2006 to 31st of December 2011. During this period of time, the Main Building was decentralized heated, using gas. The Main Building has no active cooling system, but in order to spread local heat accumulation, air circulation system was installed. Air is cooled using heat exchangers on the roof, cooling air with outside air. This process is regarded as cooling. Furthermore, the building is ventilated naturally through the façade using outside air. The Main Building has two groups of transformers (*trafo's*) for electricity use, situated both north and south in the basement of the building. Both gas and electricity use were fully monitored in the mentioned period. For a more detailed description, see appendix I.

5.6.2.1 ATES system

The Main Building is not yet connected to the ATES system. With future use, the building will be connected to the ATES system. To make a relevant comparison between current and future energy use, the current heating load, measured in cubic meters of gas, is converted to the primary energy used as if connected to the ATEs system. This way, the efficiency of the supplying heat source is taken out of the comparison and a better insight in the heating demand for current and future situation can be seen. To determine efficiency, values in table 5.12 were assumed.

Table 5.12: Assumed conversion efficiency

unit	assumed values
1 m^3 gas	0,0365 GJ[3]
1 GJ	277,78 $kWh_{thermal}$
1 m^3 gas	2,77 kWh_{elec}
COP ATES [24]	13,6
COP HP[4]	5
COP total system	3,66

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[3] Energy ratio according to Real Estate Management TU/e, 2013

[4] Relative high COP is assumed due to a more efficient inlet flow of preheated/cooled caused by ATES.

5.6.2.2. Baseload

To determine the base load (user non-related energy use) of the Main Building, data of Christmas period is collected. The university has a tradition to shut down as much apparatus and no one is using the buildings. This gives the best possible assumption of current base load.

5.6.3. Current installation concept

The indoor climate of the Main Building is conditioned in multiple ways. As aforementioned, the building is not yet actively connected to the ATES system. Moreover, due to the renovation of the low rise, different installation principles apply for high- and renovated low rise. The renovated low-rise has central air handling units for ventilation which can pre-heat or cool air, directly using outside air.

Heating:

- The building is heated using high temperature, water based heating distributed by radiators placed adjacent to the façade. The water is heated using natural gas;

- Moreover, the renovated low rise has an central air handling unit, using preheating external air.

Cooling:

- The low rise has an central air handling unit with which the outside air can be cooled;

- Some, not all, floors of the high rise are connected to another central air handling unit, cooling indoor air and connected by a loop of cooling water with three cooling machines placed on the roof of the high rise. However, due to the related high noise generation, this cooling system is more not-active than active;

- In addition, several office spaces are cooled using decentralized induction units (fan coils)which are connected to the same cooling machines on the roof, cooling circulated air.

Ventilation:

- Historically, but currently partly removed and out of use, the building was ventilated using cross ventilation (*dwarsventilatie)*, using inflow air canals integrated in the concrete floor slabs at the façade and a central outflow, using the still visible large square-like air canals. Currently, the building is only ventilated using the adjacent natural air as inflow;

- The low rise is ventilated using an air handling unit, directly connected to outside air (with no option to mix internal air with outside air);

- In the high rise, air is circulated using the air handling units. Inflow of air only due to infiltration and open able windows.

5.6.4. Current energy profile

The Main Building uses relative high amount of heating. Due to the lack of active cooling, energy usage in cooling period is low, as can be seen I figure 5.29. During weekends, energy use is reduced but still high, as can be seen in figure 5.28. Except for lighting, energy loads are still very active.

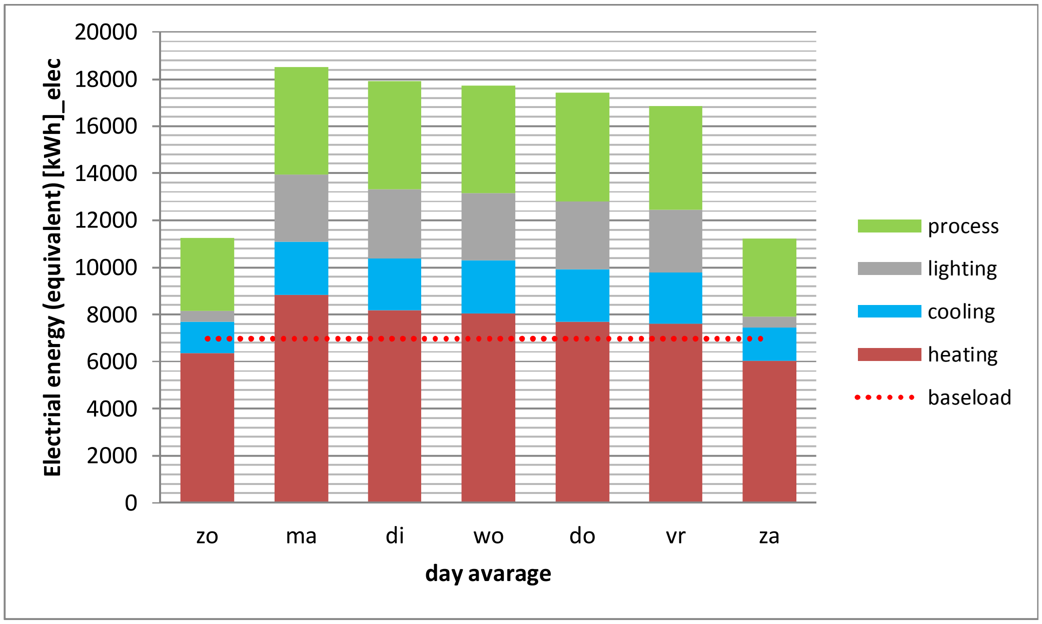


Figure 5.28 total daily use (average over period 2006-2011)

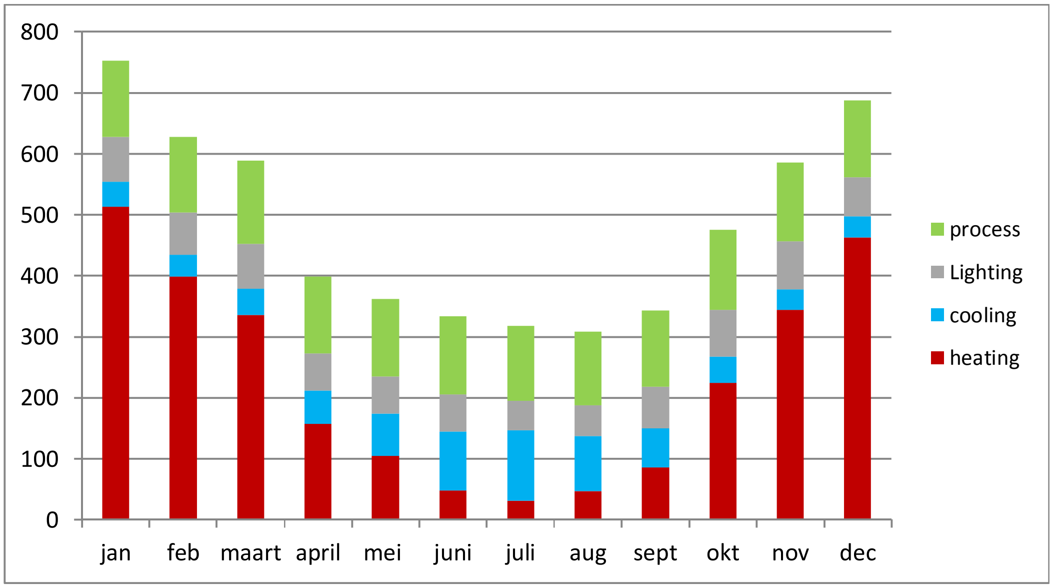


Figure 5.29 Total monthly use (average over period 2006-2011)

5.6.5. Conclusion

The total annual load is given in table 5.13. The Main Building uses a high amount of heating (65% building related energy use). Cooling, and related air circulation, only occurs sporadically due to otherwise generated noise pollution and uses little energy (17% of building related energy use). Lighting is around 18%. Based on data measured in the period of 2006-2011, total building related energy use is 95,32 kWh/m^2 . Comfort standards are low and façade is obsolete.

Table 5.13: total annual load existing situation

Annual load	MWh	% of baseload	MWh/m^2	kWh/m^2
cooling	721,83	16,94	0,0161	16,15
heating	2751,66	64,58	0,0616	61,56
process	1520,75	-	0,0340	34,02
lighting	787,44	18,48	0,0176	17,62
Total energy use	5781,68	-	0,1293	129,35
Total building related energy use	4260,93	100,00	0,0953	95,32

5.7 Compartment strategy

5.7.1. Motivation

For multiple reasons, a compartment strategy would be beneficial for the new design of the Main Building. However, it gives design restrictions as well. Four aspects are distinguished:

- To save energy and provide a flexibility, the building organisation should be able to facilitate limited usage in evening hours or (unexpected) future change in programmatic use without the need for unnecessary climate conditioning of complete floors or even larger sections of the building;

- From the perspective of fire safety, a compartment strategy could be a cost-efficient solution, compared to a full sprinkler installation. Organizing the high rise in compartments takes the limited floor height into account as well;

- The insolation pattern of the building can result in large internal temperature differences. This can result in lower comfort (due to draught, local coldness or overheating) and a higher dependency on active climate installations. Division in different climate zones could help to reduce internal temperature differences and related problems;

- The floors have a large length (dimensions: 20 x 169 m.) and can be considered as ‘indoor streets’. A spatial sequence is needed to scale this length to humane and pleasant proportions. Compartments can be a tool to scale open spaces to the right proportions. However, when the compartment are too small or the compartment walls are fully opaque, a division in compartments could have a significant negative effect on the spatial quality, making the indoor space too fragmented.

A balance should be found to give answer to aforementioned aspects. In arranged order, all four aspects are clarified to some extent. A more detailed study is needed to fully estimate cost efficiency and understand more complex phenomena, such as related costs to mentioned fire safety scenario's and the generation of internal draught.

5.7.2. Flexibility

The Main Building will facilitate both departments and supporting services. Different working concepts apply. Working in evening hours, during vacations or exam weeks can result in a low occupancy rate. Compartments can be temporary closed or due to presence detection not be activated. When installation concept allows the same scale of differentiation, this can result in significant energy savings and/or facilitating workplaces even in periods of expected low occupancy. However, from the perspective of fire safety, compartments cannot exceed 1000 m^2 in gross floor size. A potential quality of the Main Building high rise is the flexibility of adding/removing floors. Fixating compartment size can limit this freedom and reduce flexibility in future building use.

5.7.3. Fire safety

Fire safety for the built environment is often based on the strategy of comparting building zones and therefore delay the spreading of fire. Basically, compartments of a maximum size of 1000 m^2 must be separated by fire resistant internal walls, floors and the connection between floor and facade. Walls can be made out of opaque materials or more expensive fire resistant glazing. More innovative solutions are already on the market. Partitioning of floors and between floors limits design possibilities. Moreover, there are costs related to the fire resistant measures that ensure the delay of flashover between compartments. However, the alternative is most often a full sprinkler installation. A sprinkler installation is an high investment and can reduce the already limited open floor height. A more detailed study related to fire safety can be found in appendix J.

5.7.4. Climate control and comfort

The particular slender shape and orientation of the Main Building high rise can result in a high insolation on east oriented façade in the morning and a cool environment adjacent to the west oriented façade and vice versa. Even if climate installations are able to regulate these differences in internal climate, this will still result in higher energy use. Separating east from west would make climate control less difficult and could save energy.

Moreover, the thermal differences between east and west can result in comfort problems due to draught which is generated by high internal temperature differences. Placing workplaces near the façade allows a better use of available daylight and contract with exterior.

5.7.5 Spatial quality

Compartments can reduce potential spatial quality. Atria, visual sightlines and/or open staircases are difficult to combine with a compartment strategy. Even when applying fire resistant glazing instead of opaque compartment walls, it is not the same effect as full openness. Different product are available to achieve the right compartment separation for fire safety while keeping desired openness and design possibilities. A so-called 'sprinkler curtain' can be activated to provide segmentation when needed. Combined with a flexible slab or wall construction to repel smoke, an open connection between compartments can be achieved. Costs and benefits should be studied in more detail to determine the effectiveness of innovative solutions. In addition, compartments of 1000 m^2, divided over two floor heights can still be experienced as quite large and open. Interaction between floors, differentiation of space height and a limited sequence of different dimensioned spaces is still possible within one compartment. Further study is needed to determine if the spatial effect proofs to be of the desired quality.

5.7.6. Conclusion

A compartment strategy, as shown in figure 5.30, separating east from west, can support a higher comfort and energy efficiency. Compartments are a constraint but can still provide desired openness and spatial quality. Compartments of 1000 m^2 in size offer large advantages, such as no need for sprinkler installation. In addition, it offers a more flexible use when the building is only partly used.

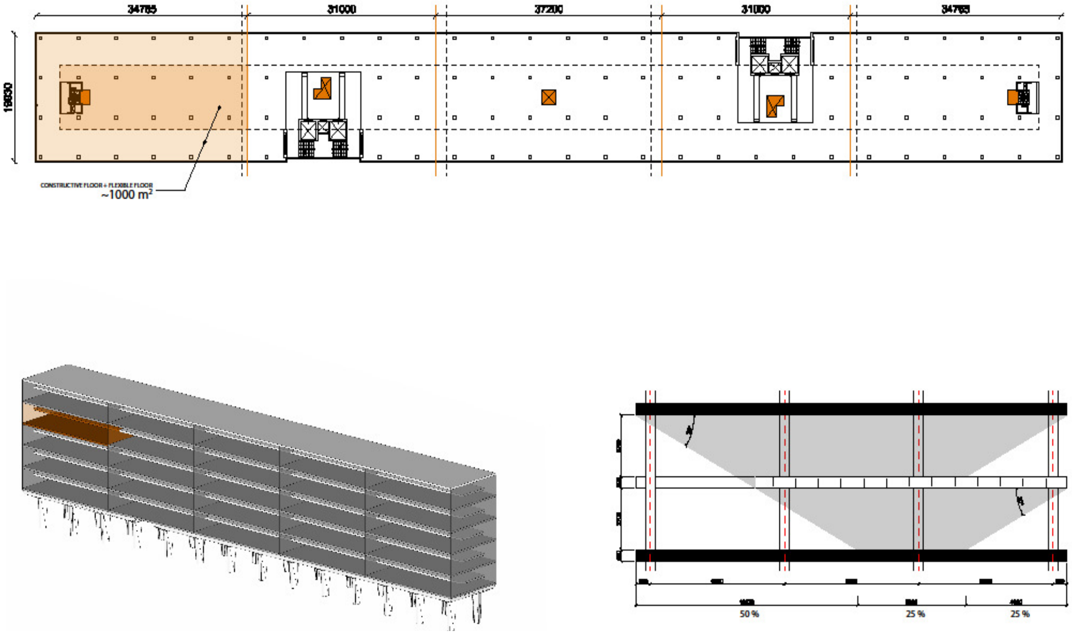


Figure 5.30. Compartment strategy Main Building high rise

5.8. Conclusion object analysis

5.8.1. Opportunities

A most fitting façade design depends on the opportunities provided by existing building construction and its environment. As a results of a broad analysis of the building and its environment, potential benefits are distinguished to which the design of the façade should relate. Most significant aspects are:

- The environment offers distinctive characteristics: the building is positioned in the heart of an attractive green park landscape with clean air and a friendly wind climate/ Moreover, despite the inner city location, there is almost no noise pollution. The environment allows a façade which is open to exterior, by using natural ventilation and enables experienced contact with surroundings;

- Moreover, unlike compact building shapes such as the Meta Forum high rise, the slender shape of the high rise allows a deep daylight admittance, able to cover 50% of total floor area, and an easy access of natural ventilation through the façade;

- The high rise construction alternatingly consists of alternately fixed heavy mass structural floors and flexible lightweight floors. The existing structural principle offers several qualities relevant to potential façade design:

    - Organizing the high rise in compartments of two floors height offers the most overall value regarding fire safety, flexibility, costs and user value;

    - Openings in each structural floors allow the placement of multiple vertical installation shafts. This organization principle should be used to avoid potential problems with limited floor heights between floors;

    - When 50% of flexible floors are fulfilling programmatic needs, placement should be done adjacent to alternately the east- and west façade, to create a better controllable, energy saving and comfort increasing east/west-zoning and to allow an optimal use of daylight;

    - Enabling ventilation through the façade avoids potential problems with the placement of, and dependency on, additional needed installations for mechanical air inflow

5.8.2. Threads

In addition to taking benefit from distinctive qualities, the façade should be designed to avoid or reduce the effect of threads. When considering the integral performance of the façade, main problems for the building and façade design are distinguished:

- Due to its shape and orientation, the Main Building high rise forms a ‘perfect solar collector’, resulting in a high external cooling load. Especially during cooling season, a high insolation will cause a high cooling load, especially when considering a desired openness of the façade. However, blocking solar radiance will always need to be considered in relation to occupants comfort and heating load during colder periods. Based on integral performance criteria, as described in chapter 4, a balance needs to be found in repelling unwanted external heat, allowing desired heat and most important user values;

- Due to possible high insolation values of the façade and internal heat generation, a high accumulation of heat and related internal cooling load can be expected. Even when repelling external energy gains most efficient, the building will accumulate heat. Expelling this heat must be done in the most energy efficient way;

- Making use of natural ventilation, both during day- and night, and enable a high quality of daylight entrance increase user values and potentially reduce mechanical ventilation and artificial lighting. However, both aspects can result in higher thermal loads and thermal discomfort. Primary challenge is to find a balance in the design of the façade;

- The high rise structural principle offers few threads relevant to potential façade design:

    - Major constrain of building construction is the limited floor height between a structural and flexible floor. Ensuring a large floor height in work and study spaces is essential for the quality of use. Especially ducts for central mechanical ventilation and suspended ceilings pose a thread for available the free floor height;

    - Covering structural floors with installation floors or suspended ceilings will reduce the capacity of available thermal mass to absorb or radiate thermal energy.

Chapter 6: Partial solutions

6.1 Façade principles

6.1.1. Motivation

The demand of sustainable and energy efficient buildings has an strong influence on the façade design. For some situations, this might result in increasingly complex façade systems. The Main Building is most suited with an curtain wall façade principle. Although many different principles and hybrid concepts exist, based on the ventilation principle, this high variety of curtain wall façade-types can be narrowed down to conventional single layer-, double skin- and climate façades. Many literature studies have been performed on comparing each type on energetic and integral (architecture, user value, operative cost, sustainability) performance. Aim of this study is to give a literature overview and determine which type of façade is best suitable of the situation of the Main Building. A more extensive overview on the performance of different types of facades can be found in different consulted studies. [7] [45].

A curtain wall façade can be framed or composed out of (prefabricated) elements. The original façade is a framed construction. Currently, prefabricated façade elements give another possibility for curtain wall facades. Although an prefabricated element façade can never be as slim as a framed construction, it has other advantages that suit very well to the situation of the Main Building high rise: [46] [47]

1. The Main Building is in the middle of the campus. An efficient and fast construction of the façade reduces construction nuisance. Element facades are prefabricated and hung in place on site;

2. As described in chapter 5.2, the shape of the high rise is constant and has a large façade surface. These are ideal conditions for an element façade, where repetition and similarity of elements greatly reduce cost price;

3. Element facade fits well with modular size of 1,24 m. double floor heights of 5,5-6,0 m. are possible as well. Existing IPE profiles could be reused for placement elements;

4. Compared to an on-site constructed framework curtain wall façade, an element façade performances better on air- and rain tightness due to controlled conditions during prefabrication;

5. When integrating complex façade systems such as internal sunshading and or intelligent natural ventilation devices, assembling in controlled conditions gives less failure (however, parts of façade elements should still be easily replaceable on site). Combined with an intelligent building management system, elements could be 'plugged-in' and ready for control, greatly reducing adjustment time (*inregeltijd*) after building completion.

6. The façade of the high rise allows a great amount of repetition and is, due to its elementary shape, continuous and repetitive. This allows an efficient production and installation of façade elements, greatly reducing costs. [47]

6.1.2 Single layer façade

A single layer façade is seen as standard. A single layer façade can be mounted with different types of window panes or opaque materials and can have extruding elements, which may cause shade and block direct solar radiance on façade openings. Essentially, a single layer façade is thermal and acoustic insulation between in- and exterior climate. Mentioned alternative, more complex, façade concepts are compared to the standard single layer façade.

6.1.3. Double skin façade

6.1.3.1. Description

The double skin facade is characterized by an double layer façade with a wide cavity. The inner layer of the façade functions as thermal and acoustic insulation and is air tight. In principle, openable windows or grates are included in the inner layer for natural ventilation. The outer layer functions as protective screen against rain, wind and deflects sound. Due to open joints or controllable valves , the cavity is in contact with outside air.

6.1.3.2. Double skin façade subtypes

The design of the cavity is of major importance for the functioning of double skin facades. To avoid heat accumulating due to solar radiance within the cavity, a high ventilation rate is of major importance. The due to thermal differences, natural thermal currents occur which result in natural ventilation of the cavity. However, this effect is limited and requires a relative wide cavity, min. 200 mm and max. 1000 mm.. An air cavity depth smaller than 200 mm significantly reduces the air change rate in the room behind a double-skin façade. Moreover, a cavity of 500-600 mm. is considered as a minimum, since accessibility for maintenance is an important constraint [48]. During cooling season, in perfect condition, the cavity temperature is can be no less than the outdoor temperature. If the cavity of a double skin façade can be too large in height, this may cause a temperature stacking effect which generates high temperatures in the cavity at upper floors and problems with heavy wind currents which can damage the inner façade construction [48]. This causes comfort problems, a high cooling load and windows are not open able due to high air speed and temperature. Moreover, sound can be deflected and ‘captured’ in the cavity, resulting in acoustic nuisance for adjacent rooms. To counter these effects, different subtypes of double skin façades are developed [7] [49]:

Multistory facades: No or less intersections between partitions and/or floors. The façade has only one or few large cavity spaces, possible causing aforementioned negative overheating effects and high wind speeds, making it unable to natural ventilate and causing a high cooling load due to transmission.

Corridor façade. The cavity is partitioned per floor, to avoid excessive windspeed and high temperatures as a result of thermal current and temperature stacking effect. Sound insulation between adjacent rooms is poor.

Boxframe façade. The cavity is partitioned per floor and room. This way, acoustic, odors and draught due to open windows are separated per adjacent room.

Shaftbox façade. The cavity is partitioned per floor and each box is connected to a central vertical shaft. Effective but complex type of double skin principle.

6.1.3.3. Sun regulating devices

An advantage of double skin facades is the protective placement of sun repelling devices in the intermediate space. Sun shading can be an effective solution in reducing cooling load. Applied externally gives greater effect then internal sun shading, but has negative effects as well. Double skin facades allow an intermediate placing of sun shading that, when positioned ideally at roughly a third of the depth of the façade cavity, gives almost the same effect against overheating and reducing the cooling load. Exact positioning of shading within intermediate space is of major importance. To avoid heating up air in cavity, or direct inflow of heated air in summertime, the shading should be positioned in the outer half of the intermediate space –ideally at roughly a third of the depth of the façade cavity, with good ventilation to the outer space above and below the sun shading. Moreover, the sunshading device should not be placed too close to inner glazing, at least 150 mm., in order to avoid heating up inner façade and keep necessary ventilation space.

When placed correctly, the negative effects of normal external sunshading are greatly reduced:

- The outer façade layer provides protection, the sunshading is less vulnerable to wind and weathering. The sunshading device is less exposed to wind and will hardly ever have to be drawn up simply to otherwise protect the device. This applies mostly for buildings exposed to strong wind loads;

- Allows a more simple (lighter, blocking less light) form of construction for sunshading and guiding tracks;

- The outer layer provides rain protection and is good against soiling, reducing cleaning efforts. Improves long term appearance of shading;

- Sunshading absorbing heat in the intermediate of the façade is main reason for air heating up and cause the natural draft that is needed for internal natural ventilation;

- Intermediate sunshading with adequate ventilation almost has the same effect as external sunshading. Much more efficient than internal sunshading.

6.1.3.4. Thermal insulation

Double skin facades have limited benefits on thermal insulation. This effect is small or can be negative. [45, p. 53]

- ‘In principle, double-skin facades provide virtually the same scope for thermal protection in summer as a single skin façade (…) as shown in graph 5-28, where identical parameters exist for single-skin and double-skin façades (in respect to proportion of glass and the type of glazing in the single or inner façade skin and the external sun shading to the single-skin façade), there will be only minor differences in terms of the cooling-energy needs resulting from the façade itself. These differences are more likely to result from alternative air-conditioning concepts (…). ‘ [45, p. 55]

- when the cavity is closeable by the use of valves, the cavity consists of stilled air and contributes to insulating the building during extreme cold periods.

- Convective heating or cooling due to wind is less because of protective outer layer.

6.1.3.5. Ventilation

Double skin façades offer the possibility of natural ventilation when otherwise wind load or ambient acoustic nuisance would cause problems. Moreover, a double skin façade offers some benefits related to night ventilation when compared to single layer facades. In all cases, key to success is the delicate balance of a well-ventilated cavity:

- A good airflow is crucial for the functioning of a double skin façade. Therefore, an increase in temperature of air in the cavity is required to get a thermal current. If not sufficient, the cavity will accumulate heat and will heat the adjacent interior space. Moreover, it will warm the inlet airflow too much due to convectional heat transfer.

- The thermal air current in the cavity is often faster than the desired inlet of natural ventilation, causing comfort problems with draught. If air current is too slow, heat accumulation occurs which causes aforementioned negative effects. Valves can control this difference in flow rate. Moreover, openings in the internal layer need to be small, unlike full windows.

- Compared with single-layered facades, double-skin construction can achieve comparable degree of thermal insulation in summer; but when two-layered facades are planned with fully glazed inner skins, the cooling loads will increase in proportion to the larger area of glazing because the amount of intermediate heat gain cannot be naturally ventilated. Especially problematic at corners.

- If inadequately ventilated, the risk of condensation occurs.

- Possibility of controllable ventilation that is burglar proof. (Due to the table construction of the Main Building), this is no significant advantage for the Main Building high rise.

- Night cooling, protected against the weather and insects due to second layer.

6.1.3.6. Appearance and materialization

- In summer, a double-skin construction offers certain advantages if the winds acting on high-rise building or because of other, aesthetical, reasons do not permit external sunshading.

- Due to protective positioning, material used for the inner layer can be less weather proof because it is less exposed to weather conditions, such as rain. High wind velocities and temperatures still occur, so inner layer should still be able to withstand those situations.

- Smooth appearance is possible due to second layer covering sunshading device. However, a double skin façade does not directly allow a larger total openness of the façade. ‘the fact that in everyday practice, many structures with double-skin facades need extensive mechanical cooling can be explained by the extent of the glazing. The scope for sunshading provided by double-skin facades and the optical properties of the glass in the outer skin have been exploited to create completely transparent facades, especially in high-rise buildings. In many cases, the inner skin is also constructed with only small opaque areas or without any at all, with the result that very large “collector surfaces” are created for solar radiation. Especially in corner rooms, this leads to the dominance of external cooling loads, which can be balanced out only by mechanical cooling systems.’ [45, p. 79]

- Additional layer means additional use of material, such as additional layer of glazing;
- Double layer façade is at least 600 mm. wide for right ventilation and accessibility for maintenance. This has a great effect on building appearance, especially in connection with concrete table of Main Building.

6.1.3.7. User values

- Façade is wider, reducing visual connection with outside environment;
- Additional layer of glass and additional depth results in less daylight entrance;
- Due to extra layer and (possible) still air in cavity, less cold radiation and downdraft occurs. However, modern (triple) glazing already are able to reduce these effects.

6.1.3.8. Costs

- Higher (operative) costs due to need for extra façade layer. Additional costs are difficult to estimate, but could be in the range of 100-150 € /m2 gross floor area [45];
- Lower operative costs due to easier accessibility sunshading device. When otherwise not possible, the ability of natural ventilation can greatly reduce energy use as well compared to alternative facades;
- Highest investment costs compared to climate façade and single layer façade.

6.1.4. Climate façade

6.1.4.1. Description

A climate facade differs strongly from a double skin facade principle. The outer layer of a climate façade functions as thermal and acoustic insulation and is air tight. With the addition of an inner layer, often a single layer of glass, a cavity is created separated from adjacent internal space. The cavity is sealed off from both internal as external climate and is mechanically ventilated, extracting heated air with a controlled in- and outflow. The heated air is carried away though insulated canals.

‘Climate facades are characterized by a closed double glass layer in the outer structure an openable single glass layer in the inner structure, with a cavity space varying from 60 to 200 mm. The cavity space between the glass structures is ventilated by means of exhausting air through the space with air drawn from the room on the inner side. Solar and daylight control facilities are located in the cavity space. The climate facade with stands maximum outdoor climate influences and offers a solution to reduce the problem of heat loss in winter and heat load in the summer, particularly in high rise buildings, which have a large and preferably clear glass facade area.’ [50, p. 9]

6.1.4.2. Characteristics of cavity

The cavity can be considerable smaller, around 60 mm. to 200 mm. width, compared to the cavity applied in double skin facades. The cavity of a climate façade is partitioned between floors and adjacent spaces, creating a sort of box per space.

6.1.4.3. Thermal insulation

- The internal climate is less subject to disturbing influences of the external climate. Especially during extreme cold- and warm days, reducing thermal load;

- Convective solar energy is collected and can be used elsewhere. However, yield is greatest when climate is warmest. Storage or other technology is required to use surplus heat.

6.1.4.4. Ventilation

- Heat can only be extracted from interior spaces using mechanical outflow. Climate facades make it difficult for an efficient heat extraction and easily ‘trap’ heat. Moreover, the heat exhausted in the cavity has to be transported through the building, causing additional heating load;

- Natural ventilation is not possible while system is operational.

6.1.4.5. Appearance & materialization

- More usable space due to more compact façade compared to double skin façade;

- In buildings requiring renovation, unlike double skin facades, thermal bridges are warmly wrapped up by outer layer and the total insulation value of the facade is increased. Principle of climate façade can be placed between floors of the high rise and do not need to extend beyond current building shell;

- No extra, space consuming, heating device needed to counter downdraft or cold radiance.

6.1.4.6. User value

- Climate façade performs well as acoustic barrier, reducing external or adjacent noise nuisance;

- Natural ventilation is only usable when system is not operational, so it is counter effective. Lacking natural ventilation gives (psychological) discomfort, lower tolerance to interior climate;

- Inner windowpane is warm, greatly reducing downdraft and cold radiance;

- Double layer and depth façade reduce visual contact interior- exterior and daylight entrance, compared to single layer façade.

6.1.4.7. Costs

- Due to controlled air inlet, less dust and air pollution enter cavity, reducing cleaning and maintenance cost of possible sunshading system;

- No need for auxiliary heating device to counter downdraft and/or cold radiance;

- More expensive than single layer façade, less expensive than double skin façade.

6.1.5. *Comparing façade performance*

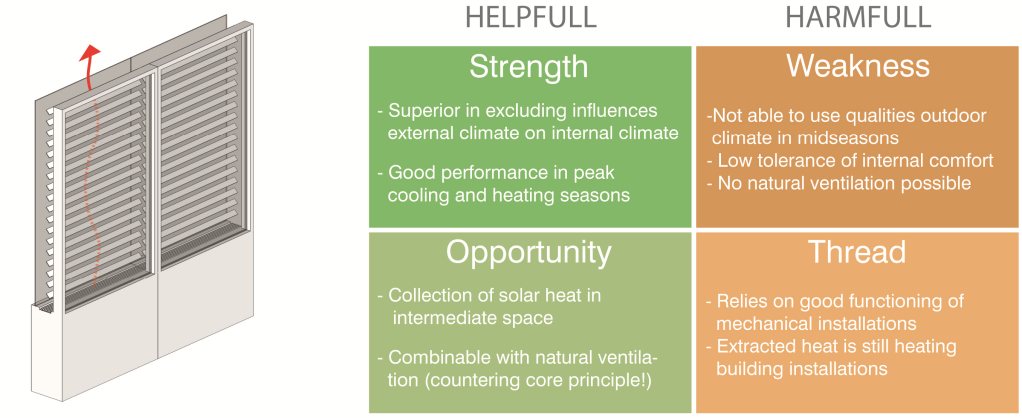
Three different basic façade principles are compared on their integral performance for the situation of the Main Building. Both climate facades and double skin facades are essentially an addition on a single layer façade (figure 6.1). Performance is evaluated from an integral point of view, regarding energy savings, user value, (operative) costs and architectural values. An extensive comparison is made using a matrix, see appendix K.. The results as shown below are discussed with various experts. [51] [46].

HELPFULL	HARMFULL
Strength - Cost efficient and robuust, low risk, solution - Most slim construction	**Weakness** - Unprotected external sunshading - Lower thermal performance in peak high summer and winter season
Opportunity - Savings due to ‘simpler’ façade concept can be used on higher quality materialization. - Façade design partly self-shading	**Thread** - Soiling and damaging of unprotected external sunshading due to heavy windload, rain etc. - Higher risk night ventilation due to uncontrollable openings/rain.

Figure 6.1. SWOT analysis single layer façade.

6.1.5.1. *Climate façade*

A climate façade will mostly performs better than a single layer façade when outside condition is far too cold or too warm. This way, especially in summer and winter season, the heating/cooling load for HVAC installations is as low as possible. Moreover, it will provide benefits when there is external noise pollution and provides a good solution or when natural ventilation is not possible due to heavy wind load anyway. However, large temperature differences between internal and external climate are scares and external climate can be even beneficial for maintaining interior climate. Moreover, climate facades make it more difficult to lose trapped heat due to difficult natural ventilation and because ventilated warm air, after extraction, remains in the ducts in the building. [51] The characteristics of a climate façade are given in figure 6.2..



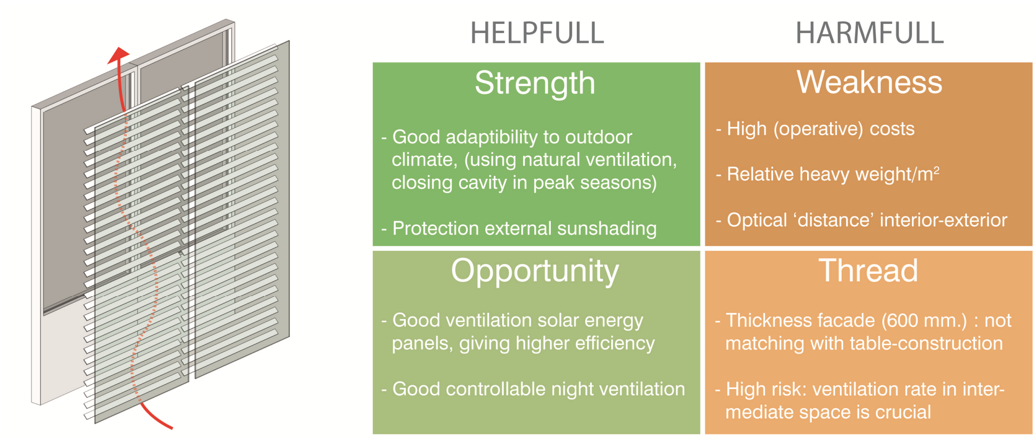
HELPFULL	HARMFULL
Strength - Superior in excluding influences external climate on internal climate - Good performance in peak cooling and heating seasons	**Weakness** -Not able to use qualities outdoor climate in midseasons - Low tolerance of internal comfort - No natural ventilation possible
Opportunity - Collection of solar heat in intermediate space - Combinable with natural ventilation (countering core principle!)	**Thread** - Relies on good functioning of mechanical installations - Extracted heat is still heating building installations

Figure 6.2 SWOT analysis climate façade

6.1.5.2. Double skin façade

In contrary with climate facades, a double skin façade creates a buffer layer which allows high rise buildings to keep interacting with the outdoor environment. Main advantage of a double skin façade is the possibility of natural ventilation in situations where otherwise ambient environment would be too noisy or windy. With advanced control, heating load might be lowered. Additional advantage is the intermediate placement of sunshading, almost performing as well as external sunshading but greatly reducing negative effects and still allows a possible smooth façade expression.

However, as aforementioned, the main advantages of an well designed double skin façade are not beneficial for the situation of the Main Building. Moreover, a double skin façade is costly, demands the use of additional material and will be a higher structural load. In addition, the ventilation of the intermediate space is very sensitive for design errors and when not designed accordingly, major cooling problems can occur which proposes an additional risk.



HELPFULL	HARMFULL
Strength - Good adaptibility to outdoor climate, (using natural ventilation, closing cavity in peak seasons) - Protection external sunshading	**Weakness** - High (operative) costs - Relative heavy weight/m² - Optical 'distance' interior-exterior
Opportunity - Good ventilation solar energy panels, giving higher efficiency - Good controllable night ventilation	**Thread** - Thickness facade (600 mm.) : not matching with table-construction - High risk: ventilation rate in intermediate space is crucial

Figure 6.3. SWOT analysis double skin façade

6.1.6. Conclusion

In performed mutual comparison, advantages on performance of both type of ventilating facades proof to be few or less valuable than included disadvantages, related to expected extra costs and/or risks. This is shown in table 6.1. A single layer façade, preferably with external sunshading, is the best trade-off between offered quality and costs [48].

Table 6.1: performance façade principles

Solution	Description	user value	cost	energy	material
A	Single layer façade	+	+	0	+
B	Double layer façade	0	-	0	-
C	Climate façade	-	0	0	0

6.2 Ventilation principles

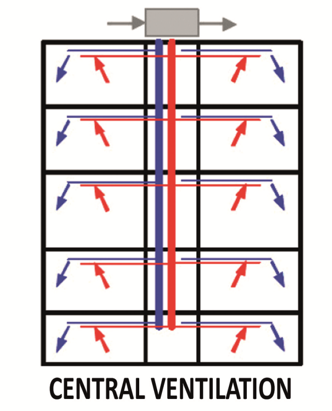
6.2.1. Motivation

As mentioned in chapter 4.2.5., the quality of indoor air is of major importance for the health and productivity of building users. The ventilation of a building can be done mechanically and by the use natural ventilation. Moreover, ventilation can have different purposes in the conditioning of the interior climate. Firstly, it is essential in sustaining the indoor air quality. In addition, it can have a psychological effect. Finally, ventilation can be used to lower indoor temperature, reducing the active cooling load. There are different ways of ventilating the building, which can be related to the façade design. This study compares the positive and negative effects of different ventilation principles and determines the most suitable ventilation concept for the Main Building.

6.2.2. Ventilation principles

6.2.2.1. Central ventilation

Central ventilation consists of an hierarchic distribution system, consisting of shafts, ducts, valves and air in- and outlets which need to be installed in the building in order to distribute and control ventilation over all floors and spaces. The system is adjusted to provide the right amount of both in- and outflow of air by the use of pressure (inflow) and underpressure (outflow). Large advantage of an central in- and outflow system is the possibility to exchange thermal energy between the currents, recovering heat and cold. Advantages and disadvantages are given in figure 6.4.:

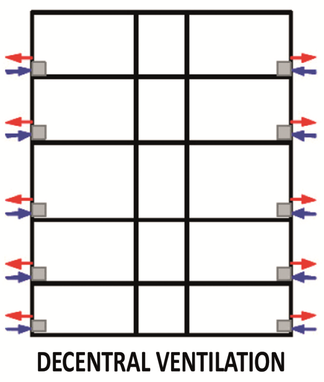


HELPFULL	HARMFULL
Strength - Large ventilation reach - Low (operative) costs	Weakness - No pers. control and adaptability - Needs ~500 mm of floor height - Less flexibility in building use
Opportunity - Advanced control system and climate ceiling make personal adaptation possible - Less complex facade construction - More efficient heat recovery	Thread - No personal control results in lower tolerance and higher climate demands of users - changing programmatic function due to no flexibility capacity install.

Figure 6.4 Central ventilation principle

6.2.2.2. Decentral ventilation

There are many decentralised ventilation systems available. Although passive systems exist, most systems are based on mechanical ventilation, ensuring a controlled in- and/or outflow of air and include a unit for active heating and/or cooling of handled air. Decentralized ventilation systems have the possibility of limited heat and cold recovery, but not as efficient as central ventilation systems. The reach of decentralized ventilation systems is limited, market available product have a reach up to 6 m. building dept. Advantages and disadvantages of decentral ventilation is given in figure 6.5.:

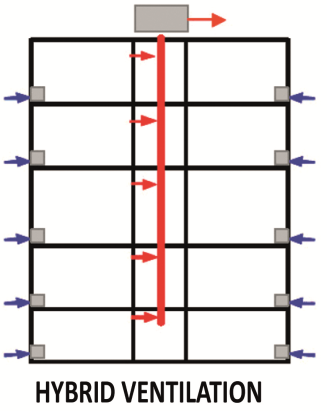


HELPFULL	HARMFULL
Strength - Spatial quality, max. floor height - Provides building use flexibility - Improves adaptivity & comfort	**Weakness** - High maintenance costs - Limited ventilation reach (6m.) - Less efficient heat recovery
Opportunity - Relative large area is servable due to high facade/floor ratio - No centralized installation needed - Controlled night ventilation	**Thread** - Ventilating inner area's require small ventilation tubes or other additional device

Figure 6.5 Decentral ventilation principle

6.2.2.3. Hybrid ventilation

The limited reach of decentral ventilation system of approximately 6,0 m. can result in the need for an additional air outflow system. A hybrid ventilation concept combines adecentral inflow with an central outflow of air. The ventilation of spaces positioned further away from the façade can be facilitated is ensured by creating underpressure, 'pulling' air inflow deeper into the building. Advantages and disadvantages are given in figure 6.6..



HELPFULL	HARMFULL
Strength - Large ventilation reach - Improves comfort & user tolerance	**Weakness** - Highest (operative) costs - Needs 500 mm. floor height
Opportunity - Controlled night ventilation	**Thread** - Colaboration of two systems is riskfull in operation and installation - Less flexible solution due to the need of two different systems

Figure 6.6 Hybrid ventilation principle

6.2.3 Natural ventilation

Instead of using a decentral, forced, inflow of air at the façade, natural inflow of air could provide a beneficial solution. Natural ventilation means letting in air through openings in the façade without the use of a fan or other type of mechanically forced ventilation.

6.2.3.1. Benefits natural ventilation

Despite the increasing trend of mechanical ventilation concepts in utility buildings, the high rise of the Main Building can benefit greatly from a ventilation concept which uses natural inflow of air. It has several advantages over a mechanical ventilation concept:

- Environment of the Main Building allows the use of natural ventilation. Exploiting this distinctive and 'free' quality enhances both image of the TU/e campus and building quality;

- The slender shape of the high rise results in a high contact surface with ambient air. Compared to a more compact building shape, it is easy to facilitate a large amount of floor surface from air inlet at the façade;

- A high ventilation rate results in a better indoor air quality, increasing the core-business of the TU/e, facilitating study and research, increasing health and productivity of building users;

- Natural ventilation enhances building user's contact with the campus. Moreover, users will have a higher tolerance for interior temperature due to the contact with ambient environment;

- When applied in an intelligent manner, natural ventilation allows a high ventilation rate while saving energy on annual mechanical ventilation and cooling load;

- Lower operative costs. By obviating a mechanical air supply, electricity costs for air circulation can be reduced. To give an estimation, 'alone with a 2.5 fold air change per hour in offices, provided by a central mechanical ventilation plant, roughly 15-25 kWh of energy will be consumed per square meter of ventilated floor area per year of power the fans. This is equivalent to about 1.5-2.5 €/m2 per annum'. [45] Furthermore, operative savings can be made on reducing active cooling load.

6.2.3.3. Ventilation control

When combined with intelligent control, the ventilation rate can be adapted to interior needs and/or external temperature. A higher inlet of air when outside temperature is beneficial could reduce the cooling load and increases the indoor air quality. When outside temperature is too warm or cold, ventilation rate could be reduced to a certain minimum inflow rate to reduce thermal energy losses at the cost of air quality. This is a trade-off of performance, which needs further study. Moreover, opening all windows, increasing ventilation rate significantly, outside office hours could cool down the thermal mass of the building, reducing cooling load and ensure the comfort of a 'fresh' indoor environment at the start of the next working day.

The building can potentially rely on natural ventilation for more than 40-50% of daytime hours while saving energy on climate condition at the same time. Ventilation of spaces is a very slow process. A manually controlled system reacts too late, resulting in thermal discomfort and/or inefficient cooling and heating. When automatically controlled, a change of ventilation rate based on predictions and early sensing provides both thermal savings on cooling and a higher comfort level. Different systems are available to control the inlet of air [52].

6.2.3.4 Flexibility due to natural ventilation

Direct rays from the sun and internal heat gains are the main causalities of heating up the building. Internal heat gains are caused by the activities, machines and people in the building. These aspects can be roughly estimated, but it is difficult to foresee activity changes in future building use and with (unexpected) events (far more people in the same room as was planned, different process installations needed that produce more heat).

To design for a future proof building means to design for a certain flexibility in use of the building. An increase in cooling load should be taken into account. This can be handled by a larger and better controllable building installation, but in practice it is very difficult to invest in an far more expensive installation, which in the near future seems oversized. An alternative could be cooling due to natural ventilation. To include the possibility for natural cooling gives more flexibility in future building use and will prevent major overheating problems.

6.2.3.5 Night cooling

Besides the admittance of solar radiance, accumulation of heat is causing high cooling loads. Admittance of an certain amount of solar radiance and other heat sources is less of a problem as long as the same amount is extracted over the same period of time. A significant problem in heating up of buildings is the dormant warming of the thermal mass of the building. Thermal mass can be effective in keeping interior space cool during daytime, but if the thermal mass is not able to cool down in time, it will radiate absorbed thermal energy (heat) to adjacent interior space, in addition to new heat gains, increasing internal temperature even further. Moreover, an employee or student will start its day in an already warmed-up building, where one would expect a fresh start in the morning. A night-time cooling of the room in proportion to the cooling of the external air will be unconsciously expected.

Ventilation at a possible high ventilation rate outside office hours, referred to as night cooling, can significantly reduce the active cooling load of the Main Building high rise. Night cooling is an effective and suitable solution for multiple reasons:

- The total thermal mass of the building, mostly related to the structural floors, can be beneficial in reducing active cooling load. However, when accumulated heat cannot be expelled effectively, the thermal mass can have a negative effect, making it more difficult to cool the building during office hours due to additional radiation of heat, which will increase active cooling load;
- To make the best use of existing thermal mass, structural floors should be in open contact with interior space. Lowered ceilings or other coverings which cause an layer of stilled air or block radiation should be avoided;
- Especially when thermal differences are not that large , outside air is just a slightly cooler than inside air, a large ventilation rate makes all the difference in being effective or not. The slender shape of the high rise allows a large and easy admittance of outside air;
- The high rise is lifted from ground level, reducing the risks of burglary;
- Night ventilation is most beneficial when thermal comfort is based on thermo regulative principles, as described in chapter 4.2.4., allowing a cool indoor temperature during the morning and a warmer interior temperature during the afternoon;

- Night ventilation is dependent on the ventilation capacity and controllability of the ventilation capacity of the façade. Ventilation grills avoid problems with birds and insects, windows should be able to be open ajar (*kierstand*).

6.2.4. Ventilation concept

The ventilation concept consists of an central mechanical outflow of air and an decentral natural inflow of air.

6.2.4.1. Air outflow

high rise has a slender shape which results in a high contact surface, making it more easy for a large and deep air inflow. However, reach of natural ventilation is limited. A central positioned mechanical outflow of air can create underpressure, 'pulling' air inflow deeper into the building to ensure the ventilation of spaces which are positioned further away from the façade.

Outflow of air can occur naturally or mechanically via the façade or via a central naturally or mechanical outflow system. However, when outflow can only occur via the façade, reach is limited and problems occur in closed of spaces or spaced positioned further away from the façade. Decentralized mechanical ventilation have a limited reach of approximately 6,0 m. , making an additional system necessary to ventilate inner floor space. A centralized outflow system can create under pressure in inner spaces, 'pulling' fresh air from adjacent spaces near the façade, ensuring the desired ventilation rate.

When naturally ventilation is used as outflow, control of climate conditioning is very limited, for example, the rate and amount of night ventilation cannot be controlled. Moreover, situations occur where exterior conditions do not generate an natural outflow, resulting in exceeded limits op tolerance of interior climate

As described in chapter 5.3.3, the existing structure of the high rise is most suitable for vertically placed installation shafts, facilitating a column of compartments over all floors of the high rise. Due to the thermal current, a natural draught can occur, causing the desired outflow of air above roof level. When ambient environment does not allow natural outflow, when temperature difference are too small to cause a strong current, an auxiliary mechanical system will take over to ensure the right rate of outflow. When this 'chimney' is dimensioned proportionately in width and difference in height is sufficient, the mechanical outflow is only needed occasionally. A combined system of central natural and mechanical outflow is most suitable solution for the high rise. The outlet of air is therefore centrally organized.

6.2.4.2 Air inflow

Air inflow consists of basic, continuous ventilation, ensuring interior air quality, and intensive, purge ventilation (*spuiventilatie*) on demand, providing flexibility in building use and comfort. Both types of natural façade ventilation can be achieved using openable windows and/or grills.

Continuous ventilation

Different performance criteria for façade design, such as *Frisse Scholen*, state that the façade, as well when continuous ventilation is active, should have an sound insulation of 20 dB.

Compared to windows, grills have the advantages of a better sound insulation, using integrated devices such as silencers or *suskasten*. Compared to openable windows, windows grills provide the advantage of lower total costs and the ability of sound insulation, using *suskasten* or filters [53].

- The façade will have a capacity of 1,75 $dm^3/s/m^2$ by means of sound insulating grills.

Purge ventilation

Intensive ventilation provides flexibility in building use by handling exceptional cooling peaks, when more people are in the room at special events or change of programmatic function, controlled night ventilation if external conditions allow it and fulfilling the psychological need of a fresh stream of air in the room. Both windows and grills can be used for purge ventilation. Compared to grills, windows have the additional advantages that the effect of ventilation is more visible to users and therefore more appreciated and resulting in higher tolerance towards unpleasant draught and acceptable indoor temperature. Natural ventilation through openable windows in the façade is most optimal solution to provide intensive, occasional, ventilation.

According to *Frisse Scholen*, label A, a total purge capacity of 9,0 $dm^3/s/m^2$ will provide the desired quality for educational spaces. This capacity will be guideline to the design of the façade:

- The façade will have, in addition to the capacity of continuous ventilation, a capacity for purge ventilation of 6,25 $dm^3/s/m^2$ by means of openable panels or windows.

6.2.5. Integral Performance

The proposed ventilation concept for the high rise of the Main Building performs best regarding the performance criteria described below:

1. *Energy performance*

As described in chapter 5.1.7, mechanical ventilation of buildings causes 25% of total energy use on the campus. Increasing efficiency of ventilation will result in potential large energy savings. Indirectly, despite efficient heat and cold recovery units are available, increasing ventilation rate can cause a higher energy use due to thermal energy losses resulting from the outlet of cool/warm air. This can cause a contradiction, increasing the ventilation rate will support a better quality of interior climate, but will cause additional energy use resulting in higher operational costs. However, using natural ventilation could as well result in a lower cooling and ventilation load. If ambient environment allows, the inlet of outside air could be used to cool and ventilate interior space, such that no mechanical ventilation or cooling is needed.

Although the balance between energy savings and losses need to be studied in more detail, natural inflow generates relevant advantages on energy performance. Natural inflow via the façade saves significantly on mechanical ventilation but increases thermal energy load because heat and cold recovery is not possible. However, the relevancy of a heat recovery is very limited and thermal energy recovery requires electricity as well. Increased thermal energy losses are reduced when intelligent control system is applied and natural ventilation can be used as ‘free’ cooling during a large period in the year, reducing the active cooling load greatly. Moreover, natural inflow has a positive effect on the balance in energy use, reduces the amount of electrical energy for cooling and ventilating and will increase the use of thermal energy which is required for heating.

2. *User value*

Natural inflow of air through the façade provides the highest amount of user value. In addition, natural ventilation enhances the experienced contact between interior- and exterior. Natural ventilation provides a high amount of user comfort and tolerance, while energy costs for ventilation stay low, making a high air quality more feasible.

Possible discomfort due to natural ventilation via the façade are downdraught via the façade and uncontrollable draught due to large thermal differences between in- and exterior. Downdraught can be largely avoided using higher quality of glazing with high insulation values and due to avoiding free heights larger than 2,5 m. of glazed façade elements. [53]

3. *Material efficiency*

Natural ventilation through the façade reduces the need for air ducts, inlets and other related installations. However, the relevance of material use for these building installations is minimal.

4. *Cost efficiency*

Natural inflow of air saves greatly on electrical energy use. Thermal energy losses are less significant due to the surplus of heat on the campus. Moreover, investment costs can be saved because no additional distribution system, including ducts, valves and fans, is needed for air inflow.

Openable grills or panels cost less than openable windows. [47] This can be an important aspect when considering panels or windows for purge ventilation.

6.2.6. Conclusion

The Main Building high rise is most suitable for a central organized outflow of air. Air outflow will be generated using the draught created by thermal currents, using existing vertical installation shafts in the building. When external circumstances do not generate enough natural draught, a mechanical auxiliary outflow will provide the necessary draught.

Air inflow, when combined with a central controllable outflow, is done by means of natural ventilation via the façade. The air inflow will be automatically controlled, by means of opening and closing façade openings, based on interior CO^2 concentration and exterior temperature. The desired ventilation capacity of the façade will be achieved twofold, using grills for continuous ventilation, capacity of 1,75 $dm^3/s/m^2$, and openable panels or windows, with an capacity of 6,25 $dm^3/s/m^2$, for purge ventilation.

The performed study has resulted in a most beneficial climate installation concept, consisting of a ventilation concept and a heating/cooling aspect. When intelligent controls are enabled, natural ventilation has the potential to save significantly on annual active cooling load and dependency on mechanical ventilation. In addition to savings on (operational) costs and energy, the most significant argument of the proposed design is that a well, natural, ventilated educational building makes interior spaces more healthy and pleasant for occupants. The design distinguishes itself from alternatives in its ability to facilitate an increased study and work efficiency, which are the core-business of the university.

6.3. Sunlight regulation

6.3.1. Motivation

A major function of the facade is to regulate sunlight admittance to the building. Sunlight can cause high cooling loads but might be a welcome source of heat during colder periods as well. Moreover, sunlight can cause comfort problems, such as glare. Regulation of thermal energy and comfort are two separated phenomena. A device used to reduce comfort related problems is referred to as a light regulation system. A device used to regulate the thermal energy for solar radiance regulation device is referred to as sun regulation.

As a study performed by TNO shows, integrating light regulation and sun regulation system in one system often gives poor results. For example, during wintertime, glare problems often occur when the provides heat caused by solar radiance is most welcome. Lowering a sunscreen removes the glare problem but blocks daylight entrance and causes a higher heating load as well. More suitable would be a semi-transparent interior light screen which scatters the direct radiance but does not repel incoming heat and daylight. A light regulation system is always needed, independent of the addition of a sun regulation system.

As aforementioned in chapter 5.1.8, sunlight radiance can be divided in diffuse, indirect solar radiance and direct solar radiance. Over 60% of total solar radiance is diffuse, making devices which only block direct solar radiance less effective in terms of thermal energy savings, but allow a higher entrance of light, increasing visual comfort and reducing need for artificial light. Therefore, when comparing different alternatives on their energetic performance, a trade-off between sometimes contrasting aspects needs to be made, based on integral performance criteria, as formulated in chapter 4.

6.3.2. Basic principles

There are many different systems to regulate thermal energy of solar radiance. Each system has different characteristics and have a balance in providing user value and reducing thermal energy load of the building. This study focusses on internal sunshading devices and external sunshading devices, both mainly screens or lamellae, and compares these two alternatives with fixed coatings on glazing. For an extensive overview of available systems, different studies are available. [54, p. 170]

Different techniques are available to regulate sunlight. However, most significant in early stage of the project is to estimate if a sunshading device would be beneficial and which type of glazing would be most suitable. Therefore, three aspects are compared on their integral performance:

1. Fixed on glazing. There are many techniques to adapt solar radiance transmittance of glazing. Fritting, foils, prints, integrated lamellae in cavity and coatings are widely available. Most common and promising are spectral selective coatings, which are dampened on the inner side of the external pane of double (or triple) glazing. The coatings are permanently fixed on window panes and only admit a certain light

spectrum, resulting in a difference in light transmittance (LT) and total energy transmittance (g-factor or ZTA). General aim is to block infra-red spectrum and allow visual light. Currently, highest performance of these coatings is to allow around 60% of light and only about 27% of total thermal energy through. The spectral selective coating is a thin metallic layer, making the glazing appear bluish, greyish or greenish which can have a large influence on the exterior appearance of the façade. Advantages and disadvantages are given in figure 6.7.;

HELPFULL	HARMFULL
Strength - Repels solar energy up to 75% and 60% light admittance - Almost no operational costs	Weakness - Green/greyish colour instead of clear glazing
Opportunity - 'Smooth' appearance of facade	Thread - Non adaptable, reducing yearly performance by repelling heat and daylight in colder/darker days as well.

Figure 6.7 Glass coating principle

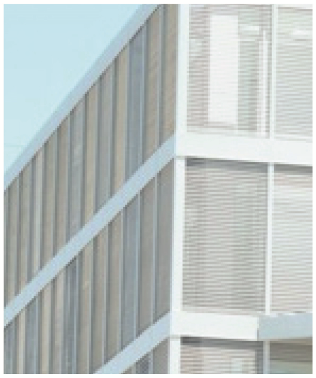
2. Internal sunshading. internal sunshading is comparable to external sunshading except for the positioning. Positioned behind on the inner side of the façade, internal sunshading performs less in repelling solar radiance but requires less investment and operative costs. Appearance might be another reason to apply internal screens. For this study, the characteristics of a common market-available products are considered. Advantages and disadvantages of an internal sunshading device are given in figure 6.8.;

HELPFULL	HARMFULL
Strength - Repels direct sunlight average - Adaptable over time - High accessibility	Weakness - Average (operation) costs - Less effective with coated glazing than non-coated glazing
Opportunity - Clear glass is possible, offering better quality daylight (less green-/greyish) and contact in- exterior - Low impact on expression facade	Thread - Not the same as light regulation - High risks on malfunctioning, causing disturbance (in appearance and work environment)

Figure 6.8 Internal sunshading principle

3. External sunshading. External sunshading is mounted on the exterior surface of the façade. The system exist of a motor to adapt the position of the shading, control system (integrated with building management system) and some sort of shading

screen or lamellae. The lamellae can be integrated in the façade and need some sort of frame or guidelines for fixation. For this study, the characteristics of a common market-available products are considered. For example, internal sunshading can consist of an metallic foil (which can have a g-factor up to 0,05 and still be translucent) or a coated fabric (g-factor up to 0,25 is possible) [55]. Advantages and disadvantages of an internal sunshading device are given in figure 6.9.;



HELPFULL	HARMFULL
Strength - Repels direct sunlight best - Adaptable over time - Active untill windpower 7-8 Bft,	**Weakness** - High (operation) costs - High rise gives low accessibility
Opportunity - Allow entrance of 'free' heat during colder days - Clear glass, offering better quality daylight (less green-/greyish) and contact in- exterior	**Thread** - High risks on malfunctioning, causing disturbance (in appearance and work environment)

Figure 6.9 External sunshading principle

6.3.3. Intelligent control system

The performance of a sunshading device is only as good as its control. Main advantage of dynamic sunshading is its dynamic performance, allowing adaption to daily circumstances. [55] A study performed by TNO, evaluating different types of devices and different control strategies for a group office in the Netherlands, as shown in figure 6.10, shows different significant results. [8]

- Manual control of sunshading might result in an increase of total energy consumption compared to having no sunshading device at all: building occupants will let sunshading screens down when they feel it is too warm, but this will often be too late to be efficient and pulling screens up again is often forgotten, increasing the need for artificial lighting;

- Automatic control of sunscreen (note: light regulation device should be manual) devices increases efficiency greatly. Control should be based primary on presence detection. Furthermore, adapting to the amount of external insolation results in an effective control strategy. A control strategy could be based on an insolation of 200 W/m^2 or 350 W/m^2 façade surface. Activating sunshading only at higher insolation levels results in a lower total energy load;

- Screens perform better than lamellae or blinds;

- Additional manual light regulation is needed for optimum comfort and energy use.

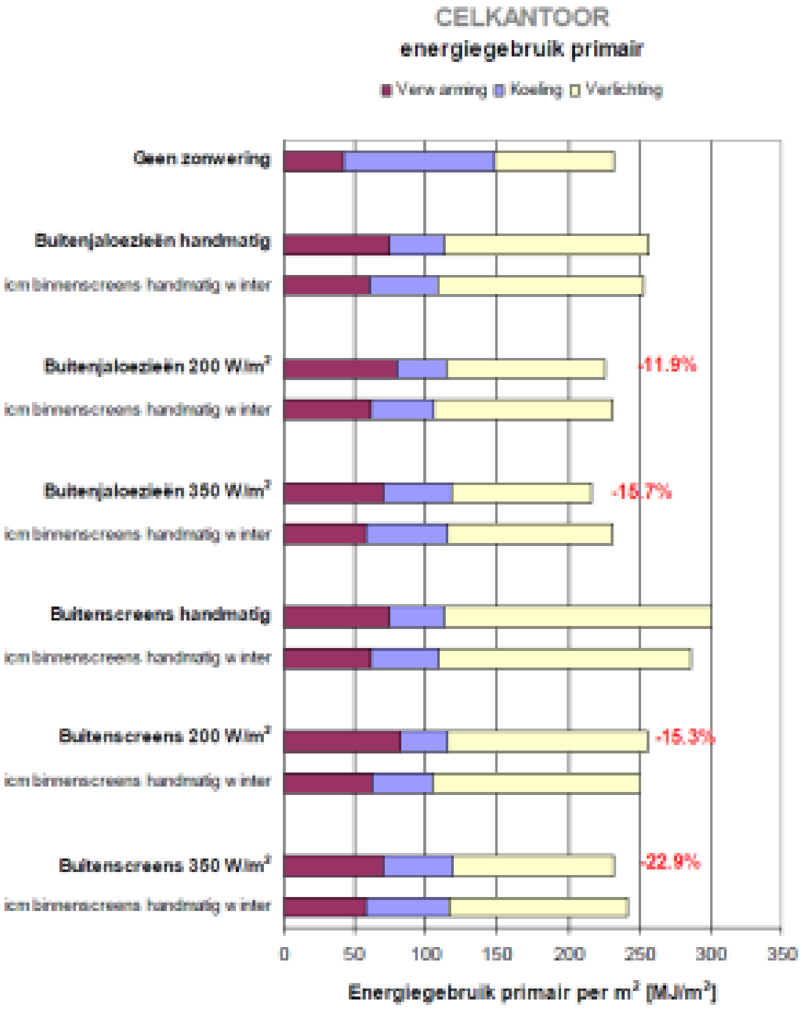


Figure 6.10 Energy use of standard office in the Netherlands, source: TNO [8]

6.3.4. Conclusion

A difference is made between sun regulating devices, repelling heat, and light regulating devices, improving visual comfort. Light regulation devices are manually controllable and considered to be necessity and part of any façade system. There are many different ways to regulate solar radiance. Most common and part of this study are fixed spectral selective coatings on glazing, internal sunshading and external sunshading. Sunshading devices are dynamic and only as good as its control system. Moreover, a trade-off needs to be found between artificial lighting load and thermal energy load. Based on research, the best in total performing sunshading systems are screens, automatically controlled, active at insolation level of 350 W/m^2. This type of system can be combined with manual controllable light regulation, a system which is common in high rise projects. [55]. To compare the energetic performance of interior and exterior sunshading systems with passive glazing coatings, three criteria are regarded: light admittance, thermal energy savings, operative costs;

6.4. Glazing

6.4.1. Motivation

The façade of the Main Building can be mounted with different type of glazing, altering the performance of the façade during both cooling and heating season. For example, triple pane glazing has a higher insulating capacity and lower solar energy transmittance compared to double pane glazing, but this higher performance might not be desirable throughout the whole year, even give problems with accumulating heat, or the effect might be very small and therefore not worth the extra investment.

Despite technical improvements, glazing is still causing the majority of energy flows in the façade. The thermal transmittance of glazing tends to be much higher than that of the adjacent opaque façade elements. Modern technologies make a far lower thermal transmittance possible (in the order of 0.15 $W/m^2/K$ for opaque elements, compared to 0,4 $W/m^2/K$ for top-edge triple glazing), and of course there is no heat accumulation due to solar radiation. The advantages of a more open façade can be expression, visual comfort, higher daylight admittance and contact between in- and exterior. From aforementioned study (C. E. Ochoa, et al., 2012) an near-optimal range of window-wall ratio (WWR) is studied for different orientations, finding a balance between the quality of daylight admittance and energy efficiency. This WWR-ratio is adapted for the rest of this study. From the perspective of energy use, the (reduced) exchange of energy flows between in- and exterior climate does not need to be a negative aspect. Net interior energy gain might be desirable in winter, or even on a summer-morning to reduce mechanical heating or cooling. The period of time is important for determining the desired energy gain. The net energy gain during working hours might be more relevant than the net energy gain on a complete day, including the cooler periods of a day. Advantages of a certain type of glazing, such as a high insulating capacity, during the heating season might give problems in cooling season, 'trapping' heat. Energy flows, of different types of glazing and during different periods and timescales, need to be studied in order to estimate which type of glazing is best suited for the different façade orientations of the Main Building. The building skin should reduce the energy load of the building climate system. This means to effectively use or reduce influences from exterior climate and considering internal heat gains of the human body and apparatus. In terms of energy flows, a constant balance in energy gain and loss generates the lowest energy load of the climate system. This balance should occur on a short timescale. An energy balance on annual basis could still demand a high interference of the climate system in order to keep a pleasant indoor climate. Therefore, the balance should be almost constant, with the allowance of small deviations. In order to strengthen this balance, glazing should minimize the misbalance between in- and outflow of energy while considering the internal energy gains.

6.4.2. Smart glazing

Instead of glazing with fixed, passive, coatings, 'smart' glazing with a dynamic performance can be mounted in the façade. Smart glazing has altering reflectance and/or transparency properties and can adapt to changing demands and weather conditions, potentially saving significant energy, providing comfort and possible desired esthetical expression. However, these innovative products are promising, but not yet market ready, either due to product immaturity or to too high investment costs and/or too small revenues. [47] Product immaturity can be a low period of guarantee or available product size. Dynamic glazing can be both electrochromic or thermochromic glazing. Products can be found on [56] and [57].

Currently, due to technical improvements, costs are dropping rapidly and performance is increasing. [58] However, production costs, varying from at least 700 €/m^2 for electrochromic glazing and 400 €/m^2 for thermochromic glazing (for comparison: top-edge coated glazing cost around 150 €/m^2), are still too high and/or revenues too low, excluding dynamic glazing from further study.

6.4.4. Methodology

Six different types of glazing were compared on energetic performance, as shown in table 6.2. The applied methodology is a simple model, based on literature, in which the energetic performance of glazing for different European climates are compared [59]. In terms of energy flows, glazing can be characterized by two parameters: [59, p. 2]

- Firstly, the *total solar energy transmittance g*, which denotes the share of the incoming solar energy, which is converted into heat inside the indoor space;
- Secondly, the *thermal transmittance U* that describes how much heat is transferred through the glazing per square meter and Kelvin temperature difference between inside and outside;
- Moreover, investment costs (**€) are relev**ant. These differ greatly per type of coating. [47]Operational costs are considered to be equal between different types of glazing;
- and light admittance (LT, or *licht toetreding factor LTA*) are important aspects to determine which type of glazing offers highest performance.

The chosen types of glazing differ strongly: glazing A represents modern high insulating triple glazing, both cavities filled with krypton and a low emissivity coating. Glazing B, high performance insulating double glazing, argon and a spectral selective coating. Glazing C is conventional double glazing without any coating and a cavity filled with air. Glazing D is a single glazing with high reflective coating. Glazing E is top-edge performing double glazing and is the highest segment as offered by glazing companies. Glazing type E is corresponding with glazing used in the high rise of adjacent Metaforum building.

Table 6.2. Glazing types

Type	Description	U [W/m2K]	g-factor (ZTA)	g/U (m2K/W)	LT (LTA)	Basic price (€) [60]
A Triple glazing	6-4-6 (argon); SG Climatop Ultra N	0,6	0,63	1,05	0,3	164.00
B Double, high performance glazing	6-12-4 (argon); SG Climaplus SUN	1,1	0,4	0,36	0,7	112,55
C Double glazing	6-12-4 (air); no coating	2,7	0,77	0,29	0,8	52,20
D Single glazing	6; SG Cool lite classic	5,1	0,28	0,05	0,2	unknown
E Double extreme performance glazing	6-12-4 (argon); SG Cool lite climaplus SK SKN 154	1,1	0,28	0,25	0,6	157,95
F Low emissivity glazing	6-15-4 (argon) climaplus Ultra N	1,1	0,63	0,57	0,8	71,20

6.4.7. Conclusion

To determine which type of glazing provides highest overall performance, performance criteria where defined. Six types of glazing are selected. The performance of smart glazing is promising but not yet market ready and excluded from further performance study.

Chapter 7: Façade performance study

7.1. Motivation

As outcome of problem analysis and literature study, different sunshading devices, ventilation concepts and glazing types provide possible advantages for the façade concept. To estimate the difference in energy savings and related cost savings of different façade design concepts, a model is composed using the software Virtual Environment, Intelligent Environmental Solutions, version 2012. Performance of different partial façade solutions are evaluated using the performance criteria as described in chapter 4.

7.2. Model description

7.2.1. Model location and climate

Since Eindhoven (51.4° N, 5.4° E) is not available for this study, the WEC climate database for Brussels, being most similar in geographical location (50.5° N, 4.8° E) is used to calculate building performance.

7.2.2. Model design

The model consists of a low rise, a table construction and a high rise. The shape of the table is imported using a Revit 2013 model and is designated as part of the building. The low rise is designated as adjacent buildings, being no part of the system.

The high rise consists out of 25 adjacent compartments, separated by interior walls including an opening with door. This organization principle is based on the concept as described in chapter X, simulating the situation with separated fire safety compartments of max. 1000 m^2 gross floor area. One compartment consists of two layers, separated by a flexible floor which is defined as being 50% open to resemble the link between both floor layers.

7.2.3. Model properties

Material properties are assigned as described:

- The concrete table is composed out of cast concrete. To thermally separate the table from adjacent compartments of the high rise, a top layer with an high insulating value (U=0,033 W/(m^2.K)) is assigned.
- The roof of the high rise is assumed to have an insulating value of U=0,27 and thermal mass (TM) of 200 kJ/(m^2*K).
- Each compartment consists of two floor levels, resembling the construction principle of the Main Building, and have uniform materialization. Opaque exterior curtain walls are assumed to be only 60 mm thick with high level insulation (U= 0,42) and low thermal mass (TM=20,0), resembling a light weight structure with modern insulation materials such as Kingspan K15. The exterior façade is assumed to be open with a window to wall ratio (WWR) different for each orientation (Openness North:70%, south 60 % , East and West 55%) and are based on literature study as described in chapter 4.2.3.

- Interior walls are composed to be 250 mm thick (U= 0,165; TM=17,16 :), assuming a fire delay of 60 min.. Included are two double doors, one for each floor level with U-value 2,2 each.

- Flexible floors (500 mm thickness) are assumed to have a light thermal mass, (U= 1,4;TM=17,2), 50% open to resemble the setbacks and connection between lower- and upperpart.

- Structural floors (500 mm thickness), vertically separating the compartments (U=2,30, TM=630) are assumed to be heavy weight and designed with a flexible top layer for system floors, including carpeting. Bottom is assumed to be concrete, increasing the active thermal mass of the floor slabs.

7.2.4. Internal cooling load

The internal cooling load is based on calculations and assumptions as described in Appendix L: internal heat gain and cooling load. The right amounts and time profiles are designed to match assumed user profiles.

7.2.5. Model validation

The model performance is significant in mutually comparing results of different type of facades and glazing, not to make a comparison between model results and other external models and or test installations. Since the study is predesign, no actual measurements are performed at the actual building. To get a better idea about model performance, the model performance is compared hand calculations based on weather data of the KNMI (2001-2007). As shown in table 7.1, calculations for insulation have a 12% deviation of simulated performance using the model. The model and hand calculations are based on different climate information. To determine if this difference in climate information causes the discrepancy, a comparison between temperature is performed as well.

Table 7.1 Deviation between model and calculations

Period of time	Data	Amount	%
Insolation June, 21st 24:00	Model (IWEC data, Brussels)	25,84	88,36
	Calculation (KNMI data, Eindhoven)	29,25	100
	Deviation	3,40	11,64
Temperature June, 21st	Model (IWEC data, Brussels)	11,67	71,25
	Calculation (KNMI data, Eindhoven)	16,38	100
	Deviation	4,71	28,75
Temperature June, 21st, 08:00-18:00	Model (IWEC data, Brussels)	13,70	71,41
	Calculation (KNMI data, Eindhoven)	19,19	100,00
	Deviation	5,49	28,59

7.3. Methodology

To determine the performance and priority of different partial solutions possible for the façade design, the performance of different types of glazing, sunscreen devices and ventilation concepts are mutually compared. The following steps have been taken:

- As a first step, 6 different types of glazing are compared on their performance;

- The performance of different configurations of internal and external sunshading, differentiating in control criteria, type of glazing and internal/external position, are compared;

- Best performing configuration of sunshading device is compared with best performing type of coated glass;

- Best performing sunshading device is compared with proposed natural ventilation concept;

- The performance of an addition of passive sunshading elements, in the shape of vertical fins, have been compared to dynamic sunshading and glass coating;

- Based on performance criteria, a priority of best performing partial solutions is chosen.

7.3.1. Performance criteria

Performance criteria are:

- thermal performance (savings on heating and cooling load). Thermal performance is based on total load, the sum of heating and cooling load, and the (in)balance between cooling and heating load. A balance is preferable for the ATES energy system on the campus, as described in chapter 5.1.7.;

- (Operational) costs;

- User value. Regarding user value, daylight admittance is most relevant for compared devices. Possible daylight admittance is not simulated with the model but is taken into account qualitatively;

- Efficient use of construction material. Addition of extra material or devices will always be regarded as a, all may it be almost not noticeable, negative effect on the sustainability of the building. For project 3, a Greencalc score is taken into account, as described in chapter 4.5.4. Greencalc score is partly based on material use.

Performance is measured on annual basis for working days (08:00-23:00) and full days (0:00-24:00). Moreover, daily performance for extreme cold and warm days are simulated to compare peak performance.

7.4. Glazing

Six different types of glazing, as described in table 6.2., are compared on thermal energy saving, costs, material use and light transmittance capacity.

7.4.1. Energy performance

The thermal performance of different types of glazing is mutually compared on the difference in total thermal load and the balance in cooling and heating load. Monthly averages are summed up to calculate the annual load. Total load is the sum of cooling and heating load. As can be seen in figure 7.1 , the total load of B and E is lowest, both 45% thermal energy use compared to glazing type D. Glazing type A, C and D cause a higher total energy load.

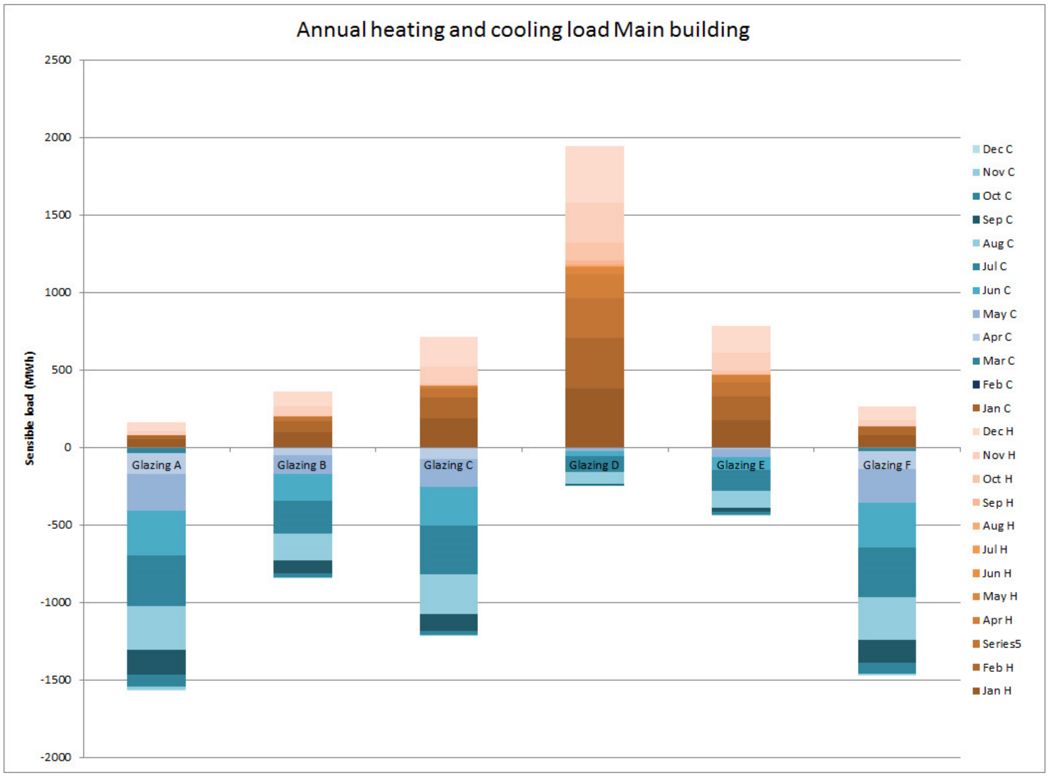


Figure 7.1. Thermal performance glazing

When looking at the balance between heating and cooling load, glazing type D, reflecting single glazing, has the largest imbalance, causing a far higher cooling load than heating load. Glazing type A (triple glazing) and F (low emissivity glazing) trap heat in the building and causes an high imbalance due to a far higher cooling load than heating load. Triple pane glazing reduces energy losses in cooler periods, but result in additional energy use in warmer periods, because of the trapped heat. [61] [38] Conventional double glazing, type C, performs most balanced. When looking at the glazing which cause the lowest thermal load, glazing type B and E, both are almost equally out of balance but in different direction. Since the ATES system already has a surplus heat, the performance of glazing type E is preferred. In addition to thermal energy savings, glazing type B allows a higher amount of daylight admittance, which will significantly reduce dependency on artificial lighting, resulting in further electrical energy savings. Moreover, artificial light always produces warmth, potentially resulting in additional savings in cooling load for glazing type B.

7.4.2. Operative costs

When comparing the costs of glazing types large differences in investment costs occur. As aforementioned, the building has a large façade surface and a small floor surface and volume. All types of glazing have equal, low, operative costs, which are ignored in the comparison.

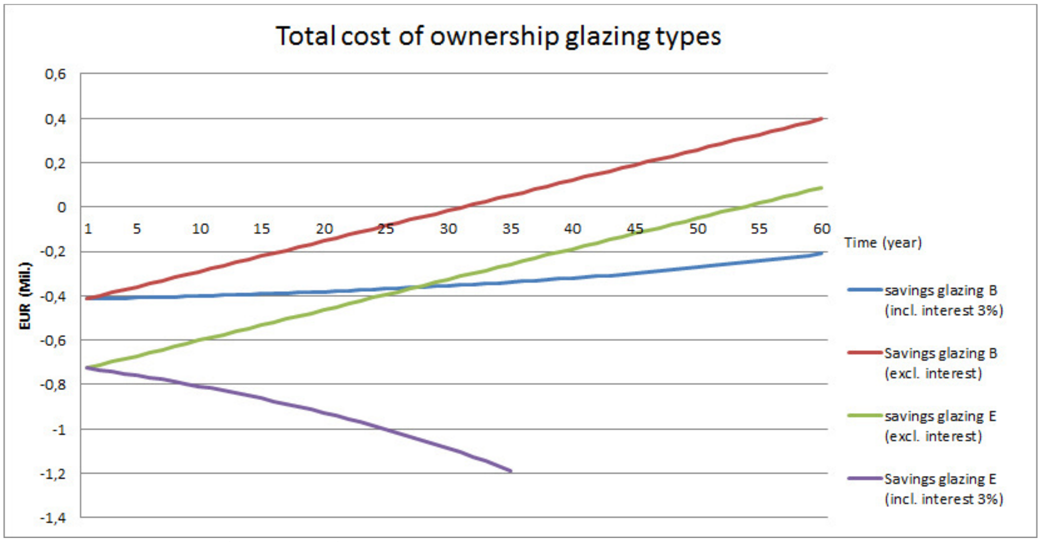


Figure 7.2. Total cost of ownership for glazing B and E

Investment costs and financial savings due to energy savings over time vary greatly for different types of glazing. Glazing E and B, which perform best on energy savings, are compared on total costs over time, as shown in figure 7.2..

When comparing annual costs and savings due to energy efficiency, the performance of different types of glazing are compared to conventional, standard double glazing. Excluding interests, both types of glazing will deliver in time a return of investment. Glazing type B has a significant lower investment cost compared to glazing type E and a payback time of about thirty years. Glazing type E will cause a larger additional investment cost of around 311.000 EUR compared to glazing B and will have a payback time of around 55 years, 25 years longer than type B. Moreover, it is questionable that the building will not be refurbished after 40-50 years. When interests are included, glazing type E causes annual losses. Glazing type B will have payback time which extends beyond 60 years. Based on cost performance, glazing type B performs best.

7.4.3. User value

Regarding glazing, thermal comfort ,due to downdraft and cold radiance, and visual comfort are most relevant. Thermal comfort is related to the insulation value. Glazing type A, triple glazing, will provide the highest thermal because the extra layer reduces cold radiance which can cause discomfort [61]. Glazing type B and E have both a high insolation value of U = 1,1 and will provide reasonable thermal comfort. Regarding visual comfort, clear glazing, type C performs best. The light admittance is most colour neutral and total amount of light admittance is highest. When comparing type B and E, glazing type B has a LT factor of 70%, which allows 17% more daylight admittance than glazing type E, which has a 60% daylight admittance. This is an significant amount. Furthermore, the light will be less greenish, greyish, dependant on the type of coating, compared to glazing type E. compared to glazing type E, glazing type B performs far better on visual comfort.

7.4.4. Material use

Glazing type D only has a single pane, using far less material than glazing type , B, C and E. Glazing type A has three panes, causing more material use.

7.4.5. Conclusion glazing

Solution	Description	comfort	cost	energy	material
A	triple glazing	+	-	-	-
B	high performance glazing	+	+	+	0
C	clear double glazing	0	0	0	0
D	Reflective single glazing	-	-	-	+
E	Extreme performance glazing	-	-	+	0
F	Low emissivity glazing	-	0	-	0

Six different types of glazing are compared on comfort, material use and energy performance. Glazing type B and E both perform the best on thermal energy efficiency. Although glazing type E results in a more preferred energy balance, costs are far higher, savings on artificial lighting are lower and especially visual comfort is greatly reduced. Glazing type B, conventional high performance glazing, performs well on energy efficiency, costs, and provided comfort. Overall, high performance glazing, type B performs overall best and has to be considered for the façade design.

7.5. Sunshading devices

The performance of sunshading devices depends on the type of glazing, positioning and the control criteria:

- To compare the performance of sunshading with the performance of coated glazing, sunshading devices are combined with both conventional double glazing and low-emission coating glazing, both cheap types of glazing which have a higher energy and daylight admittance, compared to high performance glazing, such as glazing type B.

- As described in chapter 6.3.3., different configurations of sunshading control can be applied. The performance of control criteria of activation when 200 W/m^2 (raise at 175 W/m^2) and 350 W/m^2 (raise at 300 W/m2) insolation reaches the façade are considered.

- The positioning of the sunshading device has a great effect on energy efficiency, appearance and operative costs. External sunshading performs better in repelling unwanted heat, but is more expensive and receptive for maintenance compared to internal sunshading. Moreover, external sunshading has a greater effect on the expression of the façade. However, this can be both be interpreted as positive or negative and is left out of the performance criteria.

- The performance of sunshading devices depends on which type of glazing is used. If the glazing is already coated, the effect of additional sunshading is less. Especially with internal sunshading, the coating of glazing influences the deflection of solar radiance, which can result in ‘trapping’ solar rays which results.

As a results, eight different configurations, as described in figure 7.3.,of sunscreen devices are distinguished of which monthly and annual performance are mutually compared on integral performance and compared to a partial solution with low emissivity glazing (glazing type F)and no sunshading device.

7.5.1. Energy performance

The thermal performance of each glazing type is given in figure 7.3. Glazing type F with external sunshading (200 W/m^2) results , as expected, in the highest total energy savings. Second best is glazing type C with external sunshading (200 W/m^2) and glazing type F with no sun shading device. As aforementioned in chapter 6.3.3., only activate sunscreens when insolation is above 350 W/m^2 results in a higher amount of daylight entrance and lower total energy use due to savings on artificial lighting.

A more complex performance simulation is needed to estimate interrelated savings on artificial light, comparing passive coatings and dynamic sunshading devices. When comparing sunshading devices with passive coatings, especially heating load is far less. Sunshading devices are dynamic and can be raised in colder periods, when the solar heat is welcome. Coatings are passive, blocking solar radiance even when heating is wanted. However, regarding cooling, sunscreens always have to make a trade-off between being active, and reducing daylight admittance greatly, or stay passive and allow solar radiance to enter. This results in large cooling loads.

When regarding only devices controlled with the criteria of 350 W/m^2, glazing type F with external sunshading (350 W/m^2) performs best. When regarding only internal sunshading devices with control criteria of 350 W/m^2, both glazing type F (total 1634 MWh) and C (total 1670 MWh) perform almost equally. Glazing C results in the best balance, almost equal amount of heating and cooling load.

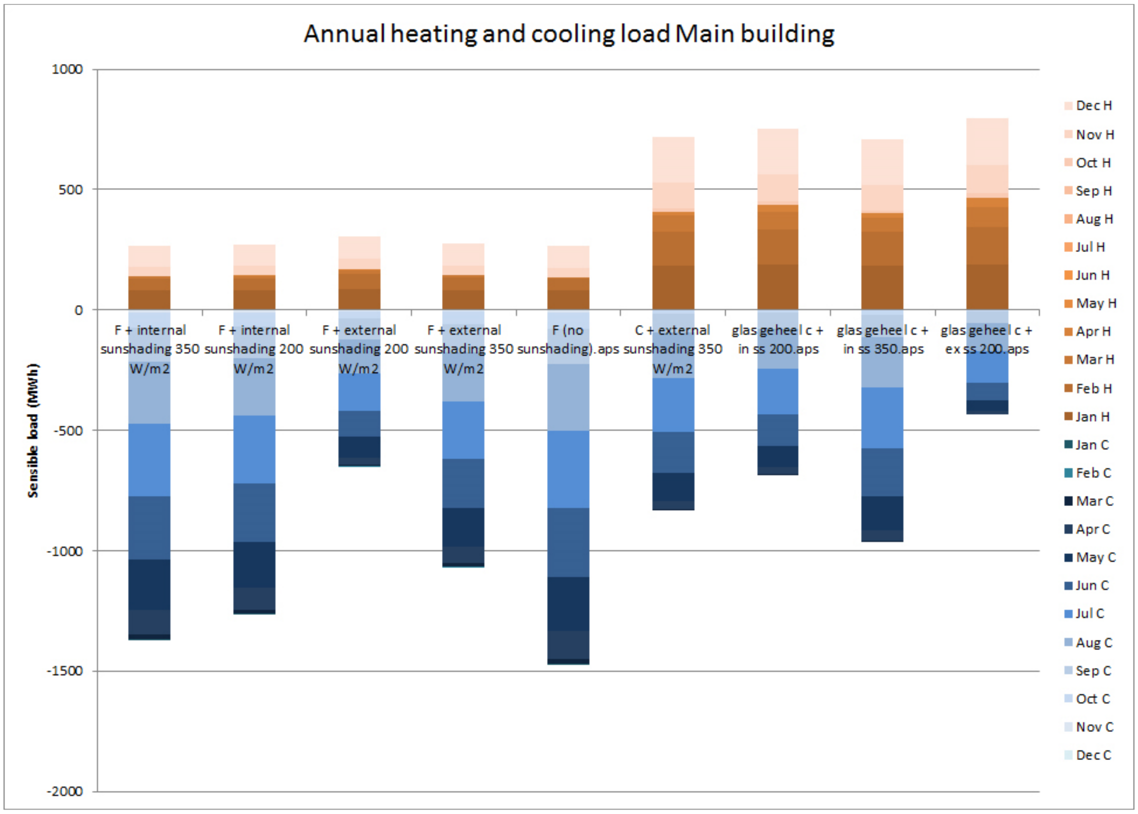


Figure 7.3. Thermal performance sunshading devices

7.5.2. Total cost of ownership

Unlike passive coatings on glazing, sunshading devices have high operational costs. Moreover, additional risks due to failure of mechanical parts or damage due to unexpected wind loads have to be considered. However, external sunshading have been greatly improved over time and when proper dimensioned can withstand high wind speeds. [55] A full replacement is assumed every 20 years.[5] As shown in table 7.2, investment and maintenance costs are considered in addition to thermal energy savings over time.

Table 7.2. Overview costs sunscreen devices

sunshading	**Screen type**	**dimen-sions (m)**	**size (m^2)**	**lifetime (year)**	**Cost screen (€)**	**Control device (€)**	**Total cost/ m^2**	**operative cost (€/p.p./y)**	**operative costs (€/m^2/y)**
External	Screen (SOMFY)	1,2 * 1,5	1,8	20	238,89	250	137,36	7	4,67
Internal	screen (VEROSOL, silverscreen)	2,35 * 3,20	7,52	20	137,36	250	73,36	1,4	0,93

The total cost of ownership of glazing type C including internal sunshading (350 W/m^2) and glazing F with external sunshading (200 W/m^2) are compared with glazing B with no

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[5] Based on experience of TU/e operational sunscreen devices

sunshading device. As shown in figure 7.4, Glazing C with internal sunshading performs better in costs and savings compared to more glazing B with external sunshading (250 W/m^2). However, for both systems, costs over time are far higher compared to solely glazing B with no sunshading device. Based on cost performance, more expensive glazing, glazing B, with no sunshading performs better than less expensive glazing with intelligent sunshading devices.

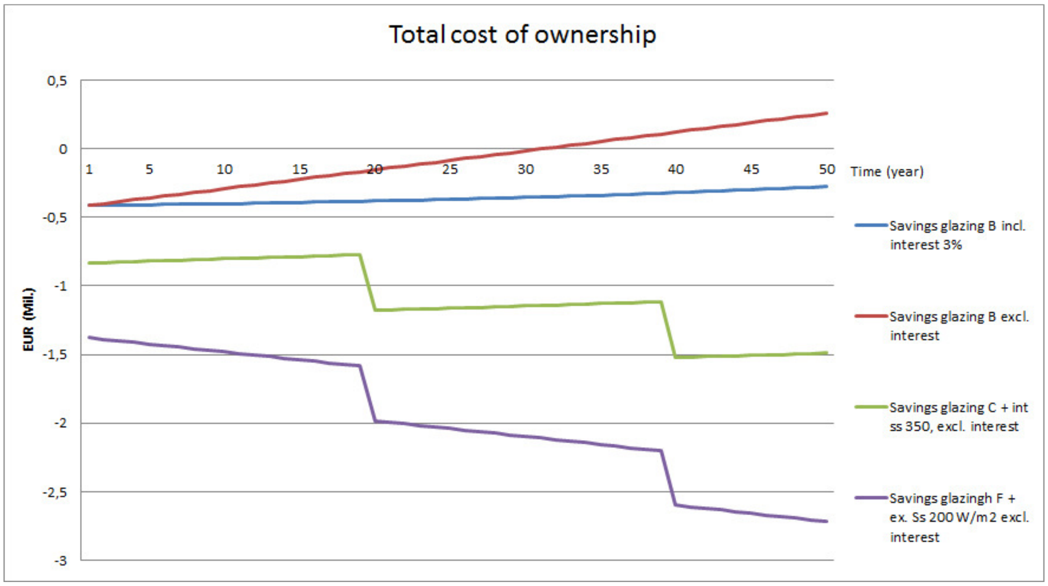


Figure 7.4. Total cost of ownership of different glazing and sunscreen devices

7.5.2. User value

Sunshading device, unlike light regulation devices, can have a negative effect on provided visual user comfort. As aforementioned, activation sunshading at 200 W/m^2 insolation results in a low daylight admittance which, in addition to energy load of artificial lighting, results in less visual comfort. Therefore, sunshading devices with a threshold of 350 W/m^2 perform less than when controlled with 200 W/m^2 as activation criteria.

When activated, sunscreens repel a large amount of daylight, resulting in a need for artificial lighting on warmer days. Coatings diminish light entrance for a smaller amount, but during the complete year, most important during cast sky and colder days. Further research is needed to estimate the effect and compare performance.

7.5.3. Material use

Compared to coatings, any sunshading device is an addition of material. External sunshading has to withstand heavy wind loads, requiring more robust material use for cabling and screens. Internal sunshading can be dimensioned light and be composed out of materials which do not need to withstand external hazards. From the perspective of material use, internal sunshading is preferred over external sunshading.

7.5.4. Conclusion sunshading devices

Internal sunshading devices, activated at an insolation level of 350 W/m^2 provide the best overall performance, as shown in table 7.3.

Table 7.3. Integral performance sunshading devices

Solution	Description	comfort	cost	energy	material
A	F + internal sunshading 350 W/m^2	+	0	-	-
B	F + internal sunshading 200 W/m^2	-	0	-	0
C	F + external sunshading 200 W/m^2	-	-	+	0
D	F + external sunshading 350 W/m^2	+	-	0	-
E	F (no sunshading)	0	+	--	+
F	C + external sunshading 350 W/m^2	+	-	0	-
G	C + internal sunshading 200 W/m^2	-	0	0	0
H	C + internal sunshading 350 W/m^2	+	0	0	0
I	C + external sunshading 200 W/m^2	-	-	+	-

However, when comparing sunshading devices with fixed coatings, the following aspects have to be taken into account:

- Thermal energy savings due to internal sunshading are comparable but slightly less when compared to thermal energy savings caused by coatings;
- However, to compare the effect on daylight admittance by both solutions, further study is needed. Coatings reduce daylight admittance by 20-35% compared to clear glazing. Dynamic sunscreens reduce daylight admittance when active and remove exterior view. Further research is needed to give a better insight in this topic;
- Coatings cost far less over time;
- From perspective of material use, sunshading devices are additions compared to coatings;
- From the perspective of comfort perspective, it is difficult to estimate the difference in performance. Further research would be needed to clarify this aspect.

Table 7.4. Integral performance coating compared with sunshading device

Solution	user value	cost	energy	material
Glazing with reflective coating (type B)	0	+	+	+
Clear glazing (type C), internal sunscreen internal sunshading 350 W/m^2	0	-	-	-

The integral performance of the best performing glass coating and sunshading device is shown in table 7.4. As a conclusion, coatings perform overall better than sunshading devices. Glazing with high quality coating offers a better integral performance compared to clear glazing with dynamic sunshading. [47] When budget only allows a certain investment, coatings would be more effective and provides a higher total value.

7.6. Intelligent ventilation

Natural ventilation through the facade has the potential to replace the inflow of mechanical ventilation and to reduce active cooling load. However, when ambient temperature is too cold or warm, natural ventilation will cause an increase of internal thermal load. An intelligent control system reduces energy losses. Based on interior air quality and ambient temperature, the ventilation rate can be adjusted to guarantee desired air quality while reducing thermal load. Moreover, increasing the ventilation during night time up to 9,0 $dm^3/s/m^2$ can cool the building, reducing active cooling load.

The performance of natural ventilation is determined by several aspects:

- Ventilation can be controlled manually or automatically, using exterior (ambient temperature) or interior (CO^2 concentration) parameters. The model takes only ambient temperature into account as parameter for automatic control;

- Moreover the flow rate influences the exchange of thermal energy.

- The possibility to include night cooling. Night cooling by means of ventilation is only possible when windows are automatically controlled. Due to the size of the façade and the need for adaptability, manual control of façade openings for night cooling is not an realistic option and will not be included in this study.

- Difference in flow rate influences the exchange of thermal energy and therefore the energy performance. A flow rate of 1,75 $dm^3/s/m^2$ is according to high level standards of *Frisse Scholen* label A. A flow rate of 0,88 dm3/s/m2 provides lesser quality of interior air but will save energy losses when ambient temperature is too warm or cold and is still meeting the requirements of *Frisse Scholen* label C. When increasing the flow rate to, for example, 3,0 $dm^3/s/m^2$, will result in high energy losses and will likely cause draught related comfort problems. Increasing the ventilation capacity to 9,0 $dm^3/s/m^2$ might be efficient for night cooling. Differentiation with ventilation rates influences comfort and energy efficiency.

The performance of intelligent ventilation is compared to the performance of intelligent controlled sunscreen device. To narrow significant down possible partial solutions, the difference in performance of four alternatives are compared:

A. High performance glazing, no intelligent ventilation device and no intelligent sunscreen device

B. High performance glazing, intelligent sunscreen device but no intelligent ventilation

C. High performance glazing, intelligent ventilation 3,0 $dm^3/s/m^2$ during daytime only

D. High performance glazing, intelligent ventilation (1,75 $dm^3/s/m^2$; 9,0 $dm^3/s/m^2$ night cooling)

7.6.1. Energy performance

Different control criteria for intelligent natural ventilation are compared to the energy performance of intelligent sunshading and plane high performance glazing. The potential energy savings of intelligent ventilation are related to its control criteria. To improve energy performance, within the constraints of comfort criteria, ventilation rate can be adapted based on internal need and outside temperature. When temperature is too cold or warm, resulting in high energy losses, the ventilation rate can be reduced to 0,88 $dm^3/s/m^2$. When exterior temperature can be used to positively influence interior climate, reducing active thermal load, ventilation rate is doubled to 1,75 $dm^3/s/m^2$. During night hours, the ventilation rate can be increased up to 9,0 $dm^3/s/m^2$, which is the maximum capacity of purge ventilation of the façade.

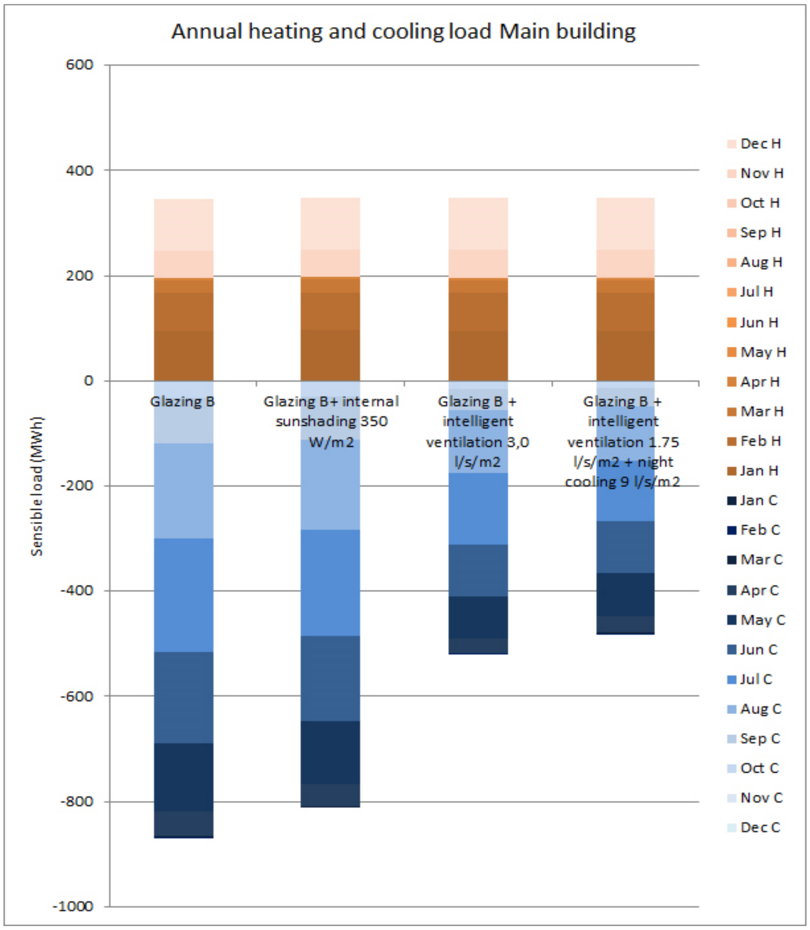


Figure 7.5. Thermal performance ventilation concept

The thermal energy efficiency of all four solutions is given in figure 7.5 and results in following conclusions:

- When comparing the performance of four alternatives, solution D performs best, reducing thermal energy use, mostly cooling load, by 32% compared to solution A, plane glazing B;
- Sunshading devices reduces thermal energy only by 5%;

- A large ventilation rate, only during daytime reduces thermal energy by 28%;
- Moreover, intelligent ventilation does not alter light admittance. Despite sunscreens are only activated at 350 W/m2, it will always reduce daylight admittance, which will result in an increase of energy used for artificial lighting.

Comparing alternative C and D, the difference is made due to the use of night ventilation. Night ventilation has the potential to greatly reduce the cooling load compared to situation A, with only high performance glazing.

- Unlike manual control, automatic control allows the use of night ventilation, reducing cooling load greatly;
- Automatic control allows the adaption of ventilation rate during daytime, temporary lowering the ventilation rate to increase energy efficiency;
- Despite a higher ventilation rate, C does not result in higher energy savings compared to D. option C provides no other benefits and will not be included for further study;
- In addition, option A, B and D will allow more daylight entrance when insolation is high, and sunscreens would be active. This result in lower use of artificial lighting, saving additional energy;
- Option D performs best in overall energy efficiency.

7.6.2. Cost

To determine costs related to an intelligent ventilation system, a comparison is made with the costs related to intelligent sunscreen devices. Costs are given in table 7.5. Assumed is that the initial invest is equal. Costs for internal sunscreen device are related to the cost of motor and actuator device, control device and screens. The costs for motor, actuator and control system for ventilation system are assumed to be approximately equal. Cost for additional openable windows are assumed equal to the costs of the screens.

Replacement time is equal as with sunscreen devices. However, costs are assumed to be lower since the windows do not need replacement, only the motor and actuator system. Replacement costs are assumed 50% of the replacement costs of sunscreen devices.

Table 7.5. Overview costs ventilation device

solution	**device**	**dimensions**	**size (m^2)**	**lifetime (year)**	**replacement (€)**	**device (€)**	**control mech. (€)**	**cost/m²**	**operative cost (€)/p.p./y**	**operative costs (€)/m2/y**
External sunshading	Screen + control	1,2 * 1,5	1,8	20	119,45	238,89	250	137,36	7	4,67
Internal sunshading	screen + control	2,35 * 3,20	7,52	20	68,70	137,36	250	73,36	1,4	0,93
Intelligent ventilation device	Control + actuator	-	-	20	34,34	137,36	250	73,36	1,4	0,93

In addition, 25% of total electricity use on the TU/e campus is caused by mechanical ventilation. In addition to financial savings due to thermal energy savings, an intelligent ventilation device would reduce operative costs when compared to sunscreen devices. By obviating a mechanical air supply, electricity costs for air circulation can be reduced. To give an estimation, alone with a 2.5 fold air change per hour in offices, provided by a central mechanical ventilation plant, roughly 15-25 kWh of energy will be consumed per square meter of ventilated floor area per year to power the fans. The proposed ventilation concept would only need mechanical outflow, assumed to be half of the energy load (12,5 kWh/m^2/y [45]). This is equivalent to about 0,96 €/m^2 per year. Assuming a total floor surface of approximately 26.395 m^2 (50% use of flexible floors), this results in energy savings of approximately 25244 €/y in addition to thermal energy savings, when comparing the ventilation device with other façade additions which do not contribute to ventilation savings, such as sunshading device.

The cost over time for option A, B and D are given in figure 7.6:

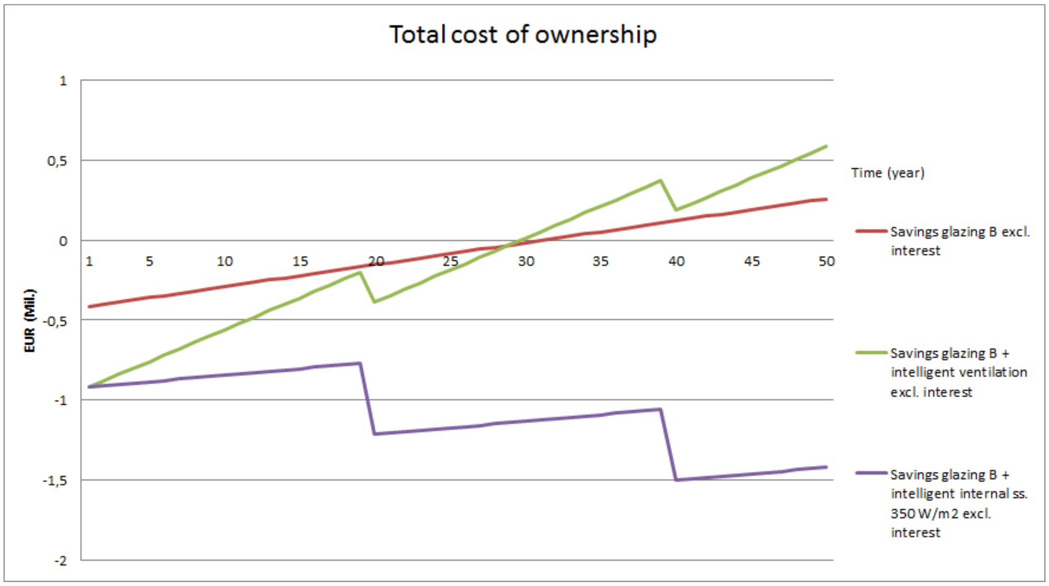


Figure 7.6. Total cost of ownership ventilation device

- Solution D, glazing with intelligent ventilation device gives the most positive total cost of ownership. Annual cost savings due to thermal energy savings are slightly better compared to solution A. However, additional energy savings due to natural ventilation are significant. Compared to sunshading devices, the ventilation concept has lower replacement costs, resulting in an estimated payback time of less than 30 years.
- Solution B, glazing with internal sunshading device results in an increasing loss over time. Costs over time are higher than potential savings. This is mainly caused by high replacement costs every 20 years, including new screens and motor device;

7.6.3. Material use

All solutions use the same amount of glazing and type of façade construction. Sunscreen devices are the largest addition to the façade. However, effect on material use is minimal and material efficiency is less significant in determining integral performance.

7.6.4. User value

The user value of different solutions are compared:

- As mentioned before, sunshading device, unlike light regulation devices, can have a negative effect on provided visual user comfort. To reduce visual discomfort, the device is only active at 350 W/m^2. However, provided visual comfort remains lower compared to other solutions;

- Intelligent ventilation devices make ventilation visible for building users. In addition, it provides a higher indoor air quality more effective. Intelligent ventilation provides a greater interior comfort compared to intelligent sunshading devices;

- Intelligent ventilation makes ventilation through the façade more feasible. Intangible effects of façade ventilation are significant, the smell of fresh air coming for outside, being in contact with exterior environment and the provides thermal comfort due to slight fluctuations in temperature.

From the perspective of user value, including comfort, productivity and health, intelligent natural ventilation performs better compared to other studied solutions.

7.6.5. Conclusion

As shown in table 7.6, intelligent natural ventilation provides an higher integral performance compared to intelligent sunshading devices. When compared to the same type of glazing without any addition, costs are considerably higher. However, performance on energy efficiency and user value are far greater, making an façade with intelligent natural ventilation a more beneficial solution compared to intelligent sunshading or plane high performance glazing.

Table 7.6. Overall performance intelligent ventilation

Solution	**Description**	**comfort**	**cost**	**energy**	**material**
A	Glazing B + conventional ventilation	0	+	-	+
B	glazing B + conventional ventilation + internal sunscreen 350 W/m^2	-	-	-	0
C	glazing B + intelligent ventilation (3 dm^3/s/m^2; daytime)	-	0	+	0
D	glazing B +intelligent ventilation (0,88-1,75 dm^3/s/m^2 daytime + 9,0 dm^3/s/m^2 night cooling)	+	0	+	0

7.7. Passive sunshading

In addition to intelligent natural ventilation and secondly intelligent internal sunshading, the performance of the façade can be enhanced by additions, increasing the depth of the façade to create some form of self-shading. The façade can be modified in different ways. A saw-tooth shape of the façade or extruded fins are common solutions. An impression can be seen in figures 7.7-7.9. Two different fin-solutions are compared with the basic solution of a flat façade:

- Basic, flat, façade with glazing B, high performance glazing;
- Façade with glazing B and additional vertical fins of 310 mm. depth for east and west façade;
- Façade with glazing B and additional vertical fins of 620 mm. depth for both east and west façade;

7.7.4. User value

Fins will decrease the diffuse and direct light admittance to the interior. Moreover, visual contact to exterior environment is reduced. As shown in figure 7.10 and 7.11, when approaching the façade at an angle, the contact with exterior environment is greatly reduced. Reducing vision and daylight entrance can be greatly reduced due to fins or other additions. [47] [51] This loss of quality might be greater than the energetic advantages. This negative effect is far less when the fins are reduced from 620 mm. to 310 mm. in depth. The visual comfort is still less but more acceptable. In addition, additional research needs to be performed to estimate the behaviour of wind, altered by the fins. Sound might be generated, creating acoustic discomfort. Moreover, the ventilation rate of natural ventilation through the façade might be decreased. From the perspective of user value performance, fins can reduce visual comfort. This effect might be acceptable when fins are only 310 mm. in depth. In addition, additional research has to point out if fins do not provide acoustic discomfort or reduce the possible ventilation rate of the façade.

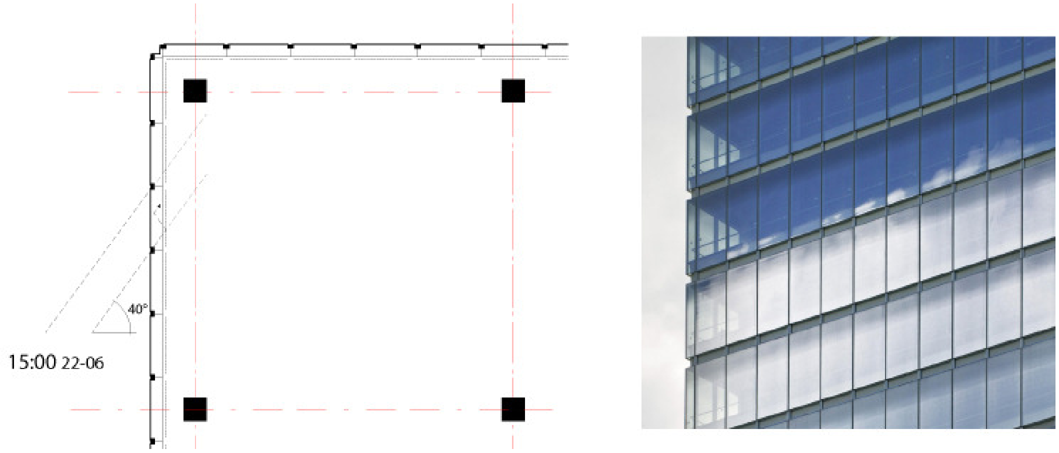


Figure 7.7. Principle flat façade

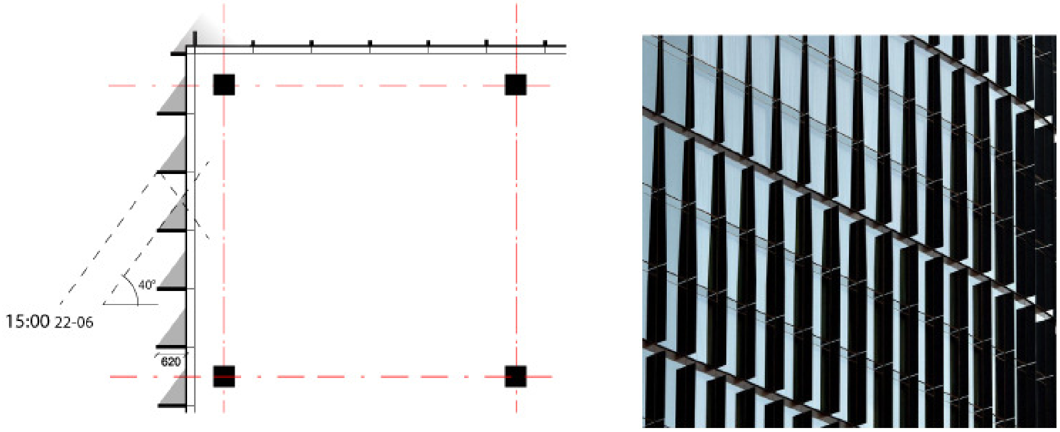


Figure 7.8. Principle fin façade

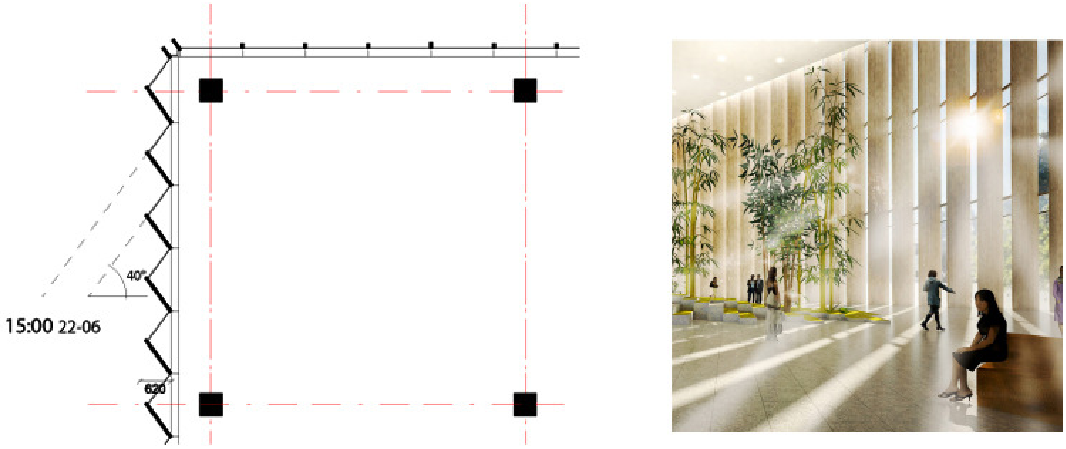


Figure 7.9. Principle saw tooth façade

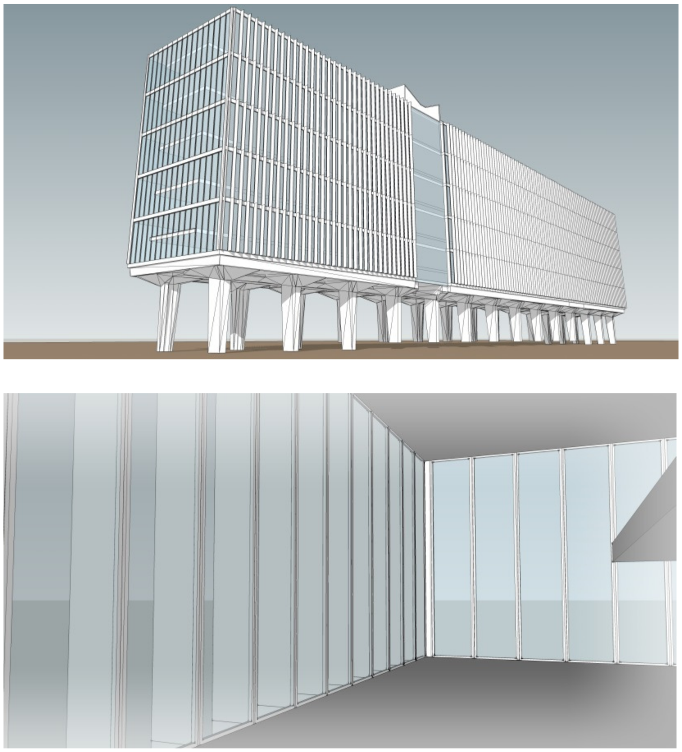


Figure 7.10. Impression Main Building with fin façade (620 mm.)

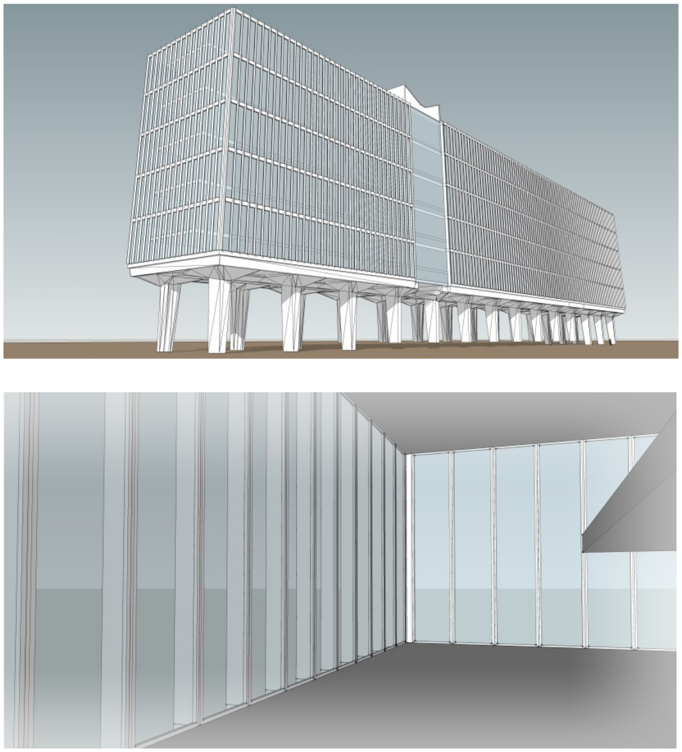


Figure 7.11. Impression Main Building with fin façade (310 mm.)

7.7.1. Energy performance

The performance of a fin addition to the façade is given in figure 7.12. A fin construction of 620 mm. depth would reduce the cooling load significantly. However, the required heating increases as well. The addition of fins of 620 mm. depth would decrease energy use by 13%, compared to a façade with high performance glazing with intelligent natural ventilation. A fin of 310 mm. in depth would be less effective, reducing energy use by 7%. However, a small fin is still slightly more effective in saving energy compared to intelligent internal sunshading device, which only saves 5.5%.

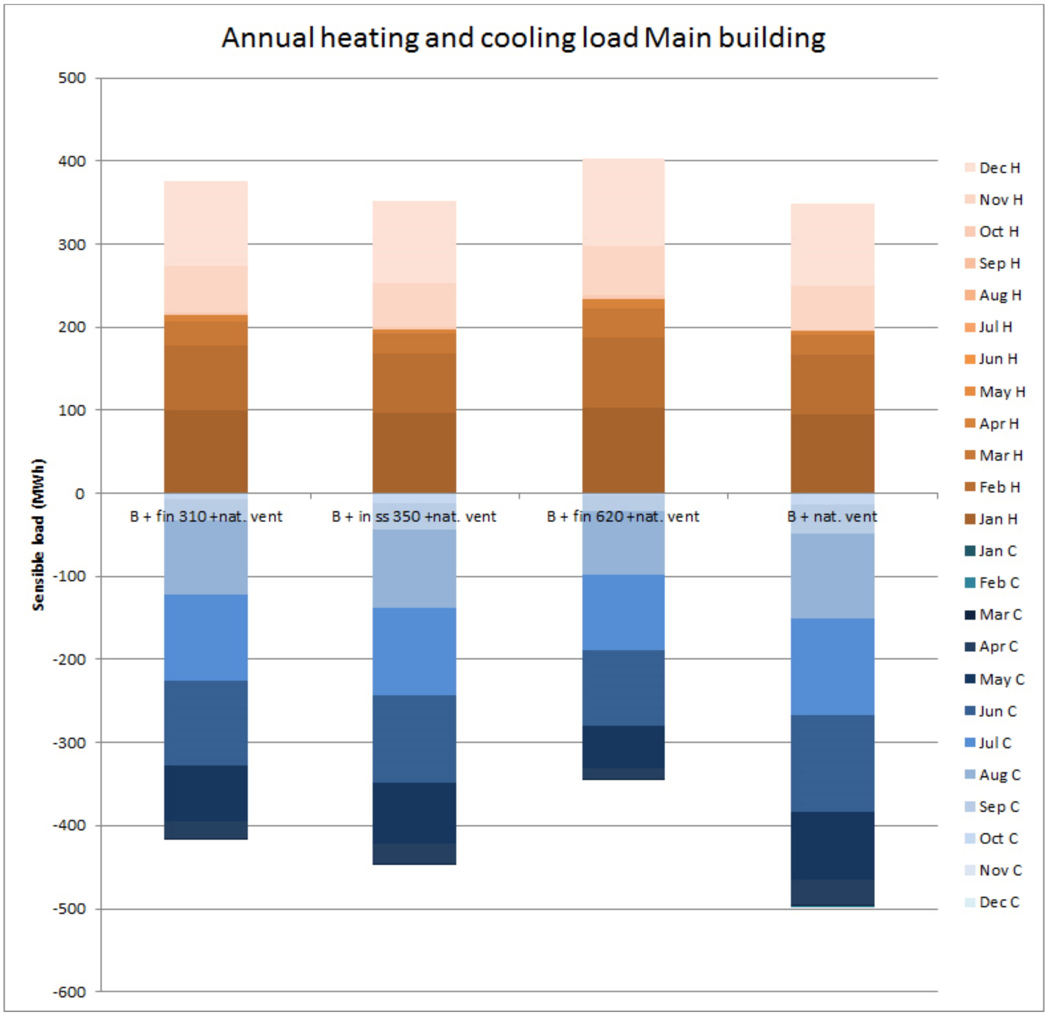


Figure 7.12. Thermal performance fin façade

7.7.3. Material use

The fins are made of robust materials which are able to withstand weather conditions and have a desired architectural impression. When the fins would be made from aluminum, wood or semi-transparent glass, the material use for the façade would increase, decreasing sustainable performance.

7.7.2. Total cost of ownership

The additional costs for a fin construction are difficult to estimate:

- It depends greatly on material use and quality of imbedding in the façade. However, costs are always higher compared to no addition;

- Maintenance costs would increase due to difficulties with cleaning and cleaning of the fins itself;

- Comparing a fin construction with an intelligent, dynamic sunshading device, costs would certainly be lower;

- Energy savings of a fin construction is greater, resulting in larger financial savings on energy.

7.7.5. Conclusion

Additions to the façade are effective in reducing the cooling load, easily up to 13% which is significant compared to alternatives such as intelligent sunshading devices. Cost might be low as well, as additions are simple, passive devices easily integrated with low maintenance costs. However, negative aspects related to user values and sustainability are significant as well. Fins increase the total amount of material which is needed, reducing sustainability of the façade. Most of all, user values are decreased, visual comfort is lowered. When comparing fin construction the alternative of intelligent sunshading, as shown in table 7.7, the overall performance can be considered higher. Material performance is lower, visual comfort is comparable, energy savings are slightly higher and total cost of ownership is likely to be a lot less because of the simplicity of the system. However, further research is needed to estimate additional risks related to acoustic discomfort and alteration of the ventilation rate of the façade.

Table 7.7. Integral performance fin façade

Solution	**Description**	**comfort**	**cost**	**energy**	**material**
A	glazing B + ventilation + fin 310 mm. depth	-	0	+	-
B	Glazing B + ventilation + internal sunshading (350 W/m2)	-	-	0	0
C	glazing B + ventilation + fin 620 mm. depth	--	0	+	-
D	Glazing B + ventilation (no addition)	+	+	-	+

7.8. Conclusion performance study

A façade can be as complex as desired, able to adapt and perform to changing circumstances. However, a limited budget requests that a balance has to be found between performance and costs. Therefore, the benefits of different alternatives is compared to determine which investment will deliver the highest gains.

- As basic principle, the façade should be a single layer façade. More complex facades, double layer and climate facades, are less suitable for the situation of the Main Building or benefits are not (cost) efficient enough. The principle of a climate façade is unable to profit from distinctive qualities of surroundings such as 'free' cooling by natural ventilation and greatly reduce experienced contact between in- and exterior, an important user value. Double layer facades are most of all too costly and benefits, enabling openable windows at great heights and reducing noise pollution, are less suitable for the given situation;

- A study on available types of glazing shows that glazing with both high transparency and energy transmittance, such as conventional 'high performance glazing', is integrally performing better compared to market available alternatives;

- Performance study per orientation shows only very limited effect of triple glazing on north oriented facades and higher reflective glazing on possible south facing facades. The heat saved by the use of triple glazing is irrelevant and the energy saved on cooling by a higher reflection of glazing on south is not significant, especially when taking the accompanied loss of heat and light gain during colder/darker periods as well;

- Comparing the performance of different configurations of in- and external sunshading devices shows that internal sunscreens offer the best performance when related to operative costs;

- However, if budget is limited, an intelligent ventilation system using natural ventilation provides even more value. It benefits from 'free' cooling, especially in midseason and during night-time, results in a higher thermal tolerance of users, increases air quality and does not, unlike sunscreens, limit daylight admittance when active. Moreover, less tangible benefits are the feeling of a fresh breeze and users are in contact with the campus environment;

- Interdependent of the implementation of a sunshading device, an additional light regulation device should be part of the façade design;

- To ensure the right capacity of ventilation while ensuring acoustic and thermal comfort, both ventilation grills for constant ventilation and openable windows for purge ventilation are proposed. An intelligent control system of openable windows ensures an optimal indoor air quality and reduces energy losses when ambient air is too warm or cold.

Chapter 8: Design concept

8.1 Prioritizing values

The Main Building is positioned at the heart of campus. After renovation, the building will house two departments and most TU/e support services, and most importantly, will be restored as the flagship of the university. In order to facilitate the long-term interests of the TU/e, the building need to fulfil several, interrelated, conditions, regarding architectural expression, total cost of ownership and sustainability. However, most significantly, the aim of Project 3 should be to create a building which facilitates and expresses an optimal environment for students and researchers to excel in their endeavours. The core purpose of the university is to facilitate education and research the best way possible. The Main Building could be an statement to potential investors and future students for what the TU/e stands for: the best learning environment possible.

The outcome of performed study has resulted in a list of guidelines which are summed up below.

8.2 Building concept

The façade design is related to the integral building design. Based on performed analysis and literature study, the following guidelines apply for the design of the Main Building high rise:

- Utilize available clean air, low noise pollution and friendly wind climate;
- Relate to the qualities of the green and open campus;
- Use the slender shape of the high rise to create an light-flooded volume, open up to the environment and communicate with its surroundings;

- ▪ Repelling solar radiance above reasonable amount is costly and greatly reduces provided comfort, mainly due to the large façade surface and orientation of the building. Moreover, it will reduce daylight admittance and increase the need for artificial lighting. A higher energy efficiency could be achieved more effectively by reducing active ventilation and artificial lighting;
- ▪ Allow natural ventilation through the façade to save on active cooling by expelling accumulated heat efficiently;
- ▪ Per compartment, 50% of the flexible floors should be placed alternately adjacent to east or west façade, to make optimal use of the admittance of daylight and to create an eastern and western zone per compartment, as shown in figure 8.2 and figure 8.3.

8.3 Climate installation concept

As outcome of the study, a climate installation concept is proposed:

- Air outflow is centrally positioned, using vertical shafts, as shown in figure 8.4 and 8.7, that function as ‘trees’ that facilitate stacked compartments. The necessary draught could be generated naturally with mechanical capacity as back-up;

- Air inflow is arranged via passive, natural ventilation through the façade. Air inflow functions as passive cooling, reducing active cooling load (figure 8.8.);

    - Ventilation grills with sound insulation, positioned at high level and horizontally, with a capacity of approximately 1,75 $dm^3/s/m^2$ should be used for constant ventilation.

    - Openable, vertical shaped, windows with a capacity of approximately 7,25 $dm^3/s/m^2$ should be used for purge ventilation.

- An intelligent control system based on CO^2 concentration and outside temperature, should be used for both types of ventilation to increase energy efficiency and comfort level;

- Concrete floor slabs should be kept in open contact with the interior climate to make the most use of the existing thermal mass for (night) cooling;

- Low temperature heating and cooling is most beneficial with the availability of the existing Aquifer Thermal Energy Storage (*WKO*) system on the campus. Slow reaction time of such a system has to be considered as well. [51] Apply low temperature floor and ceiling heating/cooling, controllable independently for each compartment’s east and west zone, as shown in figure 8.9. to create an efficient climate control [53];

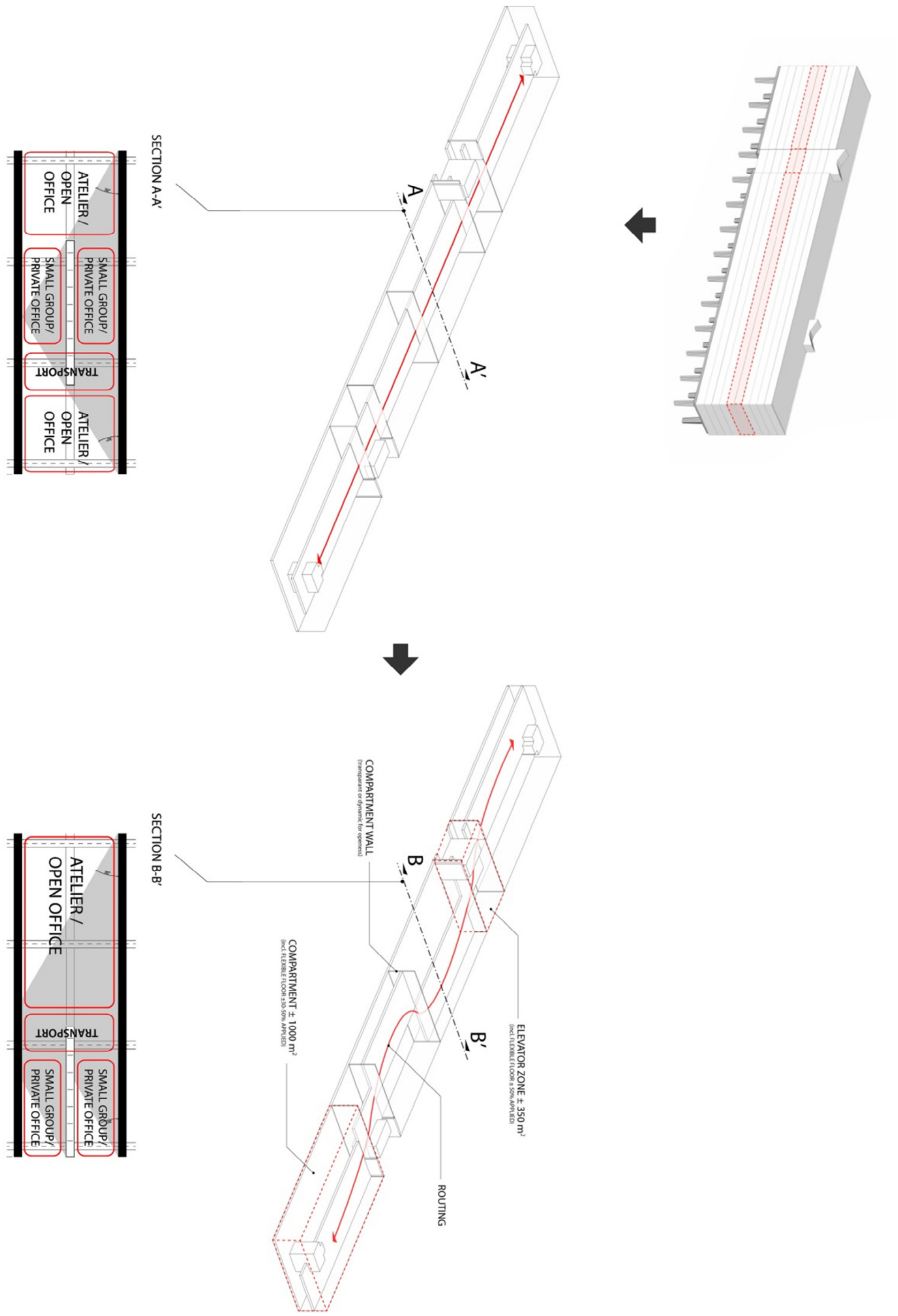


Figure 8.1. Overview Main Building high rise. Floor section as shown in figure 23 and 24 is given in orange

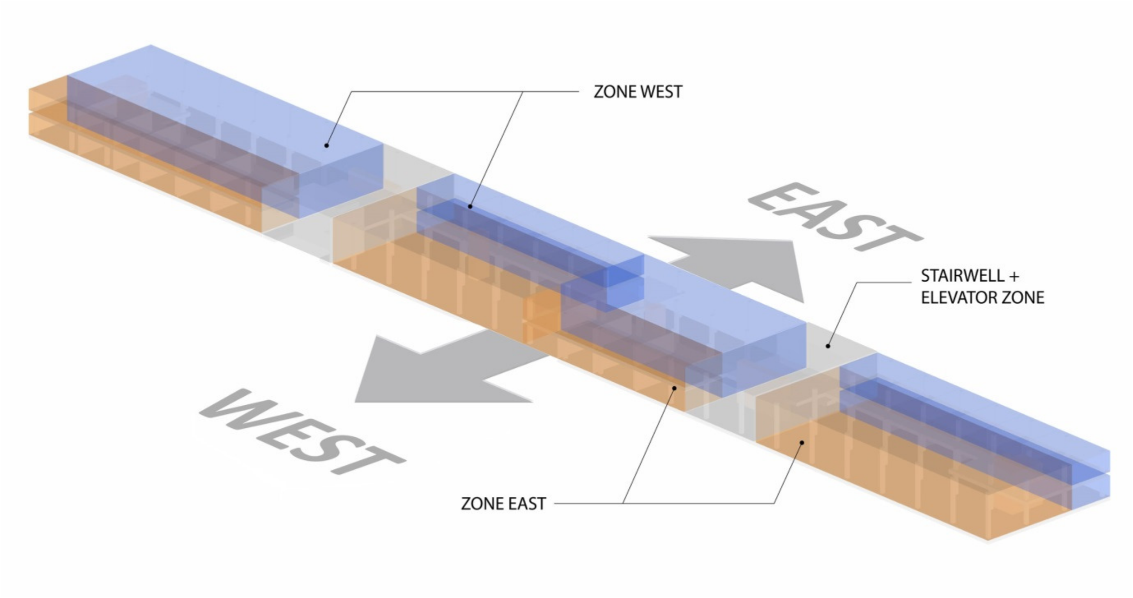


Figure 8.2. Zoning principle, axonometric

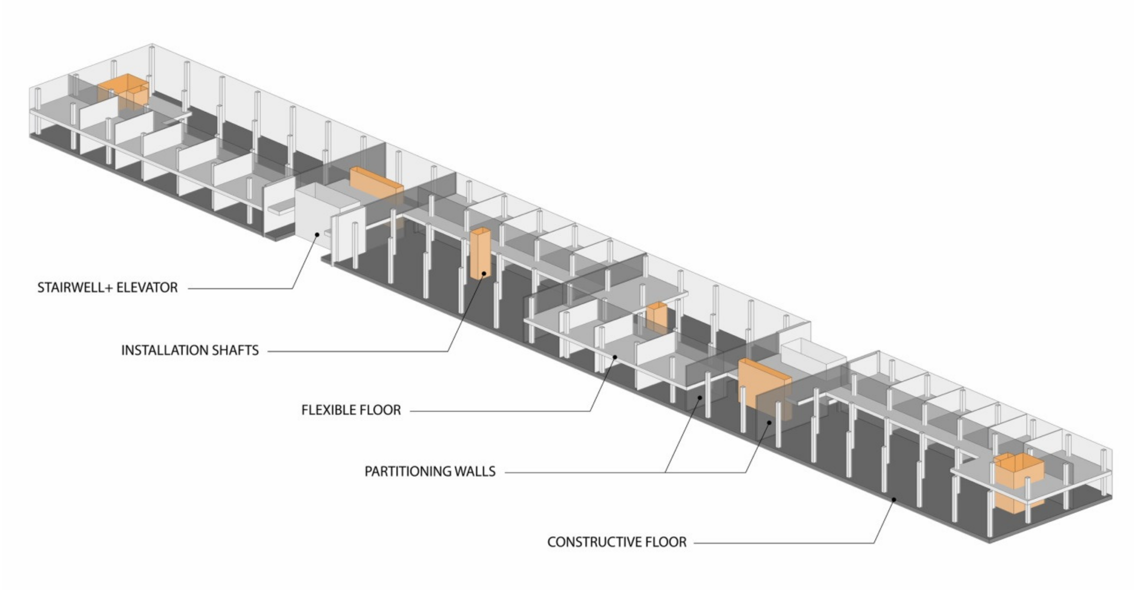


Figure 8.3. Organisation principle, axonometric

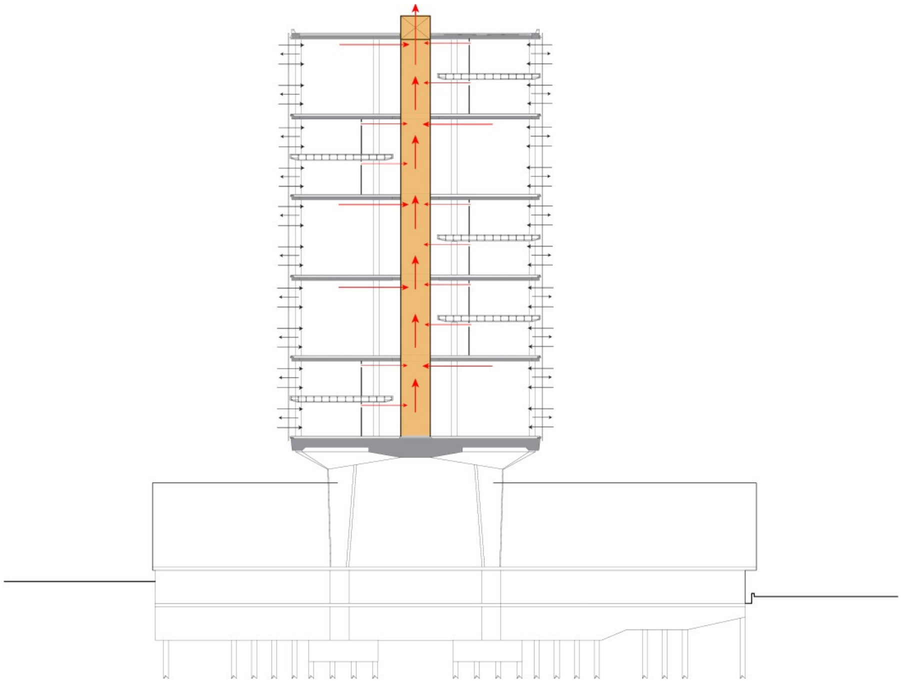


Figure 8.4, vertical intersection, ventilation principle on building level

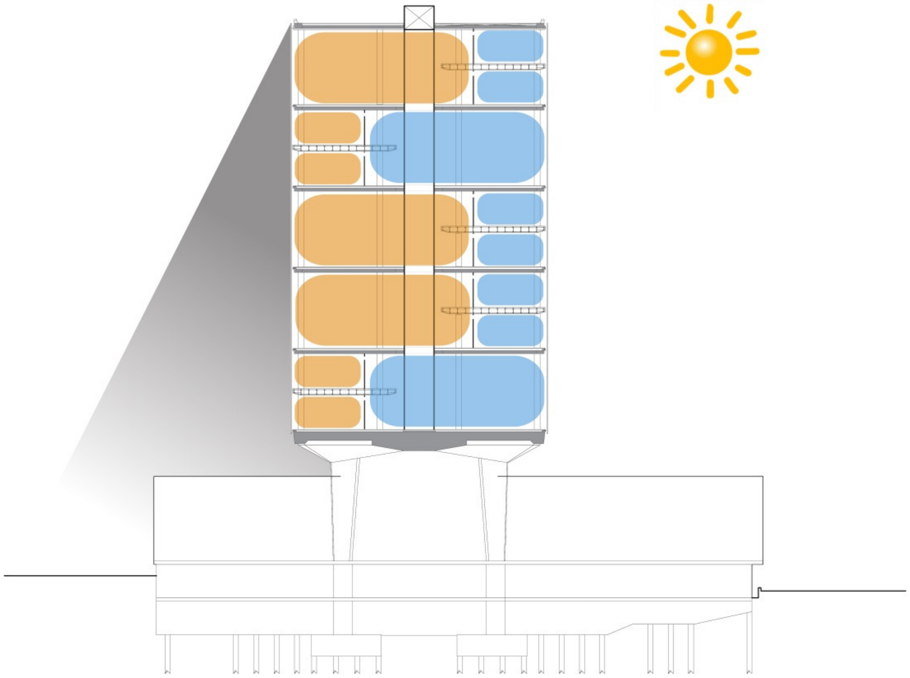


Figure 8.5 plan, ventilation principle on building level

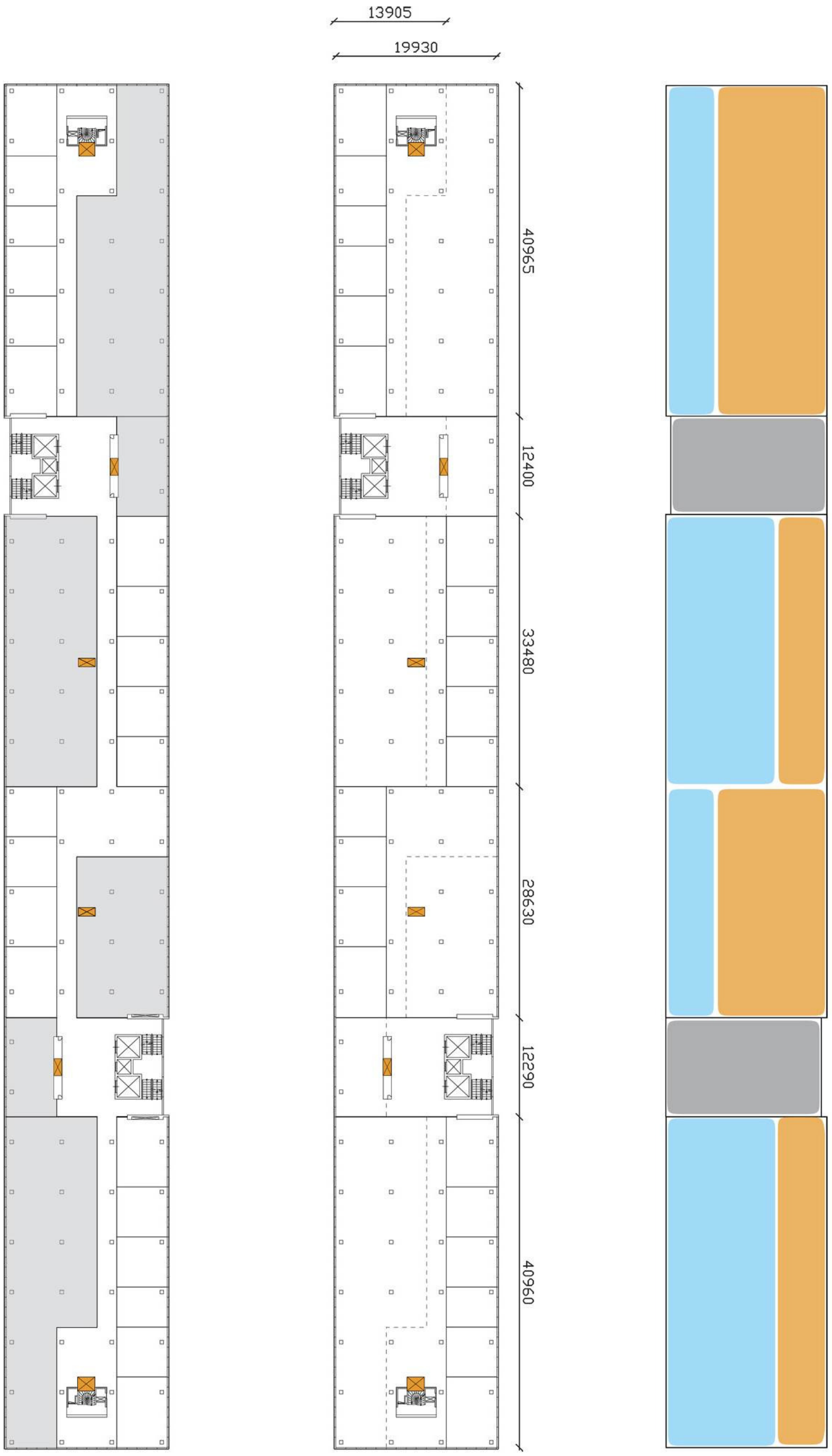
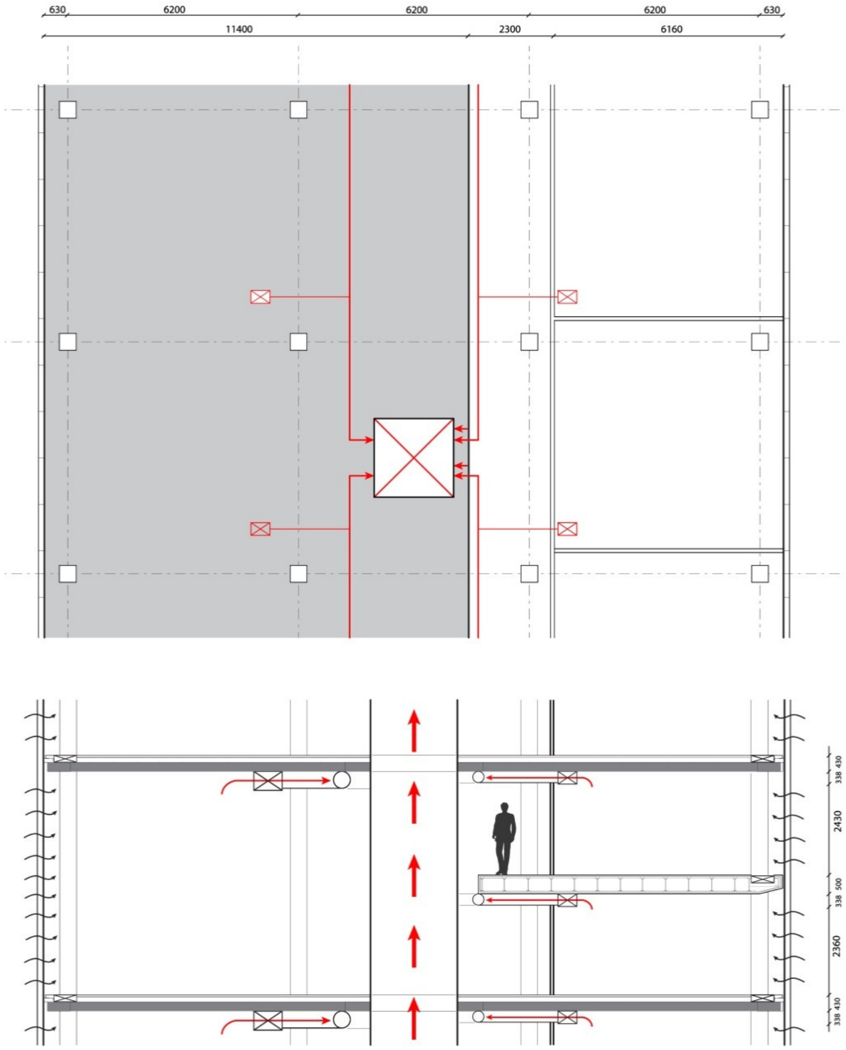


Figure 8.6. Organisation principle, floor plan. (left: flexible floor; middle: structural floor, right: zoning)



Daytime ventilation (08:00-23:00)

35% **IF: 'free' cooling**	'Frisse Scholen' label **A** **$12\ dm^3/s/p$ (= $1,75\ dm^3/s/m^2$)**	+ purge ventilation (via windows) **max. $7,25\ dm^3/s/m^2$**
65% **IF: active cooling/heating**	'Frisse Scholen' label **C** **$6\ dm^3/s/p$ (= $0,88\ dm^3/s/m^2$)**	

Night ventilation (23:00-08:00)

100%	'Frisse Scholen' label **A** **(max. $9,0\ dm^3/s/m^2$)**

Figure 8.7 ventilation principle (top: floor plan, middle: vertical section, below: characteristics)

Passive 'free' cooling gain

IF: $T_{in} > T_{ambient}$ & $16\,°C < T_{ambient} > 25\,°C$	**34 %** (08:00-23:00)

+ Partition in East and West zone

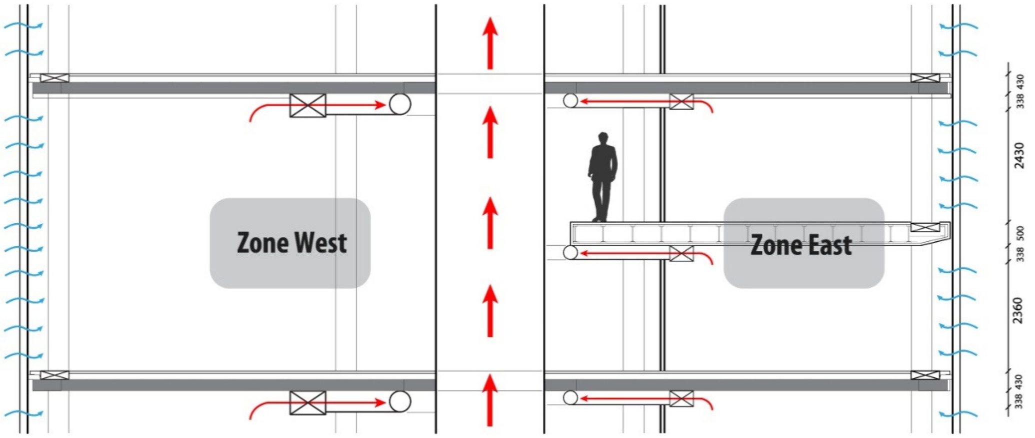


Figure 8.8. Passive cooling principle

Active heating

IF: $< 20\,°C$ T_{in}	**35 %** (08:00-23:00)

Active cooling

IF: $T_{in} > 23\,°C$ & $T_{in} < T_{ambient}$ ($\pm 3\,°C$)	**31 %** (08:00-23:00)

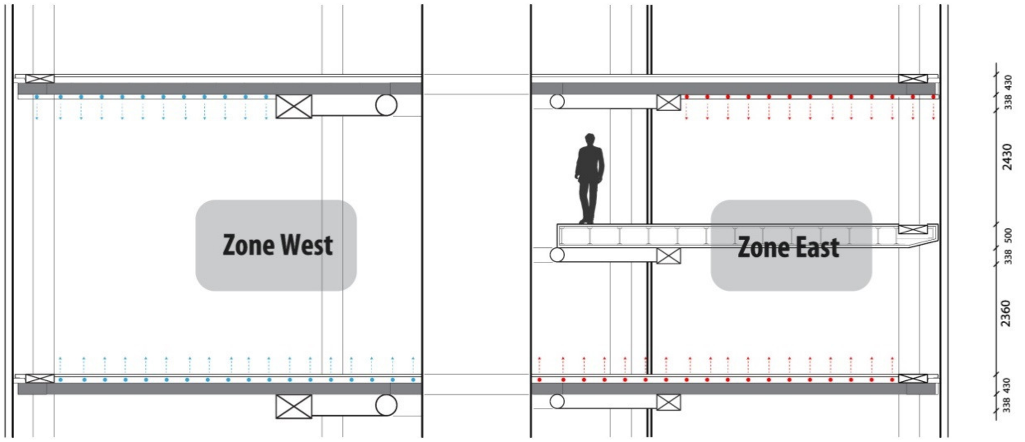


Figure 8.9. Active cooling and heating principle

8.4 Façade concept

Based on performed analysis and literature study, the following design guidelines apply for design of the facade:

- The façade is based on a curtain wall façade principle, which can consist of either a prefabricated elements or more conventional framework system;

- The façade consists of a single layer. This façade principle provides a higher integral performance compared to more complex double layer- and climate façade principles;

- The transparency of the façade is a trade-off between user value and energy efficiency. Exact openness is dependent on a large amount of criteria and cannot be predetermined exactly. However, an indication for the optimal openness is given per orientation:

    - Approximately 60% openness for south orientation;

    - approximately 50-60% openness for east and west orientation;

    - Approximately 50-70% openness for north orientation.

- Glazing performance should be in the range of more conventional types of modern glazing (in the range of U=1,1 W/m2, g-factor 0,60 and light transmittance 0,70). This will provide the highest integral performance. Benefits of available, more extreme performing, types of glazing are less significant and cause additional negative effects;

- Enabling natural ventilation through the façade provides higher integral value than the addition of sunscreen devices. Therefore, natural ventilation, as described in the ventilation concept, is preferable over sunscreen devices or other façade additions that provide shading;

- Vertical fins, saw-tooth principle or other 'self-shading' additions cause insufficient savings on cooling compared to the negative effects, such as adding material and reducing visual comfort. These shading devices should therefore not be included;

- Manual controllable light regulation should always be included, independent of additional sunscreen devices;

- The façade includes a manual operative light regulation device. This could be combined with an intelligent controlled internal sunscreen, controlled by presence detection and insolation of approximately 350 W/m^2, provides highest integral performance compared to alternative sunscreen concepts;

- The facade design allows a the future placement of PV panels if opaque panels are used in the façade design;

- The following rules apply for the façade expression:

- The facade is expresses a certain neutrality, according to the ambition of project 3: Generic expression of exterior, specific expression of interior (*Generiek van buiten, specifiek van binnen)*;

- The facade expression relates to the corporate architecture on the campus, including the dimensioning based on the modular size of 1,24 meter, as described in the Masterplan TU/e Sciencepark;

- The facade expresses the building organization principle as described in this study and shown in figure 8.4.;

- The facade expresses a certain plasticity and depth, as a result of applied techniques and façade elements;

- The façade design is related to existing iconic elements of the Main Building, in particular or concrete table and the two staircases;

- The dynamic natural ventilation capacity of the façade is distinctive quality which should be expresses in the façade design.

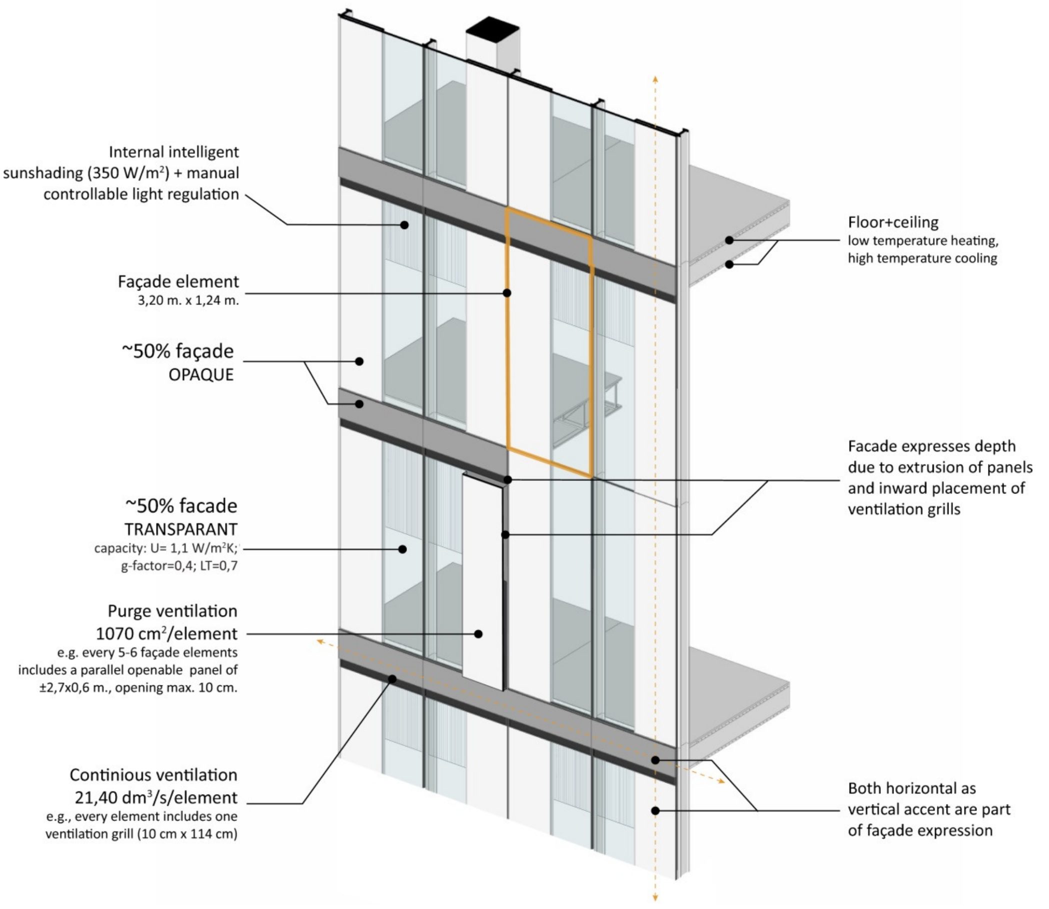
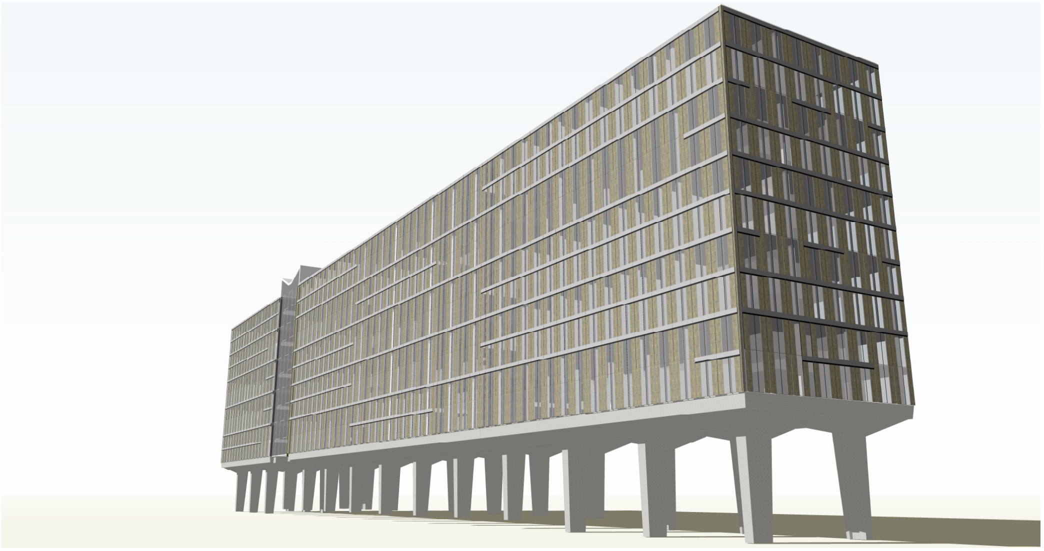
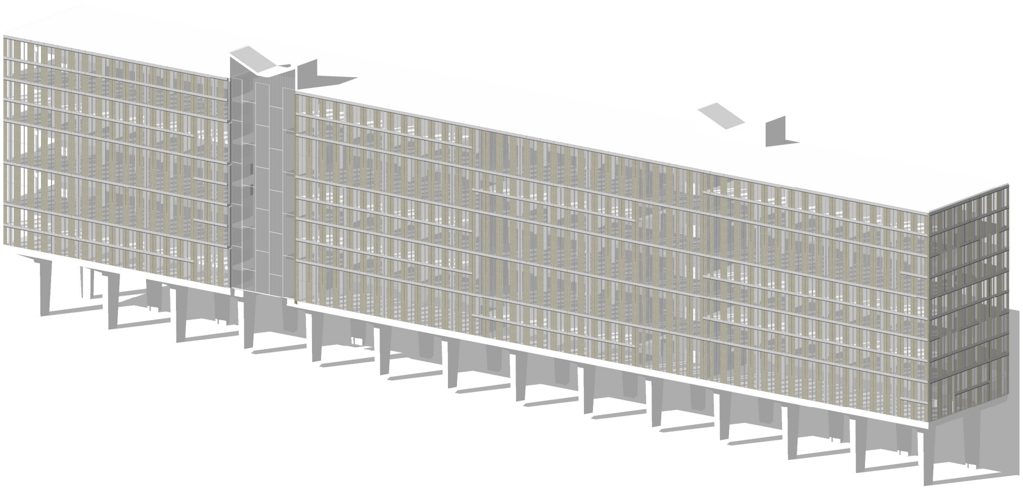


Figure 8.10.Overview façade concept





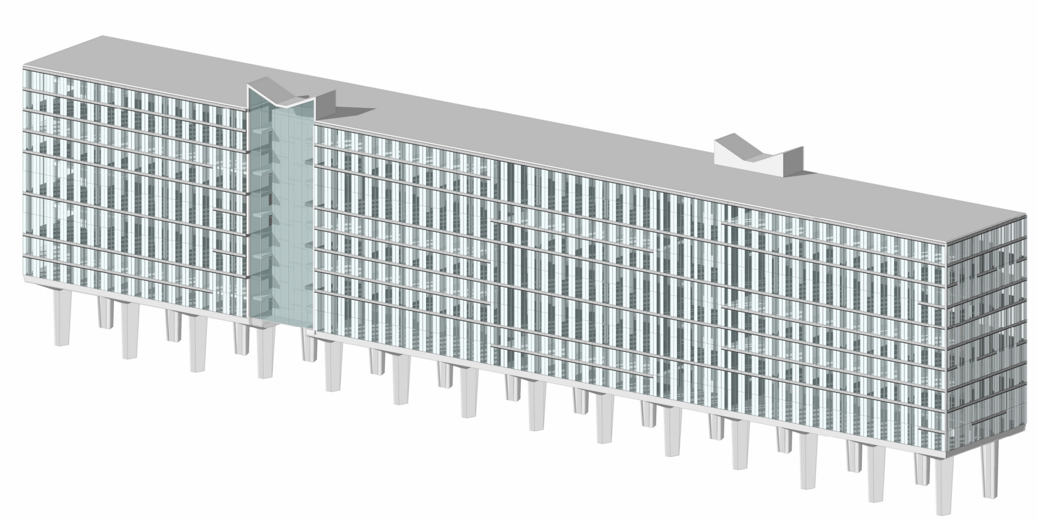


Figure 8.11. Impressions of possible façade design according to proposed façade concept

Chapter 9: Recommendations

The design concept is the result of a one year during study. Information is gathered by means of object analysis, literature study, workshops and expert consults. Although the proposed design concept is based on a structured methodology and rationale considerations, several recommendations are stated below for further research on the façade design:

- A model, as described in chapter is used to quantify thermal energy performance. However, savings on artificial lighting due to the increase of daylight and savings on mechanical ventilation due to the use of natural inflow of air are only qualitatively assessed. For example, ccoatings reduce daylight admittance by 20-35% compared to clear glazing. Dynamic sunscreens reduce daylight admittance and remove exterior view when active. Further research is needed to give a better insight in this topic;

- Although proposed considerations are based on a clear argumentation, a more extensive model which could quantify the energy savings related to ventilation and lighting, in relation to thermal energy savings, could be developed for further, more detailed, research
- The proposed openness of the façade concept, mentioned as window-to-wall-ratio, is based on literature study. Although extensive amount of aspects were taken into account, like most validations in empirical methodology, the study validates an hypothesis, not a applicable solution and some uncertainties for the given situation remain. Moreover, during expert consults, different ratios of openness were mentioned. [53] Often based on practice rather than science, the ratios mentioned suggested a lower amount of openness than suggested by literature, often to reduce energy losses. However, aspects related to user value such as health and visual comfort could be valued properly. Stated amount of façade openness should be used as a starting point, a guideline, not as static fact.
- The option of passive sunshading by the addition of vertical fins to the west- and east facade is studied. As outcome, fins should not be included. However, thermal energy savings as simulated with the model were significant. Uncertainties regarding the effect on visual comfort and foremost the generation of noise due to wind, were important arguments to exclude fins from the façade concept. Further research on the effects of vertical fins could verify if fins could be a valuable asset;

- The proposed ventilation concept includes a vertical shaft for outflow of air. As described in the report, generated thermal current or altered wind flows could potentially generate a natural underpressure which could result in the desired outflow of air and reduction of energy use caused by mechanical ventilation. However, these wind behaviour is far from clear and topic of scientific discussion. The option to include natural outflow in the Main Building is promising, but needs further research.

Chapter 10: Conclusion

The Breathing Façade is a design concept that can be used as a solid guideline for the renovation of the high rise of the Main Building on the TU/e campus. The concept comprises of interrelated building organization, climate installation, and façade concepts.

The proposed design concept organizes the high rise into large compartments, that are partitioned into an east and west zone. Each compartment consists of a double array of smaller offices/study rooms and a large open office/atelier space. The east and west zones have a separated loop of floor and ceiling heating. All compartments are connected to central ventilation shafts, which ensure a controlled outflow of air. The façade concept proposes and prioritizes a set of optimal partial solutions. Foremost, the design consists of a single layer façade with an openness that differs per orientation. The performance of the most suitable type of glazing poses a balance between a solar energy transmittance and a light transmittance factor. The façade includes ventilation grills with acoustic insulation for continuous ventilation and openable windows for purge ventilation, both controlled automatically via the central building management system. The façade is mounted with an internal manual controllable light regulation device for visual comfort, in addition, to an automatically controllable internal sunscreen device.

As a result, the Main Building high rise could, with relative modest resources, ensure a high amount of fresh air and daylight admittance, while ensuring an efficient cooling of the building. Moreover, the smooth façade will accentuate the slender shape of the high rise and the monumental expression of the concrete table. The design concept poses a promising perspective for the renovation of the Main Building and provides an innovative design concept that differs strongly from the current trend in energy efficient building design. Instead of aiming for a compact, energy-saving, yet almost ‘sealed off’ building, the overall concept of this project proposes a slender, light-flooded, volume, open up to the environment and communicative with its surroundings.

The concept proposes a promising perspective for the renovation of the Main Building. Foremost, the proposed design concept distinguishes itself from alternatives in its ability to facilitate an indoor environment that greatly supports an increased study and work efficiency, which are the core -business activities of the university. Hence, following the Breathing Façade concept as underlying guideline for the renovation of the Main Building would be a statement of the TU/e to potential investors and future students: Facilitating the best learning environment possible.

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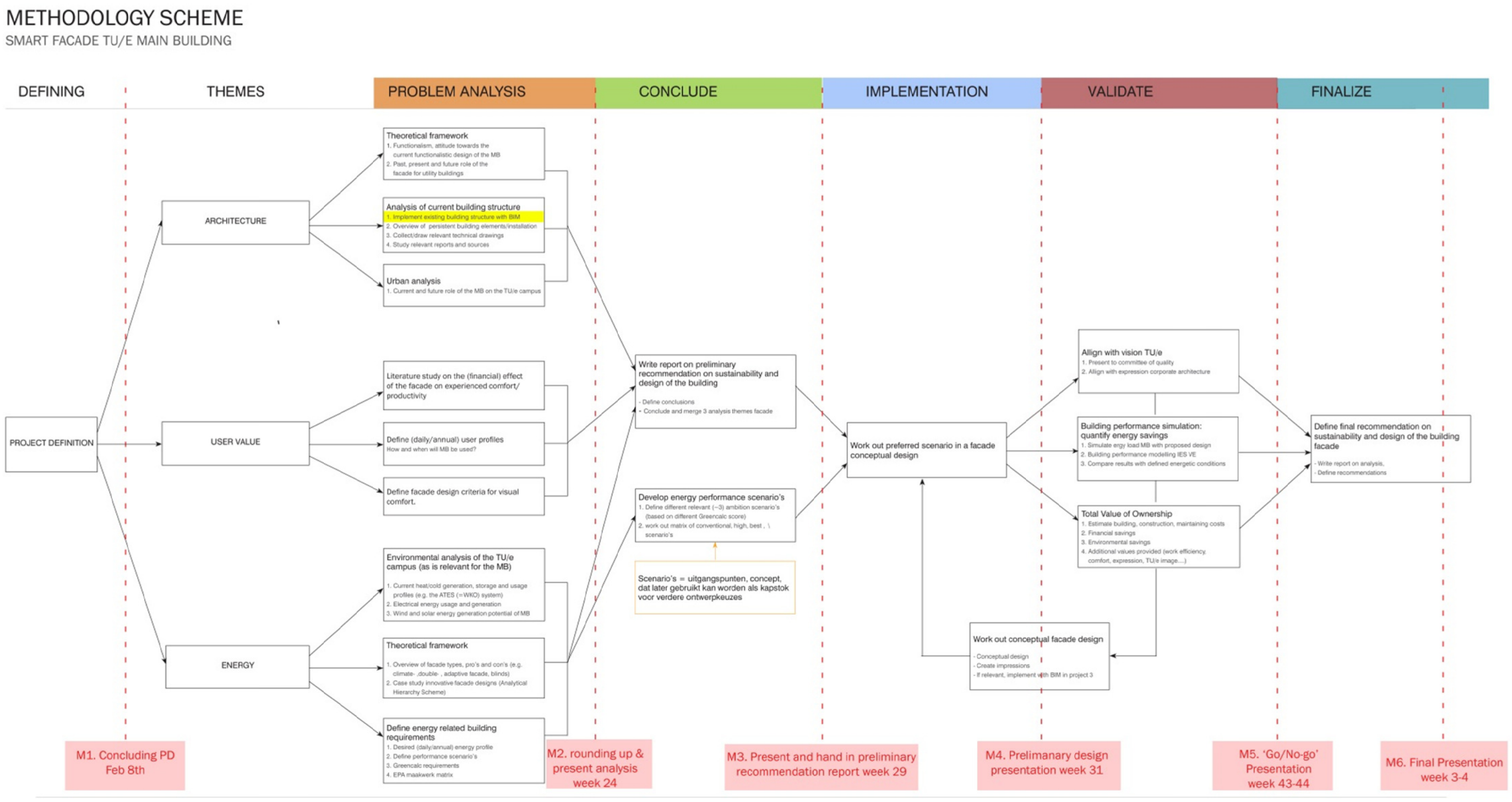
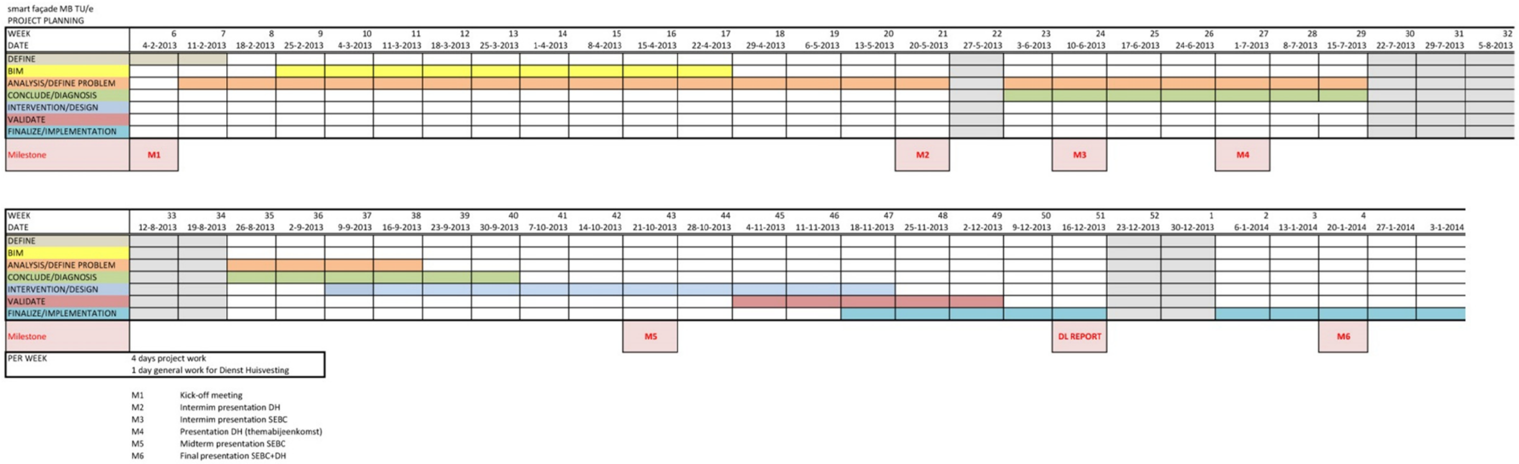
Appendix A: Project Scheme



Appendix B: project planning



smart façade MB TU/e
PROJECT PLANNING

WEEK	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
DATE	4-2-2013	11-2-2013	18-2-2013	25-2-2013	4-3-2013	11-3-2013	18-3-2013	25-3-2013	1-4-2013	8-4-2013	15-4-2013	22-4-2013	29-4-2013	6-5-2013	13-5-2013	20-5-2013	27-5-2013	3-6-2013	10-6-2013	17-6-2013	24-6-2013	1-7-2013	8-7-2013	15-7-2013	22-7-2013	29-7-2013	5-8-2013
DEFINE	■	■															░								░	░	░
BIM				■	■	■	■	■	■	■	■	■					░								░	░	░
ANALYSIS/DEFINE PROBLEM		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	░	■	■	■	■	■	■	■	░	░	░
CONCLUDE/DIAGNOSIS																	░	■	■	■	■	■	■	■	░	░	░
INTERVENTION/DESIGN																	░								░	░	░
VALIDATE																	░								░	░	░
FINALIZE/IMPLEMENTATION																	░								░	░	░
Milestone	M1															M2			M3			M4					

WEEK	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3	4		
DATE	12-8-2013	19-8-2013	26-8-2013	2-9-2013	9-9-2013	16-9-2013	23-9-2013	30-9-2013	7-10-2013	14-10-2013	21-10-2013	28-10-2013	4-11-2013	11-11-2013	18-11-2013	25-11-2013	2-12-2013	9-12-2013	16-12-2013	23-12-2013	30-12-2013	6-1-2014	13-1-2014	20-1-2014	27-1-2014	3-1-2014
DEFINE	░	░																		░	░					
BIM	░	░																		░	░					
ANALYSIS/DEFINE PROBLEM	░	░	■	■	■	■														░	░					
CONCLUDE/DIAGNOSIS	░	░	■	■	■	■	■	■												░	░					
INTERVENTION/DESIGN	░	░			■	■	■	■	■	■	■	■	■	■	■					░	░					
VALIDATE	░	░											■	■	■	■	■			░	░					
FINALIZE/IMPLEMENTATION	░	░													■	■	■	■	■	░	░	■	■	■	■	■
Milestone											M5								DL REPORT					M6		

PER WEEK	4 days project work 1 day general work for Dienst Huisvesting

M1	Kick-off meeting
M2	Intermim presentation DH
M3	Intermim presentation SEBC
M4	Presentation DH (themabijeenkomst)
M5	Midterm presentation SEBC
M6	Final presentation SEBC+DH

Appendix C: Insolation study

Zie digitale bijlage

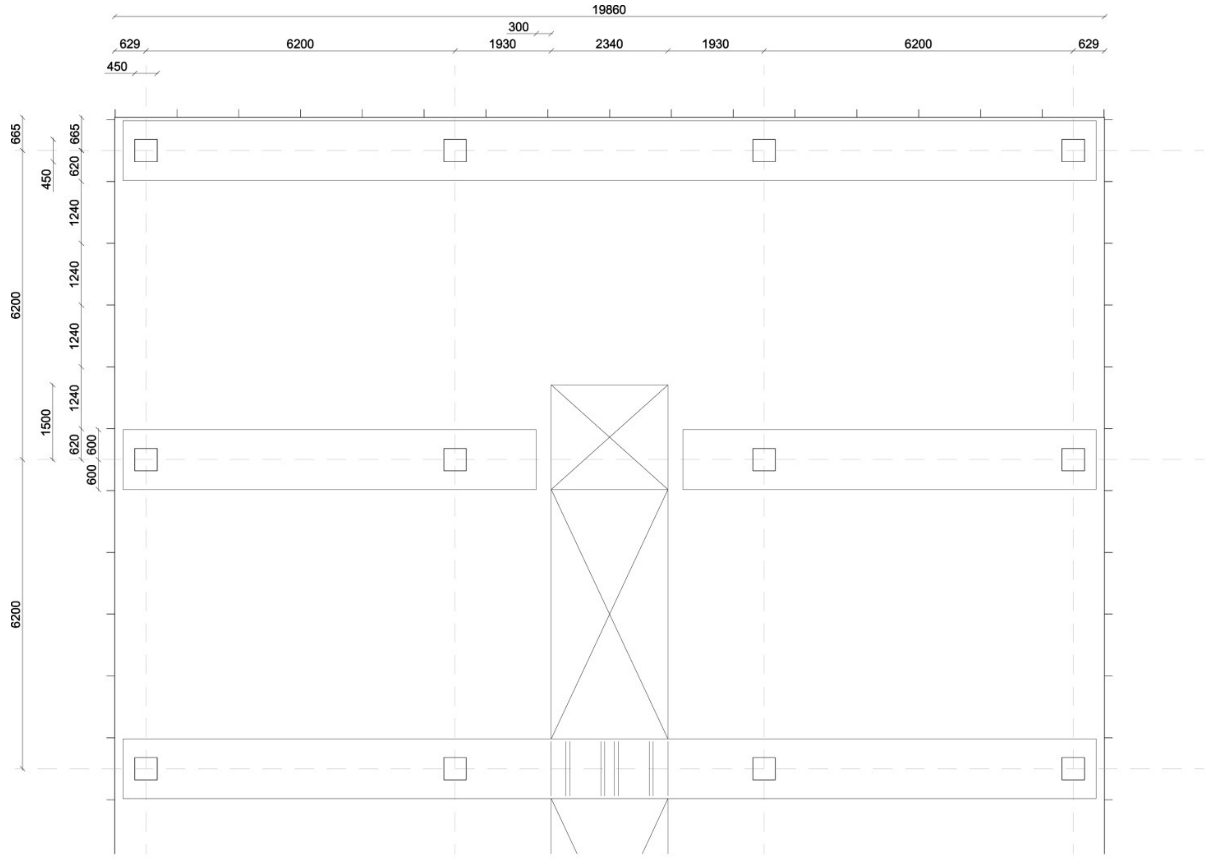
Appendix D: Floor size of the Main Building (dutch)

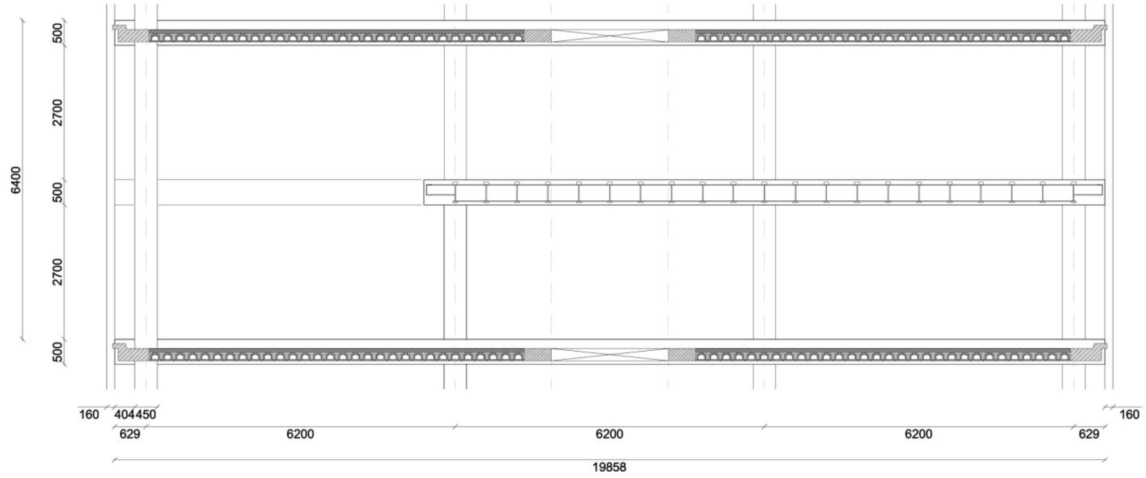
Vloer (huidige staat)	BVO (Bruto Vloe	*waarvan beton/tra	*waarvan hout	NVO (Netto Vloe	NO ookwel GO (N	TO (Tarra Oppervla	gebouw factor (BV	installatie en verkeersoppv (N\	% install + verkeers van NVO totaal
-2	2.264,25			2045,63	956,8	218,62	2,37	1088,83	53,23
-1	4.873,14			4251,5	2889,84	621,64	1,69	1361,66	32,03
0	4.811,79			4459,73	2254,86	352,059	2,13	2204,87	49,44
1	3.152,76			2937,88	1683,66	214,88	1,87	1254,22	42,69
2	3.430			3270,75	2454,5	159,25	1,4	816,25	24,96
3 (tussenvloer)	2.834,77	366,45	2.468,32	2633,43	1831,48	201,34	1,55	801,95	30,45
4	3.430			3272,02	2850,8	157,976	1,2	421,22	12,87
5 (tussenvloer)	2.258,78	366,45	1.892,33	2079,05	1212,31	179,73	1,86	866,74	41,69
6	3.430			3236,47	2392,18	193,53	1,43	844,29	26,09
7 (tussenvloer)	2.309	366,45	1.942,55	2169,03	1360,85	139,97	1,7	808,18	37,26
8	3.430			3235,78	2386,02	194,22	1,44	849,76	26,26
9 (tussenvloer)	2.187,51	366,45	1.821,06	2024,58	1217,11	162,93	1,8	807,47	39,88
10	3.430			3231,48	2407,08	198,52	1,42	824,4	25,51
11 (tussenvloer)	2.186,62	366,45	1.820,17	1992,3	1233,21	194,32	1,77	759,09	38,10
12	515,43			509,86	99,47	5,57	5,18	410,39	80,49
13 (oa. dakpaviljoen)	155,39			124,22	0	31,17	0	124,22	100,00
totaal	44.699,44		9.944,41	41.473,71	27.230,17	3.225,73	1,642	14.243,54	34,34
totaal beton	34.755								
totaal hoogbouw	29.598			27.779	19.445	1.819		8.334	
totaal hoogbouw beton	19.653								
totaal onderbouw (0+1)	7.964,55								
totaal kelder	7.137,39								

Bepaling tussenvloer	aantal	afmeting ~	totaal
platform liftkern+grote trappenhuis	2	164,77575	329,5515
platform zij-trappenhuis	2	18,4512	36,9024
totaal beton			366,4539

	BVO [m2]
max mogelijk tussenvloer	17.150
huidige invulling tussenvloer	11.776,68
totaal min. mogelijk	34.755,03
totaal 50% vulling	41.497,76
totaal max. mogelijk	50.072,76
Hoogbouw min. mogelijk	19.653
Hoogbouw max. mogelijk	34.971
Hoogbouw 50% vulling	26395,82

Appendix E: Principle plan and vertical section high rise





Appendix F: Weight allowance façade construction (dutch)

Samenvatting

De ophanging van een nieuwe gevel aan de bestaande constructie brengt een nieuw krachtenspel teweeg. Om de toepassing van verschillende gevelconcepten (met drievoudige beglazing, dubbele gevelhuid, externe zonwering, etc) te overwegen, moet eerst bekend zijn wat de bestaande draagcapaciteit van de gebouwconstructie toelaat. Het blijkt dat een bewuste keuze voor een licht gewicht gevelconstructie is gemaakt, ondermeer voor de realisatie van een rankere constructie en daaraan gerelateerde kostenbesparing. De berekeningen uitgevoerd voor de dimensionering van de oorspronkelijke constructie geeft een beperkt mogelijk gevelgewicht van 70,0 kg/m^2. Een kleine berekening geeft aan dat dit geen problemen hoeft te geven, maar de waarde blijft een belangrijke maatstaf. Meerdere oplossingsrichtingen, welke nog verdiept moeten worden, zijn mogelijk.

Aanleiding

De renovatie van het hoofdgebouw zal betekenen dat vanaf de bestaande constructie weer wordt opgebouwd. Gezien de opgetilde plaatsing van de bovenbouw op de betonnen tafel, is het aannemelijk dat de gevel voor de bovenbouw aan de bestaande constructie wordt gehangen om zo de krachten via de bestaande kolommenstructuur af te dragen naar het maaiveld. Ook in de bestaande situatie zijn gevelstroken aan elke constructieve vloer opgehangen, een vliesgevel dus.

Overwegingen en berekeningen van bestaande gevel en gebouwconstructie

Om te begrijpen op welke gronden, ten tijde van het oorspronkelijke ontwerp, de keuze werd gemaakt voor een vliesgevel, is een in 1957 opgesteld rapport geraadpleegd. wordt het ontwerp van de bestaande constructie verantwoord met een rapport opgesteld door Van Embden en J. Choisy. In dit rapport, 'beschouwingen over de constructie van het skelet en de samenstelling van de gevel van het centrale hoge gebouw voor de technische hogeschool te Eindhoven' wordt de keuze voor de gebouwconstructie en voor de gevel uiteen gezet. Een afweging wordt gemaakt tussen een betonnen en een deels uit staal opgetrokken constructie. Ondermeer is te lezen hoe nauwkeurig inschattingen werden gemaakt over het extra gewicht en gerelateerde kosten. Ook wordt de keuze voor de gecentreerde kolommen op de begane grond (de kenmerkende 'betonnen tafel') uiteengezet. Deze oplossing leidde tot meerkosten die volgens Van Embden vanuit architectonisch oogpunt te verantwoorden waren. Opvallend is de zakelijke argumentatie van het gehele rapport, misschien wel passend bij het rationele karakter van het gebouw.

Voor deze deel-analyse zijn de afwegingen gemaakt voor het gevelontwerp belangrijk. In het rapport wordt het voorgestelde, uiteindelijk ook toegepaste, gevelprincipe vergeleken met een gevelvariant opgetrokken uit beton en baksteen. De gevelconcepten worden vergeleken op:

- *<u>beperking van gewicht</u>;*
- *voldoende weerstand tegen windaanval van de (lange) raamstijlen;*
- *onderlinge afstand der raamstijlen van 1.24 m;*
- *aanpasbaarheid van de borstwering aan veranderende gebouwindeling;*
- *een zo ruim mogelijke lichtinval;*
- *goede thermische kwaliteiten.*

Wat betreft het gewicht: 'In de keuze van gevelconcept worden meerdere aspecten aangehaald. Een aspect is het eigen gewicht per gevel-travee. Met <u>dubbel glas</u> worden drie typen gevels vergeleken (metaal, beton en baksteen). De variant metaal weegt 20,0 ton en is daarmee de lichtste variant (resp. 90,6 ton en 125,0 ton).'Verder geeft Van Embden aan dat de doorbuiging bij windbelasting bepalend is bij de dimensionering van de gevelstijlen. En tot slot: 'Uiteraard moet worden nagestreefd naar een zo <u>licht</u> mogelijke gevel; verzwaring toch van de gevel voert tot een vermeerdering van de kosten voor de constructie van vloeren, kolommen en funderingen.'

In het huidige ontwerp heeft het gewicht van de gevel dus een bewust aspect bij het dimensioneren van de gebouwconstructie. Om een betere inschatting te maken van de kwantitatieve waarden van het toelaatbare gewicht voor een nieuwe gevelconstructie is een korte archiefstudie verricht naar de berekeningen van de constructie van het hoofdgebouw:

In de berekeningen (blad 1380) wordt aangegeven:

'Gevel 6,20 m (travee maat) x 700 = 440 kg/m' '. Hieruit is af te leiden dat de aanname wordt gedaan dat de eigen belasting van de huidige gevel 70,0 kg/m^2 toe laat. Het is niet vermeld of dit gewicht een gevel met dubbel of enkel glas betreft, een punt van aandacht om nog uit te zoeken. In de detaillering van de vliesgevel is dubbel glas aangegeven (zie: tekening 11, blad p8-131 'details curtainwall').

In de berekeningen voor het palenplan (blad 400) wordt aangegeven:

Middenkolom
Eigen gewicht hoofdvloeren:
dak= (2,43x2,40 : 2,77 x 3,90) x 600=20,51x600 = 12350 kg
4 hoofdvloeren = 20,51 x 610 x 4 = 50200 kg
Gevelpui = 6,20 x 34,00 x 75 = 15800 kg
Extra van randstrook 6,20 x 100 x 4 = 2480 kg
Eigen gewicht kolommen = 15000 kg
____
Totaal eigen gewicht = 96830 kg

Nuttige belasting hoofdvloeren (incl. dak)
= 20,51 x 300 x 3,5 = 21500 kg
Belasting tussenvloeren
Eigen gewicht = 20,51 x 125 x 5 = 12850 kg
Nuttige belasting 20,51 x 250 x 3,2 = 16450 kg
____
Kolomdruk op de 1^e verdieping = 147630 kg

Voor een hoekkolom en normale randkolom zijn vergelijkbare berekeningen gemaakt en ook te bezien in dit document.

In berekeningen (blad 971) wordt aangegeven:

a. eigen gewicht
Gevelpui = 15800 kg
Extra voor randstrook: idem = 2480 kg
Eigen gewicht kolommen = 15000 kg
____
= 33280 kg
Per 12,40 m': P = 66560 kg neerwaarts.

b. nuttige belasting
1. Bij volbelasting, dus op alle verdiepingen en nuttige belasting aangebracht, mag gereduceerd worden volgens de T.G.B.
In Cross-programma is gerekend op overal 500 kg/m^2. (...) '

Zoals reeds vermeld is met de dimensionering van de bestaande constructie oa de toelaatbare kolomdruk) rekening gehouden met het eigengewicht van de gevel. Deze maakt ca. 10% uit van de totale verticale druk. 'Uiteraard moet worden nagestreefd naar een zo licht mogelijke gevel; verzwaring toch van de gevel voert tot een vermeerdering van de kosten voor de constructie van vloeren, kolommen en funderingen.' (Van Embden 1957). Uit de oorspronkelijke berekeningen blijkt een toelaatbaar gewicht (inclusief veiligheidsmarge) van de huidige gevel een gewicht heeft van m_{gevel}=70,0 kg/m^2, wat neer komt op m_{gevel}=15800 kg per middenkolom en m_{gevel}=19900 kg per hoekkolom. Er van *uitgaande dat de huidige gebouwconstructie niet wordt verzwaard, zal het toelaatbare gewicht voor de nieuwe gevel beperkt zijn is het noodzaak om deze waarde vast te stellen aan de hand van de toelaatbare, bestaande, kolomdruk.*

Toelaatbaar eigengewicht nieuwe gevel

Moderne gevels kunnen door de complexe opbouw en meerdere glaslagen flink zwaarder zijn dan de oorspronkelijke gevel van het hoofdgebouw. Wellicht dat een beperkt toelaatbaar gewicht enkele gevelconcepten bij voorbaat al bijna geheel uitsluit. Ook kan gekeken worden wat gewichtbesparende materialen kunnen worden toegepast. Aluminium weegt minder dan het huidig toegepaste staal. Ook moet gekeken worden naar de berekende nuttige belasting. Past deze bij het toekomstige gebruik van het gebouw?

soortelijk gewicht glas	*2,5*	*kg/dm^3*	
	0,0000025	*kg/mm^3*	
	0,00001	*kg/4mm^3*	*dikte 4 mm*
	10	*kg*	*per m^2 (4 mm dikte)*
	15	*kg*	*per m^2 (6 mm dikte)*
travee maat 6,2 m	*62*	*kg*	
IPE profiel 160 staal	*16,1*	*Kg/mtr*	*maatgevend is windbelasting*
aantal stijlen/travee	*5*		
	80,5		*per travee*
	12,983871	*kg*	*per m^2*
totaal gewicht/m2			
dubbelglas	*32,98*	*kg*	*2x4mm glasdikte*
drievoudig glas	*42,98*	*kg*	*3x4mm glasdikte*

Deze korte berekening blijft opvallend genoeg ver onder de tolerantie van 70 kg/m^2. Meer deskundig onderzoek is nodig.

Mogelijke oplossingsrichtingen

1. lichtgewicht gevel passend bij de bestaande constructie en gelijke nuttige belasting

2. Zwaardere gevel is toelaatbaar binnen de bestaande constructie. Nuttige belasting blijft gelijk

3. Zwaardere gevel toepassen en gewicht besparen op andere aspecten om zo de totale kolomdruk gelijk te houden.

Appendix G: Calculation solar energy generation capacity (dutch)

Summary

The aim for the main building will be energy neutrality. Solar energy generation can be a good opportunity for local generation. The building shape (rectangular and constant, flat shape) and no obstruction of other high rise structures make the roof, south and west-facade interesting for the placement of PV panels. As the sun study shows, only a small fraction of the east façade is obstructed by shadowcast and is interesting for solar energy systems as well.
Mass and insolation
Door de positionering en dat het volume opgetild is van het maaiveld valt nagenoeg geen slagschaduw van andere gebouwen of bomen op de gevel. Met een klein geveloppervlak gericht op de noordzijde betekend dit dat het opgetilde volume een grote bezonning kent gedurende het gehele jaar.

Motivation

For aforementioned reasons, the university aims to increase its energy neutrality in 2020. In addition to decreasing the energy load of the campus, new means to implement distributed energy resources (DER), such as solar energy systems, are needed to achieve this ambition. A promising technology to might be solar energy systems. As stated in the Urgenda report 'City of tomorrow ', large horizontal area is needed to generate considerable amount of solar energy.[6] *Since the usable surface area is limited to mostly roofs and some scarce plots of ground, the possibility to implement solar panels on facades becomes a 'second best' option.*

With Project 3, the possibility of implementing solar energy systems, most common are photovoltaic (PV) panels. Other promising solar technologies are under development. For this study, PV panels with a module efficiency of 15% were chosen because of their wide implementation and availability in the market. Furthermore, an energy conversion efficiency of 81,2% is estimated due to other losses (cabling, conversion, etc) in the complete system.

Tilted above ground level by an monumental 'concrete table', the high rise forms a very regular and flat shape hardly distorted by any shadow from its surroundings. Only the east side is cast in shadows by the adjacent Metaforum building. The high rise orthogonal shape 32,595 (h) x 20,37 (b) x 169,173 (l) is perfectly oriented to the north, should be considered for the implementation of PV panels.

To give an estimation about the energy generation potential of the high rise facades, an estimation is made, 'non-realistic' assumption of covering the full façade with panels. The breakdown of the calculation can be seen in the appendix file.

Façade	*South*	*West*
generation capacity[7] *[kWh/m²/y]*	*98,22*	*67,27*
Total surface area facades [m²]	*663,96*	*5514,10*
WWR	*0,6*	*0,5 – 0,6*

---

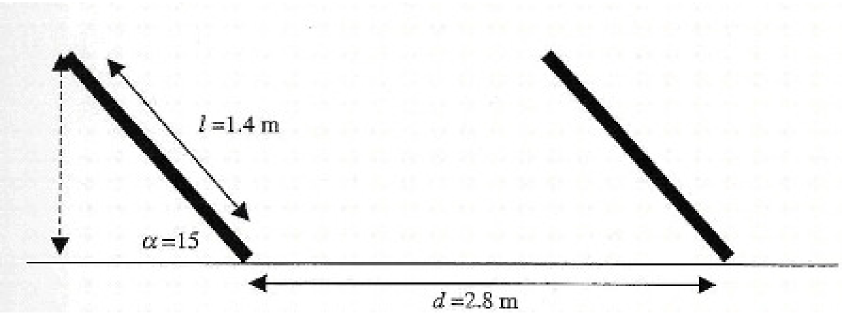
[6] Towards the city of tomorrow, Urgenda, 2012, p.34

[7] Capacity based on KNMI climate file and verified with IES simulation with IWEC climate file

PV Panel surface	*398,38*	*3032,75*
Total annual yield [MWh/y]	*39,13*	*204,02*
Total cost price for TU/e [€/MWh]	*76,50*	
Savings [€/y]	*2.993,46*	*15.608,88*

The energy yield for the roof is also being calculated. As can be seen in table X, the energy yield of the roof depends greatly on the usable surface, furthermore, the effective use of the available surface is reduced because the arrays of panels need some distance from each other in order not to cast any shadows on the next array. The optimized distance between arrays is given by the SBR[8]*:*

'Optimale afstand
Als de rijen zonnepanelen op het platte dak ('arrays') te dicht op elkaar staan, worden ze door elkaar beschaduwd. Hierdoor neemt de energieopbrengst af. Als ze echter te ver van elkaar af zijn geplaatst, wordt onvoldoende gebruik gemaakt van de beschikbare oppervlakte en neemt ook de energieopbrengst af. Er is dus een optimale afstand tussen de paneelrijen. Hierbij is de energieopbrengst maximaal in relatie tot het beschikbare dakoppervlak. Tabel 1 geeft op basis van een simulatiestudie de optimale afstand weer voor de verschillende hellingshoeken en afmetingen van de toegepaste zonnepanelen. Hierbij is naast de directe zoninstraling ook rekening gehouden met diffuse straling.'



Roof	*[m^2]*
Gross surface	*3445,99*
Distance to edge for wind turbulence = 1 m	*-375,08*
Installations space 20% of total roof space[9]	*-689,20*
Usable space for PV arrays	*2381,71*
Effective roof usage [%]	*69,12*
Array-afstand (d)/ paneel lengte (l) 36° = 3,10	
Panel surface/ effective roof usage ratio [%]	*32,26*
PV panel surface on roof of MB (36°, south)	*768,29*
Total annual yield [MWh/y]	*135,32*

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[8] http://www.sbr.nl/producten/infobladen/plaatsing-van-pv-panelen-op-platte-daken last referred on 8-3-2013

[9] KH: het is maar de vraag in hoeverre er installaties op het dak komen. MF heeft ventilatie en WTW installatie op het dak. Verwarming en koeling gaan via WKO en die wordt waarschijnlijk in de kelder geplaatst

Savings ratio [€/m^2/y]	*4,35*
Savings [€/y]	*10.352,89*

Mainly due to the mutual array distance, the savings ratio for roof panels appears to be lower than the savings ratio for façade-mounted panels. This comparison does not take into account the extra maintenance costs for façade panels and difficulties involved in integrating panels in a high rise façade. In addition, panels on roofs are ventilated well. The ventilation of façade panels is complex. Well ventilated panels have a higher over-all efficiency. Placed on a horizontal roof, panels are easy accessible and can be placed after building construction.

Sun radiation study

In order to estimate the energy yield for the high rise of the main building, several steps have been taken.

As a first step, the insolation is being determined. Insolation is a measure of solar radiation energy received on a given surface area and recorded during a given time. Using the KNMI weather file average over a period of 2001-2008, the insolation on a horizontal surface in the region of Amsterdam is given. To validate the data, the insolation is also being calculated using the simulation tool IES VE.

Secondly, correction factors were determined for different orientations (north, east, south and west) and different array angles (vertical for façade, 36° for optimal angle on the roof) using data from NASA meteorology and the tool PVWatts, developed by The National Renewable Energy Laboratory (NREL), the United States' primary laboratory for renewable energy and energy efficiency research and development.

As a third step, the PV system efficiency was determined. A 15% module efficiency (the amount of energy from the sunlight that is being captured 'inside' the panel) was assumed . Furthermore, an energy conversion efficiency of 81,2% was assumed (caused by aspects such as unexpected shading, electricity conversion, metering, cabling).

PV module efficiency:	*15 %*

deviation from STC cond.	*4,5%*
soiling	*2,5%*
temp	*3,5%*
shading	*2,0%*
mismatching & dc-dc conv.	*3,5%*
mpp mismatch	*1,5%*
meter	*3,0%*
Total conversion losses:	*81,2%*

As a fourth step, the surface area theoretical usable for PV panels per orientation was determined. Focussing only on the high rise of the main building (32,60 (h) x 20,37 (w) x 169,17 (l)), the window wall ratio (WWR) has to be estimated. Using the outcome of an design optimization study[10] (considering both energy efficiency and visual comfort) the following WWR was assumed:

---

[10] Carlos E. Ochoa et al., *Considerations on design optimization criteria for windows providing low*

	South	*North*	*East*	*West*
WWR	*0,6*	*0,5-0,7*	*0,5-0,6*	*0,5-0,6*

With the openness of the façade estimated, it is assumed that the closed part will be completely covered with PV panels. This assumption is quite optimistic, at least. The annual yield is calculated for all orientations.

Façade	*South*	*North*	*East*	*West*	*Total*
Generation capacity [kWh/m²/y]	*98,22*	*42,03*	*68,07*	*67,27*	*208,31*
Total surface [m²]	*663,96*	*663,96*	*5514,10*	*5514,10*	*12356,11*
Usable surface [m²]	*398,38*	*398,38*	*3032,75*	*3032,75*	*6862,26*
Energy yield [MWh/y]	*39,13*	*16,74*	*206,43*	*204,02*	*466,32*
Savings [€/y][11]	*2993,46*	*1280,92*	*15793,01*	*15608,88*	*35676,26*
Savings ratio [€/m²/y]	*7,51*	*3,22*	*5,21*	*5,15*	

As can be seen and for obvious reasons, north orientation provides the lowest yield. East and west provide can generate the highest amount of energy. However, as can be seen in the sun study of the main building, the east side is shaded for a large amount by the high rise of the Metaforum building. The south and west side are the most interesting sides for sun energy generation.

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energy consumption and high visual comfort, 2012

[11] Based on energy cost prices of 2012-2013, (76,51 **€**/MWh), provided by Dienst Huisvesting

Appendix H: Historical energy use Main Building (dutch)

Samenvatting

Om inzicht te verkrijgen in het toekomstig energiegebruik (warmte, koelte, elektriciteit) is het historische verbruik in kaart gebracht over een periode van zes jaar in welke het gebouw vol operationeel was. Met behulp van het software pakket Erbis voor energie beheer is de data opgevraagd over de periode van 1 januari 2006 tot en met 31 december 2011. . Verwarming van het hoofdgebouw gebeurde in deze periode via een gas gestookte CV installatie. Het hoofdgebouw maakt nog geen gebruik van het WKO systeem, de aansluiting is al wel aanwezig. Het hoofdgebouw wordt elektrisch gevoed via meerdere travo's die op zowel de zuid- als de noordzijde onder het gebouw zijn gelegen. Zowel gas als elektra zijn in de vastgestelde periode gemonitord. Meer gespecificeerde informatie is terug te vinden in het excell bestand 'HG_energieverbruik_2006_2011'

Werkwijze

De metingen van het hoofdgebouw zijn uitzonderlijk nauwkeurig te noemen. Dit komt doordat de lasten op meerdere travo's, behoorlijk 'schoon' zijn aangesloten. Dat wil zeggen, op een bepaalde travo is alleen verlichting aangesloten. Voor koeling zijn de metingen minder precies. Door te kijken naar enkele aansluitingsgroepen op de travo's bestemd voor koeling, werd in overleg met B&O van Dienst Huisvesting een schatting (proces 'vervuiling' van 10%) gemaakt welke is opgenomen in de metingen. Verwarming is geconverteerd naar electrische last, alsof deze door de huidige WKO (COP 13,6) zou worden geproduceerd. Alleen op deze wijze kon een relatief eerlijke vergelijking tussen warmte en koellast worden verkregen

Appendix I: Overview indication transformers (dutch)

Hoofdgebouw 11

Elektrisch licht

11ELN-051502-DAT (trafo 1N HG)	L2	Noord	Traf01 500 kvA
11ELZ-030810 (trafo 2Z HG)	L1	Zuid	

Noodstroom

11NKN-051505-DAT-C (El. NK HG)		Noodstroom	

Koeling

11KMA-051504-DAT (trafo 2N HG)		Rekenwaarde travo R1	
11KMA2 (hoofdgeb. Trafo 2N)	R1	Noord	Traf04 630 kVA
11KMA-051503-DAT (trafo 4N HG)		rekenwaarde travo R2	
11KMA1 (hoofdgeb. Trafo 4N)	R2	Noord	Traf02 630 kVA

Aanname: Travo's R1 en R2 zijn in gebruik voor koelmachines (51KK2/2, etc) enkele algemene aansluitingen (zoals K103, K104) vervuilen metingen maar zijn licht in gebruik en aangesloten functies. WKO pompen hebben eigen meting en zijn aftrekbaar. In samenspraak met B&O schatting van 90%
gemaakt. Koelmachines zijn omgekeerde 'warmtepompen', uitwisseling met lucht. Freon in loop.

Proces

11OKZ-030811-DAT (trafo 4Z HG)	K1	Zuid	Traf04 315 kVA
11RKN-051506-DAT (trafo 3N HG)	W2/K2	Noord	Traf03 500 kVA
11RKZ-030812-DAT-(trafo 3Z HG)	W1	Zuid	Traf03 315 kVA

Aanname: 10% van (R1+R2-WKO K1A/B) optellen bij Procesgebruik om totaal gebruik te meten. Zie comment bij koeling. Bij W2/K2 valt ondermeer de lift 17&18. W is kantoor-achtige functies, K is kracht voor machines en lab's.

WKO 91

WKO K1A	aangesloten op R1, gebruik pompen WKO
WKO K1B	aangesloten op R2, gebruik pompen WKO

Appendix J: Fire safety (dutch)

Samenvatting

Naast klimaatbeheersing zal het hoofdgebouw brandveilig moeten zijn. In gesprek met Jan van de Kerkhof (DH) kwam naar voren dat het gebouw qua brandveiligheid wellicht als 'nieuwbouw' wordt gezien, wat strengere brandveiligheideisen betekend. Met open vloeren en atria is het lastig om aan de benodigde compartimentering te voldoen. Sprinklerinstallaties zijn een logische keuze maar betekend dat er per vloer een installatie aan het plafond wordt aangebracht.

Brandveiligheid

In principe wordt er gekeken naar drie belangrijke aspecten.
Brandcompartimenten, rookcompartimenten en vluchtwegen.

Vluchtwegen.

Het hoofdgebouw –in tegenstelling tot bijvoorbeeld Potentiaal- het geluk dat er vier trappenhuizen aanwezig zijn die de bovenbouw ontsluiten. Hiermee voorkom je extra maatregelen in de kopse kanten, waarvan nieuwe trappenhuizen de meest problematische zouden zijn. Wel moet er gekeken worden of de twee vluchttrappenhuizen capaciteit genoeg hebben en of er wellicht een brandvertragingszone rondom de trappenhuizen nodig is. De bovenste laag van het hoofdgebouw, oa de cafe/zaal 'de Tureluur' ligt boven de 50 m. hoogtegrens. Voor de brandveiligheid moeten trappen door deze hoogte een voorportaal hebben.

Brandcompartimenten.

IIn het huidige ontwerp bleek het zeer lastig om compartimenten aan te brengen. De brandoverslag bij de gevelaansluiting bij de tussenvloeren maakt dat compartimenten per dubbele verdieping zijn gehanteerd. Elke dubbele vloer is opgedeeld in vier zones plus de trappenhuizen. Deze oplossing zal in het nieuwe ontwerp niet meer voldoen omdat de compartimenten kleiner moeten zijn. Kantoorruimtes-compartimenten mogen maximaal 1000 m2 zijn. Als de toekomstige vloerindeling meer openheid vereist, moet gekeken worden naar alternatieven oplossingen voor brandveiligheid. Sprinkler installaties zijn een voor de hand liggende mogelijkheid. De scheiding tussen ruimtes met sprinklers er andere compartimenten moet 60 min brandwerend zijn. Deze oplossing is gecertificeerd en maakt een flexibele, toekomst bestendige vloerindeling mogelijk. Er zijn alternatieven die bijvoorbeeld door partijen als 'Effectis, TNO' kunnen worden gecertificeerd. Een spinkler gordijn, zoals ondermeer toegepast bij het hoofdkantoor van DHV, is een alternatief. Vraag blijft dan wel of er afdoende rookwering mee wordt bereikt en of het veel 'installatieplafond-oppervlakte' scheelt. Wellicht dat een extra rookgordijn en/of draftstop samen met een sprinklergordijn de brandveiligheid kan borgen.

Rookcompartimenten. – Naast brandcompartimentering moet tegen het gevaar van rookvorming in ruimtes zonder sprinklerinstallatie ook vluchtroutes mogelijk zijn van maximaal 30 m lang (of 20 m hemelsbreed) naar een andere ruimte gescheiden van de rook.

Integraal plan brandveiligheid

Brandveiligheid in al zijn facetten is voor project 2 opgenomen in het integraal plan brandveiligheid. Dit heeft als doelstelling om brandveiligheid overzichtelijk te houden en actief te betrekken bij eerdere ontwerpfases.

Oplossingrichting

1. Sprinklerinstallatie
Mogelijk is een sprinklerinstallatie per vloer een goede oplossing. Dit geeft flexibiliteit in toekomstig ruimtegebruik, de gewenste openheid van vloeren en open verbindingen naar oa atria. De oplossing vereist wel een installatie aan de onderkant van de bovengelegen vloer, met of zonder verlaagd plafond. De vloerhoogte is beperkt (2,7 m vrije hoogte).

Option 1. Sprinklerinstallatie	*Helpful*	*Harmful*
Internal	*Strength:* *- open vloerindeling*	*Weakness:* *- Expensive* *- Additional installation needed under floors needed*
External	*Opportunity:* *- Openess enhances daylight entrance* *- Less segmentation needed*	*Thread:* *- Sprinkler system is not flexible and doesn't stroke with modular system building construction (1,24 m)*

2. Sprinklergordijn met rookgordijn. Deze oplossing maakt de gewenst compartimentering mogelijk ten tijde van brand en houdt vloeren/atria open in verbinding. Deze beperkte installatie zal op enkele plekken 'neerlaatbare' muren vormen. Deze stroken kunnen verticaal, gelijk aan bijvoorbeeld de centrale installatieschachten voor ventilatie ed. ontsloten kunnen worden. [62]

Option 2. Sprinkler and smoke-'curtain' wall	*Helpful*	*Harmful*
Internal	*Strength:* *- Smaller installation needed* *- low costs*	*Weakness:* *- floors divided in compartments*
External	*Opportunity:* *- Openness enhances daylight entrance* *- Less segmentation needed*	*Thread:* *-*

3. Vloeraansluiting en beperking brandoverslag. De huidige onafdoende aansluiting van (tussen)vloeren op de gevel zorgt voor een dubbele hoogte van de compartimenten. Een brandveiligere aansluiting zal de compartimenten opdelen per vloer (waar gaan dubbele hoogtes zijn toegepast, dus met name de kantoorruimtes die ook qua branveiligheid hogere eisen hebben dan onderwijs/atelier ruimtes) in plaats van per twee vloeren.

Compartimentering. Maximale grootte 1000m^2 compartimenten, over een dubbele verdiepingshoogte om zo de openheid tussen tussen- en constructievloer te behouden. Zo voorkom je sprinklers en moeilijke aansluitingen op de gevel van tussenvloeren.

Option 2. Sprinkler and smoke-'curtain' wall	*Helpful*	*Harmful*
Internal	*Strength:* *- per floor larger compartments possible*	*Weakness:* *- connection with façade is difficult*
External	*Opportunity:* *- open floors with no sprinkler installation needed.*	*Thread:* *- Atria will connect floors again, so are less good combinable with this solution*

Appendix K: Façade concepts matrix

Façade type			description	zonwering	mogelijkheid natuurlijke ventilatie	Mogelijkheid mechanische ventilatie in gevel	buitenhouden ongewenste warmte (koeling)	binnenhouden gewenste warmte	kwijtraken ongewenste warmte via gevel	Isolatie	Transparantie	modulemaat	acoustiek	architectonische inpassing	cultuur historisch	bouwkosten	onderhoud	uitvoering
Enkele gevel	Vliesgevel/Gordijngevel	hangend stijl- en regelwerkgevel	Dubbele beglazing	intern	ja	nee	-	-	+	-	++	+	-	+	+	++	-	0
				extern	ja	nee	+	-	+	-	++	+	-	-	+	+	+	0
	Vliesgevel/Gordijngevel	elementengevel	Dubbele beglazing	intern	ja	nee	-	-	+	-	+	-	-	+	-	++	-	+
				extern	ja	nee	+	-	+	-	+	-	-	-	-	+	+	+
		hangend stijl- en regelwerkgevel	Drievoudige beglazing	intern	ja	nee	-	+	+	+	++	+	0	+	+	+	-	0
				extern	ja	nee	+	+	+	+	++	+	0	-	+	0	+	0
		elementengevel	Drievoudige beglazing	intern	ja	nee	-	-	+	+	+	-	0	+	-	++	-	+
				extern	ja	nee	+	-	+	+	+	-	0	-	-	+	+	+
Klimaat gevel	klimaatgevel - enkel glas binnenzijde		Drievoudige beglazing binnenblad en enkele laag buitenblad		nee	noodzakelijk	+	++	--	++	+	+	+	+	+	-	+	+
	(semi) klimaatgevel - doek binnenzijde				nee	noodzakelijk	+	+	--	++	-	+	+	+	+	0	+	0
Dubbele gevel	Tweede huid-gevel	Dubbele gevel	Drievoudige beglazing binnenblad en enkele laag buitenblad	opgenomen in spouw (1/3 van buitenblad)	ja	mogelijk	+	+	0	+	+	-	+	0	+	--	0	-
		Gevel, boxframe	Drievoudige beglazing binnenblad en enkele laag buitenblad	opgenomen in spouw (1/3 van buitenblad)	ja	mogelijk	+	+	0	+	+	-	+	0	+	--	0	-
		Corridorgevel	Drievoudige beglazing binnenblad en enkele laag buitenblad	opgenomen in spouw (1/3 van buitenblad)	ja	mogelijk	+	+	0	+	+	-	+	0	+	--	0	-
		Shaftbox gevel	Drievoudige beglazing binnenblad en enkele laag buitenblad	opgenomen in spouw (1/3 van buitenblad)	ja	mogelijk	+	+	0	+	+	-	+	0	+	--	0	-

integratie solar energy systemen anders dan PV	integratie zonnepanelen PV	gewicht 1=lichtgewicht	mogelijkheid tot nachtventilatie	integratie verwarming/koeling	tegengaan brandoverslag	warmte winning	benodigd vloeroppervlakte	CO2 materiaal gebruik	(personal) controllability comfort	eenvoud constructie (itt complexity)	thermisch comfort	tussenseizoen	winter	zomer	demonteerbaar voor lifecycle	flexibel toekomst pv	contact in- en exterieur
-	-	1	+	-	0	-	+	0	+	+	0	0	-	0	0	0	+
-	-	2	+	-	0	-	+	0	+	+	0	0	-	0	0	0	+
-	-	2	+	+	+	-	+	0	+	++	0	0	-	0	++	0	+
-	-	3	+	+	+	-	+	0	+	++	0	0	-	0	++	0	+
-	-	3	+	-	0	-	+	0	+	+	+	0	0	+	0	+	+
-	-	4	+	-	0	-	+	0	+	+	+	0	0	+	0	+	+
-	-	4	+	+	+	-	+	0	+	++	+	0	0	+	++	+	+
-	-	5	+	+	+	-	+	0	+	++	+	0	0	+	++	+	+
0	-	6	--	+	0	++	-	0	--	--	0	-	+	0	--	-	-
0	-	6	--	+	0	++	-	0	--	--	0	-	+	0	--	-	-
+	+	7	++	0	--	+	--	+	+	-	+	+	0	+	0	++	--
+	+	7	++	0	-	+	--	+	+	-	+	+	0	+	0	++	--
+	+	7	++	+	-	+	--	+	+	-	+	+	0	+	0	++	--
+	+	7	++	++	--	+	--	+	+	--	+	+	0	+	0	++	--

Appendix L: Calculation internal cooling load

The Main Building interior climate is influenced by internal heat gains due to operational processes. These processes consists out of people, apparatus and lighting heat generation. The internal cooling load for an compartment is determined using the method as described in ISSO publication ‘Kleintje koellast’, 2010.

Total heat gain

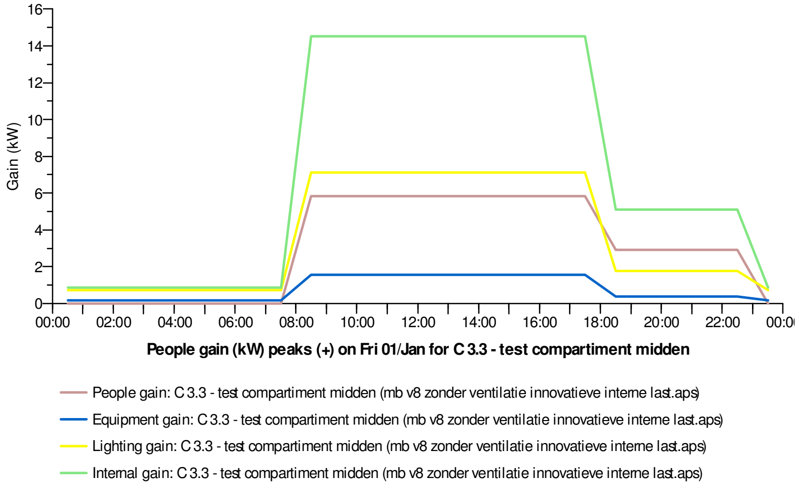
Time profile people

The Main Building will be flexible in use, assumed is an 50% occupancy rate during office hours (08:00-18:00) and 25% occupancy rate during evening hours (18:00-23:00). During nighttime (23:00-08:00) the building is closed and there will be no users present.

Time profile Apparatus and lighting

Due to presence detection for artificial lighting and automatic standby switches on apparatus, the time profile will be almost the same as for the people, except for nightly hours (23:00-08:00), where both lighting and apparatus will be active for 10%, due to safety lighting and standby modus.

Time period	0800-18:00	18:00-23:00	23:00-08:00	24:00 gem
Internal heat gain [W/compartment]	17461,20	4365,30	1746,12	8839,73
Average [W/m2]	17,37	4,3429	1,74	



Heat generation devices

For heat generation of apparatus, two scenarios are defined. The first is conventional, where a normal rate of PC's and laptops is assumed. A 15 W/m2 is defined by ISSO publication 33 (1996). This is an rather old standard and with modern technologies of tomorrow, not suitable for future estimations. The second scenario assumes a more innovative media, based on the concept of 'thin clients' a general datacenter (in basement or elsewhere on campus) is assumed, and within compartments, people are working with screens/tablets only within the TU/e cloud. This VDI-solution assumes a 11 Watts/person, where conventional laptops (57 W) and PC's (90 W) would produce a much higher power output.

Formula	**Q_m=N*m_1*m_2 [W]**		
N = nominal connected power	[W]		
m1 = usage factor			
m2 = similarity factor			
Conventional scenario	N [W/m2]	N [W]	
Warmteafgifte apparatuur	15	15077,43	
laptops/beeldschermen/desktops	-	30	
kopieerapparaat	-	400 (10)	
koffiecorners etc	-	30	
Grote grafische schermen	-	150	
Adapter telefoon etc.	-	10	
Innovative scenario	N [W/p]	m1*m2	W/comp
VDI-oplossing, *thin clients* concept	11	0,5;0,5 (44)	483,0054
kopieerapp.	3	0,9 (standby); 0,1 (use)	147
Grote grafische schermen	4	1,0	600
koffiecorners etc	4	1,0	120
Adapter telefoon etc.	10	0,5;0,5	219,5479
Q_m (total app. per compartiment)			**1569,55**

Heat generation lighting

For lighting, daylight and presence detection are both possible. Assumed is an average installed power capacity of 8,5 W/m2, comparable with the value assumed for Project 2 on the campus. Open ceiling are assumed with no extra heat extraction.

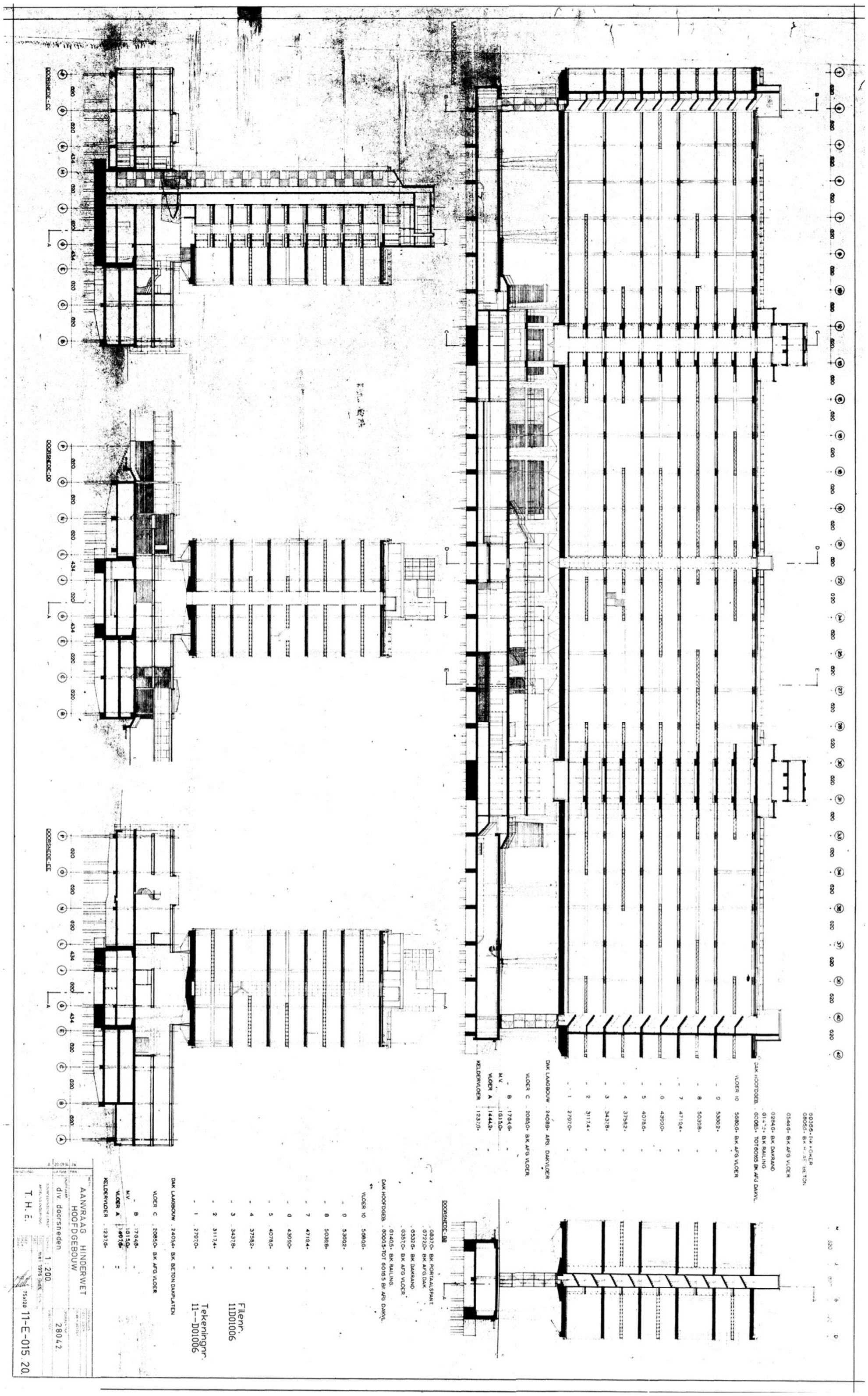
Formula	$Q_l=N_1*l_1*l_2$ [W]			
Average installed power	$N_{average}$	[W/m2]	8,5	
Total installed power	N_l	[W/m2]	8543,88	
Reduction factor heat extraction armature	l_1	[-]	1	*No heat extraction at armatures*
Adjustmentfactor accumulation active thermal mass	l_2	[-]	0,832143	*Free placement, no local heat extraction*
Convection factor	CF_l	[-]	0,5	*Assumed Active thermal mass factor '90'[SWM]*
Heat generation artificial lighting	**Q_l**	**[W]**	**7109,728**	
Adjustment factor heat extraction		Time	S_{lv}	
Source: *'tabel 3.7+3.8 Kleintje Koellast'*		12:00	0,58	
		13:00	0,61	
		14:00	0,64	
		15:00	0,66	
		16:00	0,71	
		17:00	0,72	
		18:00	0,73	
		Average	0,66	

Heat generation People

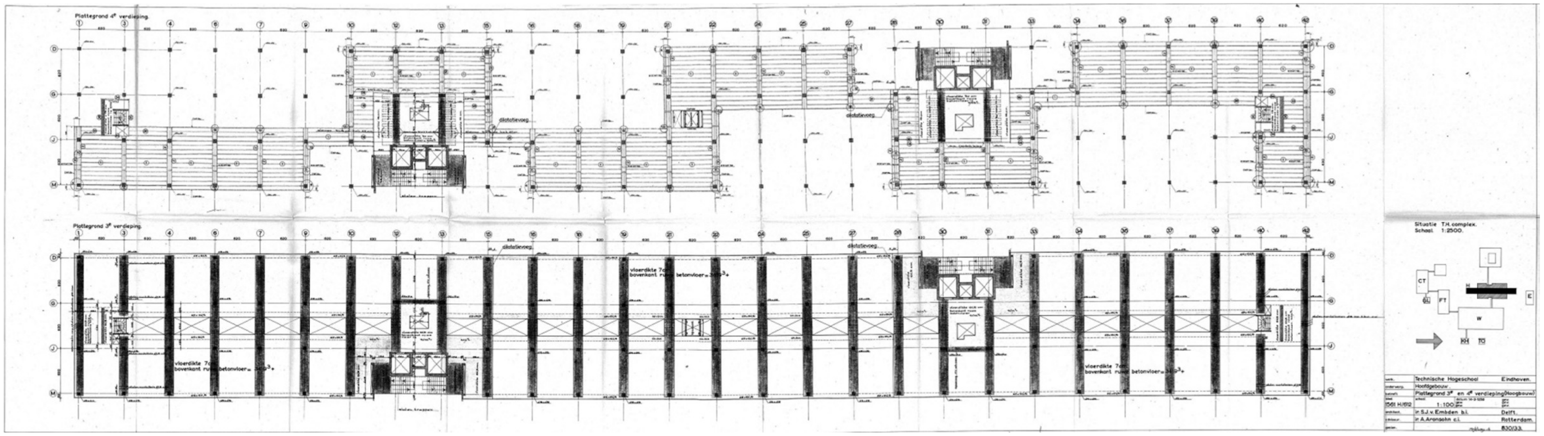
The Main Building will be mostly used for office related and educational purposes. People have an average power output of 100 Watt. The occupancy profile are based on Project 3 standards. On average, this gives an average full (100%) occupancy of 117 people per compartment.

Formula	$Qp=n*c_k*P_p$				
Number of persons in compartment daytime	n	87,81917			
Correction factor clothing	c_k	1			
Sensible heat per person [W/p]	P_p	100			
Heat generation [persons/compartment]	$Q_{p\ [W]}$	8781,917			
Pp sitting in office [W]	100				
Correctiefactor kleding	C_k [-]				
zomerkleding [clo 0,3-0,5]	1				
Compartiment [m2]	1005,16				
Structural floor [m2]	670,1082				
Flexible floor [m2]	335,05				
Bezetting	p/m2 P3 standards	% total	n	Occupancy rate	
Student	6,27	0,72	115,0802	0,5	57,54011
MW	9,12	0,27	29,4606	1	
HG	18,24	0,01	0,818458	1	
totaal		1,00			87,81917

Appendix M: Original building drawings



Original building floor plan


Plattegrond 4e verdieping.
Plattegrond 3e verdieping.
vloerdikte 7cm
bovenkant ruwe betonvloer
Situatie T.H. complex.
Schaal 1:2500.
CT
GL
FT
H
W
E
KH
TO
Technische Hogeschool Eindhoven.
Hoofdgebouw.
Plattegrond 3e en 4e verdieping (Hoogbouw)
1561 H/612
1:100
ir. S.J. v. Embden b.i. Delft.
ir. A. Aronsohn c.i. Rotterdam.
830/33.

Appendix N: Dimensioning of the façade

The guidelines for the façade result in a dimensioning according to following assumptions:

Table 0.1. Characteristics per compartment

Persons (p)	Size (m^2)
145,36	1005,16

Table 0.2. characteristics per facade array

Dimensions	Broadness (m)	broadness opening (m)	Height (m)	floor depth (m)	Façade surface (m^2)	adjacent floor surface (m^2)
façade array	1,24	1,14	3,2	9,93	3,968	12,31

Table 0.3. Required ventilation capacity

Frisse Scholen label A	$dm^3/s/p$	$dm^3/s/compartment$	$dm^3/s/m^2$
Continuous ventilation	12	1744,31	1,74
Purge ventilation	-	-	9

Table 0.4. . Ventilation capacity per facade array

Needed capacity	continuous ventilation (dm^3/s)	Purge ventilation (dm^3/s)
Façade array	21,37	89,45

Ventilation grills capacity

Grill(0,10 m height) has a capacity of 20 $dm^3/s/m$ (by means of the broadness of the grill)
1,14 broadness * 20 dm^3/s = 22,80 l/s > 21,37 dm^3/s, exceeding requirement of Frisse Scholen label A, continuous ventilation;

Openable windows

- Ventilation capacity: 1 dm^3/s per 12 cm^2 opening (Source: NPR 1088; 3.2.1.1.)
- 89,27 * 12 = 1071,25 cm^2 opening surface per façade array
- 1071,25 /114,0 (façade broadness) = 9,42 cm. required depth for a window covering full broadness of an façade array minus framework for maximum purge capacity.
- Openable windows (klepramen) as in potential building (adjacent and similar conditions as Main Building) have an openable depth of 10 cm and height of ± 45 cm.
- OR: vertical parallel openable window (parallel uitzetraam), which has a larger open surface area. Over full height length of 2,70 m. 270*2*4=2160 cm^2 opening, more than double of required purge ventilation capacity.
- Assumed openness of the façade for west and east is 50-60%. Per façade array (1,24*3,20), this results in a closed part:
- Adjacent to opaque floor: 05,*1,24=0,62 m2
- Framework (2*0,07 m. broadness) + apron wall (borstwering) of 0,88 m. height
- Open part: Opening: 1,14*1,82= 2,0 m2

Appendix O: description excel files (dutch)

Als bijlage aan dit rapport zijn drie excel files toegevoegd. Omwille van de bruikbaarheid van de berekeningen en herleidbaarheid van gebruikte informatie en formules, is er voor gekozen de bestanden niet te 'bevriezen' maar op te schonen en als werkbestanden aan te bieden. De informatie per bestand zijn hieronder beschreven:

Overzicht informatie excel-bestand *'Hoofdgebouw_bezonning_thermal load_pv berekening'*:

1. Data bezonning KNMI
2. Berekening horizontale en verticale bezonning
3. Façade en dak PV paneel energie efficiency en jaarproductie
4. Vergelijking verschillende type beglazing op basis van thermische energie efficiency Hoofdgebouw
5. Berekening koellast HG hoogbouw op basis van ISSO Kleintje Koellast
6. Data bezonning afkomstig uit model studie Hoofdgebouw (IES model)
7. Modelstudie uitkomsten (IES model)
    - vergelijking 6 type beglazing op basis van energie efficiency
    - vergelijking energie efficiency verschillende type zonwering
    - vergelijking energie efficiency externe fin-constructies
    - vergelijking energie efficiency verschillende ventilatie concepten/debieten

Overzicht informatie excel bestand ‘*Hoofdgebouw_algemeen’*:

1. Data TU/e WKO installatie
2. Vloeroppervlak
3. Indicatie gewicht gevel
4. Vergelijking meerdere vloer/gevel ratio’s
5. Matrix vergelijking geveltypen
6. Matrix vergelijking ventilatie principes
7. Matrix vergelijking ventilatie principes
8. Technische specificatie meerdere type beglazing
9. Ventilatie eis per compartiment
10. TU/e uitgaven 2012

Overzicht informatie excel bestand '*Hoofdgebouw_energieverbruik 2006_2011*':

1. Proces+noodstroom data
2. Koeling data
3. Licht data
4. Warmte data
5. Licht
6. Koeling
7. Warmte
8. Proces
9. Energie verbruik totaal
10. Bezetting historisch
11. Bezetting toekomstig

3TU.School for Technological Design, Stan Ackermans Institute offers two-year postgraduate technological designer programmes. This institute is a joint initiative of the three technological universities of the Netherlands: Delft University of Technology, Eindhoven University of Technology and University of Twente. For more information please visit: www.3tu.nl/sai.