Sustainable Facades
For The Energy Museum

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August 2010

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Preface

This Master Thesis finishes my degree in Civil Engineering at the Technical University Delft. The thesis is made possible with the help of the section of Building Engineering, Climate Design, Structural Engineering and Sustainability.

This master thesis is about sustainable design with respect to the design of the energy museum. The main concern lies in the sustainability of the facades of the energy museum. This report shows the results of the different aspects which appear while designing the energy museum in a sustainable matter.

I would like to thank all the members of the graduation commission, Prof.dr. ir. E.M. Haas, Prof.dr.ir. J.C. Walraven, ir. H.R. Schipper, dr. G.J. de Bruin-Hordijk and ir. R.H.J. Looman for all the help and guidance during this process. It was a great honor to have been given the opportunity to study under guidance of this inspiring commission. I would also like to thank those who were involved in any kind of matter and for supplying me with useful information with respect to the subject of this master thesis.

Solmaz Esmailzadeh
Amsterdam, August 2010

Abstract

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1. Introduction

In this section of the master thesis a brief description about the history of sustainability is given. Subsequently the problem description, the aim and the outline for this master thesis are described.

1.1 History

In the year of 1992 a conference for environment and development of the UN took place in Rio de Janeiro. Member states agreed to pursue sustainable development globally[1]. Ever since this term has reached the society on an international scale.

The term sustainable development can be defined as the development which provides in the need for the current generation without endangering the need of future generations. At this moment human society lives in too great style, humanity demands more from the earth, than it can provide. Moreover the impact of climate changes as a result of the increasing greenhouse gas emissions is tremendous. It is therefore of high importance that a positive change is made.

There are many different ways to contribute to 'Sustainable Development'; one of those ways is by Sustainable Construction. Research by Professor Hendriks (TU Delft) showed that the contribution coming from the building industry to the infestation of the Ozone layer is 25% and the contribution of the construction industry to the greenhouse impact is about 33%. Looking at waste products the impact is even higher, namely 40%.[2] It is therefore important that the environmental effects from the construction industry should be looked at very critically.

[1] Report of the United Nations Conference on Environment and Development, Rio de Janeiro, 3-14 June 1992

[2] Prof. dr.ir. Hendriks; TU Delft-Duurzame Bouwmaterialen 1999

Sustainable construction can be defined as a manner of constructing where environmental- and health effects due to constructing, usage, restoration or dismantling will be reduced to a minimum. Sustainable construction can contribute by that manner to the solution of the worldwide environmental issues such as climate infestation by greenhouse gasses and the exhaustion of the natural resources.

The design of facades lends itself strongly for an approach where sustainability is an important criterion. The facade itself is an intermediate between inside and outside climate. The facade of the building is the visible outer side with the primary function of protecting the inside of the building from influences coming from outside. The facade provides daylight, protects against rain, wind, noise and sun and controls heat transmissions.

There was an idea to create an energy museum on the pier of Scheveningen. The energy museum should be a museum where expositions about different theme's of renewable energy should be given. The presentation about the knowledge concerning renewable energy and its innovation would be the main topic.

The location for the energy museum will be on the pier of Scheveningen on one of the existing islands. The exact location is not yet determined. A location on sea where there is a lot of wind, sun and wave action is ideal for a research centre that is concerned with renewable energy. Scheveningen is also a city where tourism is very common. Tourists from all over the world could visit the museum. In image 1 an impression of the pier and its islands is given.

The application of sustainable facades for this specific building has a lot of potential, while there can be a strong relation between the function of the building and the design of the building envelope. It is for this reason that this specific building is used as an illustration of the potential of sustainable facades in this master thesis.

Img. 1 Pier of Scheveningen, the location of the energy museum will be on one of the platforms

1.2 Problem Description

From an occupant point of view buildings should not be made without a climate concept. The facades can play an important role in this matter, while it strongly determines indoor climate e.g. building physical aspects like thermal insulation, sound insulation, ventilation, moisture and light entrance. In the building decree all the building regulations are laid down, also the regulations concerning the above mentioned aspects. The building decree presumes a minimum level, but in practice the quality level is pushed much higher. This makes construction even more complex.

Besides the building physical demands there are more aspects concerning facades which should be taken into account, which are also laid down in the building decree:

- Health
- Accessibility
- Structural Safety
- Fire Safety

Sustainability is not yet a term which is described in the building decree. However it is a very important theme of this moment. The ultimate scenario would be if facades meet all the requirements concerning energy and comfort. This means that an intelligent skin for the building would contribute enormously.

Nowadays there are quite some developments on the field of facade systems. The active facade, also known as the climate facade is a good example. This facade uses daylight, sun heat and ventilation in an intelligent way to control the climate indoors. These types of sustainable facades are kind of rigid. Modern facades should be more open and especially more adjustable in their lifecycle. Energy production-, savings- and distribution, but also optimizing comfort inside, such as light regulation and ventilation, are themes which fit excellently in the field of sustainable facades. An optimal facade can contribute enormously to using natural resources and energy in a responsible way. This can lead to high reduction of the environmental loads.

In fact we could assume that an optimal facade depends strongly on the function of a building. In this thesis, the building for which an optimum sustainable facade will be designed is the energy museum described above. For this specific case, the situation is excellent to apply a special facade system which can be called ‘sustainable’ as well. The building has the form of a Cube. The architect decided to go for the cube because it is a pure form which offers a lot of possibilities.

1.3 Aim

Sustainability is a broad conception; in 1987 the World Commission on Environment and Development defined sustainable development as development which meets the needs of the present without compromising the ability of future generations to meet their own needs'.[3] It is clear that sustainability can be accomplished in many different ways and fields. In this master thesis, sustainability within buildings is the main topic. Material usage and energy consumption are by far the two most important factors within sustainability in the building industry.

The aim of this master thesis is to obtain certain knowledge about sustainability in the building construction industry to eventually translate the knowledge into the design of the energy museum and in particular the facades of the energy museum. By means of a research in three subjects which concern sustainability, namely: materials, renewable energy and innovations on facades the aim is to combine elements from the three subjects in the design of the energy museum. The purpose is then creating an optimal building envelope for the energy museum, which is located on the pier in the sea, by combining different kind of sustainable measures, which are as less as possible endangering for the environment.

The building envelope should fulfill more than one function at the same time, optimized on material and energy level.

1.4 Thesis outline

The research is structured as follows:
In the following chapter a brief description about the history of sustainability is described. This is then followed by a summary of the cradle to cradle (C2C) concept and Life Cycle Analyses. Subsequently an overview of available tools which can be applied during sustainable design is given. In the following chapters a literature review on three aspects within the sustainability field is done. The three aspects are: materials, renewable energy and innovations on facades.

In chapter 3 five commonly used facade materials and their properties are described. First descriptions are given about their properties which are not related to sustainability are given, this part is to get to know the materials in general and obtain knowledge about their general properties, before starting to look at materials on sustainability part. Followed by tables and information about their relation with respect to the environment and sustainability. The purpose of this approach is to obtain some information about these materials before looking at these materials from a sustainable point of view, to eventually combine both general advantages and sustainable advantages in the design.

Energy plays an important role in designing sustainable buildings. There are quite some innovations on energy level, nowadays there are several forms of renewable energy available. In chapter 4 an overview is given of the most common types of renewable energy. The chapter ends with a comparison of the different kinds of methods, where eventually a choice is made for one type of renewable energy to be applied in the design of the energy museum.

After a review on materials and renewable energy, innovations on facades are looked over. The review of this topic is given in chapter 5. Like both other aspects also in this chapter a choice is made for which innovative techniques will be applied in the energy museum.

With all the available information concerning the topics above, the report continues with several practical examples of buildings which are built with different sustainable measures on different levels in chapter 6. The aim is to obtain knowledge about how the building sector at this moment looks to sustainability and on what level sustainable measures are applied.

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[3] *United Nations Department of Economic and Social Affairs(DESA);* 96th plenary meeting *11 December 1987 http://www.un.org/documents/ga/res/42/ares42-187.htm*

The actual architectural design of the energy museum, all the requirements and the structural concept are laid down in chapter seven. The requirements are distinguished in general requirements, requirements especifically for facades and then followed by the requirements with respect to sustainability. The concept for the architectural design is made clear by means of drawings. The concept for the structure of the energy museum is also described in this part of the thesis.

From this point on with the knowledge about sustainability and the design of the building with its requirements the research can be initiated. Chapter 8 is the part where the actual research takes place. Three sustainable measures, one on material part, one on renewable energy part and one measure on innovations on facades will be investigated. At first all three measures are researched separately, where in the end all three measures are combined in the facades of the energy museum, which is the eventual aim of this master thesis.

2. Review of sustainability

In this chapter a review of the relevant literature concerning the research topic is considered. After a summary of background information with respect to sustainability, the recent development about the principle 'cradle to cradle' is considered. This principle shall be taken into account very carefully during this master thesis, because of the growing development of sustainability and the ability to build as sustainable as possible. Subsequently the term 'life cycle analysis' will be explained. This procedure is indispensible within sustainable construction. To optimize sustainability within the construction industry several tools are developed for the design process and also software tools are available to measure sustainability during the design process and afterwards. These tools are also described in this part of the thesis. One of the measuring tools will be applied further on in this thesis to measure sustainability on material and energy part.

2.1 Background information

In June 1972 UN's first major conference on international environmental issues took place and marked a turning point in the development of international environmental politics. The conference also known as the Stockholm Conference was an initiative of the Government of Sweden[4].
The meeting agreed upon a declaration containing 26 principles concerning the environment and development. In that same year one can say that the first warning about the rapidly growing world population and finite resource supplies was given by the Club of Rome in a book called: The limits to growth. This study presumes the current growth in world population, industrialization, pollution, food production and exhaustion of natural recourses. With these variables the development from 1900 till 1970 was determined. Subsequently the trends were preceded assuming

[4] UNEP; Report: Integrating Environment and Development;p.4
http://www.unep.org/GEO/geo3/pdfs/Chapter1.pdf

that no important changes will occur in physical, economical and social relations. The output of this extrapolation was shocking. The natural recourses would be worn out in the near future. The world population and pollution would increase in a short period of time, but because of the deterioration of the food supply and the healthcare it would lead to stagnation and later to decrease in world population[5]. Eventually none of the prognoses came true and there was a lot of criticism towards the report. However the report did take care of the fact that the 'environment' was now an important issue on the political agenda worldwide[6].

In 1988 the greenhouse effect was recognized as a problem by the establishment of the IPCC (Intergovernmental Panel on Climate Change). The greenhouse effect relates to the gases in the earth's atmosphere, which form a protective layer and are quite transparent to incoming short wave radiation from the sun. However the gases forming the atmosphere are opaque to longer wave radiation which is emitted back from the warmed surface of the earth. Without this effect the temperature of the earth would be that low, which would make the earth not livable. Because of humans activity the concentration of greenhouse gases has increased and is therefore believed to be responsible for the warming of the earth's surface.

The greenhouse gas carbon dioxide (CO_2) is considered to have the most significant effect on global warming. The main anthropogenic source of greenhouse gases is the combustion of fossil fuels, mostly for energy and transportation. Increasing of population, industrialization, energy and resource consumption are examples of ways of exacerbating the greenhouse effect.

[5] Meadows, D; Randers, J; Meadows, D; Synopsis: The limits to growth-a 3o year update; http://www.clubofrome.at/archive/limits.pdf

[6] UNEP; Report: Integrating Environment and Development;p.3 http://www.unep.org/GEO/geo3/pdfs/Chapter1.pdf

Especially after the conference which was held in Rio de Janeiro on Environment and Development, the whole world is informed about sustainable development; sustainability has become a wide ranging term that can be applied to almost every facet of life on Earth, from a local to a global scale and over various time periods.

2.2 Cradle to Cradle

Because of this global environmental thinking the concept Cradle to Cradle (C2C), created by Michael Braungart and William McDonough was introduced to the world. According to the authors, current human technology is a product of 'cradle to grave' design. We pull resources from the earth, shape them into a product, use it and throw it away. The problem here is as we have spread all over the planet, is that there really doesn't exist such a thing as 'away'[7]. Considering the typical 'recycling' what is presented to the public as a way to endlessly reuse raw materials is in fact a downward spiral of degradation in material quality until, just as before it becomes unusable. Sometimes the recycling process itself produces additional toxic waste[8]. The strategy that is proposed in the book Cradle to Cradle is called 'eco-effectiveness'. It revolves around the idea that in nature, waste equals food[9]. Other than incoming energy from the sun, our environment is basically a closed system. Whenever non human life on our planet uses a resource, it is left in a form readily useable to other life. The case is that also humans must do the same thing. The book envisions a world where, when a material item gets worn out, you simply throw it on the ground to decompose.

Building with the C2C concept goes further than building energy efficiently, CO_2 neutral. Recovering nutrients and allow for material flow

[7] Braungart, M; McDonough, W: Cradle to Cradle, Remaking the Way We Make, p.37
[8] Braungart, M; McDonough, W: Cradle to Cradle, Remaking the Way We Make, p.71-74
[9] Braungart, M; McDonough, W: Cradle to Cradle, Remaking the Way We Make, p.114

management is a huge part of the C2C principles. Eliminate the concept of 'waste' entirely. Every residue should become a natural resource so that all human creations (techno sphere) stays in balance with the natural world (biosphere). To fully implement C2C in architecture one needs to enhance the working knowledge on materials and building products and their continuous cycles.

Eco-effectivity

Eco-efficiency is about limiting the damage to the environment and reducing waste and pollution. Whereas eco-efficiency is concerned about minimizing the negative effect of the industry, eco-effectiveness is about maximizing the positive effects of the industry. Cradle to Cradle is covering the concept of eco-effectivity. A new strategic vision for designing industrial processes so that these are safe, healthy and profitable and besides that they should also have economical, ecological and social values[10].

Eco-effective concepts presume a cyclic approach. Walter Stahel is the founder of this manner of thinking. He came up with concepts as eco-design and Life Cycle Analyses.

In the book Cradle to Cradle the authors came up with a plan containing five steps to eco-effectiveness[11]:

1. The removal of a specific chemical from a product widely known to be harmful, such as lead or chlorine.
2. The customer or manufacturer makes a list of preferred, readily available materials based on scientific experience.
3. Producing a so called 'passive positive material' list; in this step you examine the palette of materials used in an existing product while it continues to be manufactured. The goal is to replace problematic substances so production can continue.
4. The initial design phase of new eco-effective products. The activation of the 'positive list' takes place in this step.
5. Reinventing; this final step has no absolute endpoint and the results can deliver a totally new product compared with the product you had in mind in the starting phase. It will be more of an evolution of that particular product.

2.3 Life cycle analysis

LCA can be defined in several ways, according to ISO 14040 LCA is a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle[12].

The different stages in a life cycle assessment are the following:

- Extraction and processing of materials
- Manufacturing process
- Distribution of products
- Usage of products
- Life ending of a product

In all stages waste is produced and energy is consumed. An LCA determines the environmental impacts of products during all above mention stages.
Most life cycle assessments are carried out with software tools. According to a survey of LCA practitioners 58% of respondents used GaBi Software,

[10] Braungart, M; McDonough, W: Cradle to Cradle, Remaking the Way We Make, p.85-91

[11] Braungart, M; McDonough, W: Cradle to Cradle, Remaking the Way We Make, p.202-220

[12] ISO 14040.2 Draft: Life Cycle Assessment - Principles and Guidelines

developed by PE International, 31% used SimaPro developed by PRé Consultants, and 11% a series of other tools[13].

2.4 Manual for sustainable design

In the Netherlands there are three toolkits available with concepts and practical manuals for sustainable design. These manuals can be applied for the design of dwellings or utility buildings. Below one can find a brief description of all manuals.

The three manuals are the following:

- The manual for sustainable dwelling II[14]
- The manual for existing buildings[15]
- The manual for sustainable office buildings[16]

Manual for sustainable dwelling II

For dwelling the aspect energy is most important, how to reduce the energy consumption inside a dwelling by means of energy concepts. Within this manual twelve energy concepts are given to reduce the CO_2 production. Water is also important within dwellings. Especially for domestic water and water used for heating has a strong relationship with energy consumption. Therefore both aspects are taken into account. One can contribute to quality aspects like comfort health, safety and sustainability by applying concepts which are laid down in the toolkit for dwellings II. The twelve energy concepts are examples of how materials and installations in a dwelling can be applied to gain the desired level of comfort.

[13] Cooper, J.S.; Fava, J. "Life Cycle Assessment Practitioner Survey: Summary of Results" (2006), *Journal of Industrial Ecology*

[14] Toolkit Duurzame Woningbouw; Uitgeverij ENEA

[15] Toolkit Bestaande Bouw; Uitgeverij ENEAS

[16] Toolkit Duurzame kantoren; Uitgeverij ENEAS

Manual for existing buildings

This particular toolkit for existing buildings can be considered a manual with practical and integral solutions for energy savings and also information on how to apply renewable energy in existing buildings. The manual contains 90 renovation concepts distinguished for 5 types of dwellings. All 90 concepts are based on EPA-calculations. Energy is the concept which takes the most important role.

Manual for sustainable office buildings

This manual is a manual which makes it possible to manage the development and design process of sustainable and energy efficient office buildings. The manual contains three reference offices for which multiple energy concepts have been calculated on energy consumption and CO_2 emissions. This particular manual is provided with tools which can be applied to measure sustainability. All scores are regarded in the manual.

2.5 Software tools to measure sustainability

Not only is it of high importance that there are tools available which makes the design process with respect to sustainability easier, it is also important to actually measure the rate of sustainability of a building. At this moment there are several tools available which measure the sustainability of a building. The units in which they measure are not all the same. However the future plan is to obtain harmonization for all commonly used tools. Below one can find a brief description of commonly applied tools in the Netherlands.

GPR Building

GPR (which stands for Gemeentelijk Pratijk Richtlijn) building is a digital tool which shows the sustainability of dwelling, utility buildings and office buildings. Aspects like energy, environment, health, usage quality and future value are measured on a scale from 1 to 10. This tool is not only applicable for new buildings, but also for already existing buildings. For the last category it is possible to apply GPR building and to gain insight on the quality improvement after an operation.

GreenCalc+

GreenCalc+ is a tool which can be compared to GPR building. This software tool estimates a single building or a district on sustainability. The unit in which the results are measured is called the environmental-index. This environmental-index is a value which contains aspects like; water usage, energy usage, material usage and mobility. The MIG-value is the output of the lifecycle analysis of a building that comes from the software GreenCalc+. Energy use determines the eventual results for 75 till 85%, materials about 15 till 20% and water usage for 2 to 3%. The higher the value the more sustainable the building is.

BREEAM-NL

This tool is a method which estimates sustainability for buildings. BREEAM (which stands for Building Research Establishment Environmental Assessment Method), officially this tool was developed and introduced by the Building Research Establishment (BRE). The addition NL clarifies that this version of the tool consists of a Dutch version. It is specifically meant for the certification of new buildings and renovation projects. The system measures several quality aspects and the unit in which it measures is a total score with a value as: pass, good, very good, excellent or outstanding.

DuboCalc

DuboCalc is a software tool which calculates the environmental effects of the material and energy usage of infrastructural projects. DuboCalc converts the environmental effects to so called Environmental Costs Indicator (MKI). DuboCalc is based on life cycle analysis and shows the impact of a project towards the environment. Because it is based on life cycle analysis all environmental effects starting from extraction to demolition and re-use phases are considered.

Cooperation

The owners of the different above mentioned software tools GPR building, GreenCalc+ and BREEAM-NL have taken the initiative to develop one shared language when it comes to measurements of buildings on sustainability aspects. When all these tools start to use the same calculation methods and make use of the same concepts a consistency can be reached. Besides that, in this way these tools can be complementary to one another.

DuboCalc is not part of this cooperation and because of the fact that within this paper the main focus lies on buildings, DuboCalc will not be taken into account further more.

GreenCalc+ will be the first tool which will implement appointments which were made by all parties who cooperate in the harmonization of all tools. The first update of GreenCalc+ will be presented in the autumn of 2010. Also the measuring of sustainability within this master thesis GreenCalc+ will be applied, both on material performance and also on energy performances.

3. Facade materials

3.1 Introduction

In this part of the master thesis several materials which are applied frequently as facade materials will be discussed. This section starts with a description of four commonly used materials and their properties as its advantages and disadvantages. In the first place this part is not about the sustainability of these materials, because it is not possible to discuss all materials which are applicable for facades a few common ones are considered. The materials are discussed in the following order: concrete, steel plates, timber and glass.

Facades are one of the most technically challenging, complex and multidisciplinary parts of a building. A facade defines not only a buildings appearance, but also how well it functions with regard to comfort, safety, pleasant ambience and sustainability. The facade is the intermediary between the in- and outside climate. It provides daylight, resists rain-, wind-, sound and sun influences and prevents heat losses. Therefore facades play an important role and have to fulfill several technical and architectural demands and functions related to a broad range of aspects and engineering disciplines[17]

3.2 Concrete

Facades in concrete contain two techniques which are both used for facade structures, namely: 'in situ concrete' and 'precast concrete'. Precast concrete lends itself more for the application in the facade industry in comparison with 'In situ concrete'.

Within the facade sector one can also distinguish concrete load bearing facades and concrete non-load bearing facades. In the case of load bearing concrete facades the facade elements bear the floors and the above lying structure. The classic form of this type of facade is the sandwich panel which consists of two concrete panels which are separated by a layer of thermal insulation. The inner panel normally has the function of the load bearing panel. The facade can also consist of load-bearing parapets. These then function as beams which transfer the loads from the floors to the columns.

Non-load bearing facades only fulfill the separating function besides the building physical functions. The elements can either be connected to the structure separately or they can be self supporting.

Some important features and advantages of concrete are listed below.

- Design flexibility
- Aesthetics
- Quality control
- Structural capabilities, integration with structural purposes
- Durability
- Thermal mass and acoustical insulation
- Fire resistance
- Low maintenance
- Quick assembly and labor savings
- Air tightness
- Ground sources for the production of concrete are common and easy to gain on planet Earth

[17] Bersgma, A; AR3B430: Façade technology Course Information: version 27-08-2009; Course description Facade Technology

Besides these advantages there are also some disadvantages to the application of concrete in the facade industry.

- Sustainability (CO_2 emission)
- Use of energy during transport
- limited adaptability

3.3 Steel

Whenever steel is used as a material for facades, one usually speaks in terms of steel plates. There are two types of steel kinds which are applied for facades and roofs. Carbon steel and Alloy steel. The alloyed steel kinds can be applied in facades and roofs without them being treated beforehand. Though, attention to detailing and precipitation is needed. Strength steel is nearly never applied when not treated beforehand.

Rolled, thin plates are mostly applied as facades. It is possible to provide for a structure, texture or cloques, before applying a coating. The reshaping can be done with hot or cold rolling and additional treatments

A steel plate can fulfill a structural function as well as an esthetical function. In case of facades the steel plates are visible. In case of sandwich panels a core of insulation with two thin plates are glued on both sides. The facade can be made wind and waterproof in one time.

The composition of steel facades is often still 'traditional'. The steel plate and insulation are constructed on a stony background, which is for example a steel or concrete inner leave. This distinguishes the outer facade and the construction behind it. During detailing of the outer facades one has to pay attention to avoid thermal bridges, air leakages and water disposal. Thermal bridges can arise because inner cladding and the steel plate are connected directly to each other, where conductance of heat or cold from outside to inside and vice versa can occur. This can lead to problems in large surfaces. A good insulation can be realized by minimizing the number of contact points between inside and outside or to interrupt the direct connection with the insulating material, the so called thermal bridge-obstructer. In detailing the direct connection between the outer plate and the inner cladding should be disconnected.

Water disposal is important in all situations where a plate material is applied for the facade. By unequal flows of rainwater, dirt can do damage and cause stripes on the underneath or materials close by.

In case of sandwich panels the skin and the insulation are prefabricated as one element. Onto a core of mineral wool or a synthetically insulation material, two thin plates are glued. These panels combine different (building physical) performances: a good fire resistance (90 minutes and more) with high thermal insulation values, yet small thicknesses. The R-values lie between 2.5 and 5 $K*m^2/W$. Sandwich panels are self supporting and can be connected directly to the steel structure. However tolerances are limited; it is therefore quite important to pay good attention to detailing. The connection from the sandwich panels is designed in such way that thermal bridges and air and vapor leakages are avoided.

Advantages:

- There is a lot of freedom in shapes
- Large variety in colors and appearance
- Low dead weight

Disadvantages:

- Good conservation is needed
- Very sensitive for corrosion
- The durability of the coating and the steel plate depends on the climate in which the material is being applied; cost areas or inlands

3.4 Timber

Durability is an important term when it comes to the appliance of timber in facades. There are quite some types of timber which can be distinguished from each other. For many of those timber types there are 5 classes which describe the level of sustainability. The five classes are described in table 1.

Class	Durability	Life span in contact with humid ground
I	very durable	more than 25 years
II	durable	15-25 years
III	moderately durable	10-15 years
IV	poorly durable	5-10 years
V	not durable	less than 5 years

table.1 Durability Classes of timber[18]

Timbers out of the first two classes are very well suitable for facades; with the right maintenance a life span of 50 years or more is achievable. When applying timber out of class III or IV the timber needs to be treated beforehand, by impregnating with a timber preservation material.
The advantage which comes along with timber is the fact that this building material is hardly damaging to the environment. This goes for the production, the use and the decay phase. Timber has no harmful emissions and doesn't require a lot of energy during production and tooling.

Advantages:

- A high load bearing capacity at a relatively low dead weight
- Easy to process and repair
- Possesses a striking insulating capacity
- Demountable
- Easy to recycle; there are no large amounts of energy necessary to recycle in comparison most other building materials; almost all the timber waste produced at the manufacturing stage is reused as fuel for drying kilns, or as wood products such as particleboard, fibreboard, chips or mulch.

Disadvantages:

- Dry rot
- Maintenance frequency is high (for example painting)
- Bending boards
- During preserving of timber materials are sometimes applied which are not environmental friendly

3.5 Glass

According to Renckens the glass facade is a continuous, non-load bearing, inside climate regulating and outside climate anticipating energetic intermediate, industrially manufactured and low weighted element[19].

Most glass facades obviously exist for a large part out of glass. The glass is applied for windows, transparent parts and parapets. There are different

[18] Geveltimmerwerk, KVT '80 Studie-uitgave

[19] Renckens, J.L.M.; Gevels & Architectuur 1996 p.30

types of glass which are applicable for the glass facades also known as the ‘curtain wall’. The profiles and fasteners are mostly made out of a metal or timber.

The most common glass types are the following:

- Floatglass; this type of glass is very flat and has the same thickness almost everywhere.
- Insulating glass; this type of glass is mainly to increase the insulation value, by means of a cavity between the layers of glass filled with insulating glass.
- Solar control glass; by coloring the glass or providing the glass with low E coating, the warmth absorbing features can be improved
- Safety glass; there are three types of safety glass to distinguish:
    - Reinforced glass
    - Laminated glass
    - Hardened glass

Advantages:

- Low dead weight
- Daylight entrance
- Esthetics
- Heating of the building through the glass facade

Glass plays an important role in the total energy consumption of buildings. By increasing the thermal resistance of the glass, one can achieve striking energy savings.

When designing a glass facade there are some aspects that need to be taken into account very carefully. In case these aspects are not taken into account, disadvantages of the glass usage will apply. Underneath there is a description of these aspects:

Building physics

- Air- and water tightness
- Sound abatement
- Light and sun screening properties
- Thermal bridges

Safety

In the Building Codes one can find several demands concerning safety when applying glass facades. Safety can be subdivided into subjects as follows:

- Structural Safety
- Fire Safety
- Users Safety

In this section commonly used materials where described. For the decision of which material will be applied for the energy museum it is important to consider the general (dis) advantages of all materials. Specifically the advantages of all materials are important for the eventual choice in material which can work out positively in the design of the museum.

3.6 Material testing in GreenCalc+

In the previous paragraphs it became clear what the general (dis)advantages where of the four chosen materials, but within this master thesis the aim is to obtain knowledge about materials and their relationship towards sustainability The relevance lies in the way they act towards the environment. With the help of GreenCalc+ it is possible to test materials and also buildings in relation to sustainability. To compare the different materials a certain building was put into GreenCalc+ several times. The only building element that changed was the facade material, the main purpose lies in facades in this research and was therefore the only variable. The building was eventually put into GreenCalc+ five times, every time with a different facade material. The facade materials that were applied are the same which are described in the previous paragraphs. However, the curtain wall facade was tested twice, the first time in combination with an aluminum frame and the second time with a timber frame.

In table 2 environmental results from the different materials are summarized. One can see that the results are compared with a reference building. The reference building is a standard building within GreenCalc+ dated from 1990 and has a MIG (Milieu Index Gebouw) value of 100. The MIG-value is the output of the lifecycle analysis of a building that comes from the software GreenCalc+. It expresses the rate of sustainability with a value, a building in GreenCalc+ is judged on material, energy and water level. Within GreenCalc+ results are measured in environmental costs per year. The higher the MIG value the more sustainable the building is.

	Reference building (Environmental costs in €)	Concrete (environmental costs in €)	Steel (environmental costs in €)	Timber (environmental costs in €)	Curtain/Al (environmental costs in €)	Curtain/Timber (environmental costs in €)
Foundation	1789	1789	1789	1789	1789	1789
Facades	2435	740	351	408	2285	411
Indoor walls	2721	2721	2721	2721	2721	2721
Floors	3288	3288	3288	3288	3288	3288
Roof	1184	1184	1184	1184	1184	1184
Installations	1282	1282	1282	1282	1282	1282
Interior	364	364	364	364	364	364
Total	**13063**	**11368**	**10979**	**11036**	**12913**	**11039**
Material index	**100**	**115**	**119**	**118**	**101**	**118**
Facade index	**100**	**329**	**694**	**597**	**107**	**592**

table 2 GreenCalc+ Summary of the tested materials; materials were tested on sustainability while functioning as facade materials.

** The material index is the ratio between the total environmental costs of the material from the reference building and the total environmental costs of the different materials.*
** The facade index is the ratio between the environmental costs of the facade of the reference building and the environmental costs of the different materials.*
** The reference building is a standard building within GreenCalc+ dated from 1990 with a MIG value of 100.*
** The higher the index (MIG value= Milieu Index Gebouw) the better the score on sustainability, this means improvement compared to the reference building.*

It is noticeable that the material steel had a low value in comparison to the other materials while the material itself is not necessarily more environmental friendly. However the numbers can be explained by taking into account that when applying steel as a facade material there is only a small amount of material necessary, especially in comparison with concrete. The conclusion is that the environmental costs depend not only on the material, but the function for what they are used are quite important, thus the amount of applied material.

3.6 Environmental data of materials

NIBE which stands for Dutch institute of Building Biology and Ecology brought out the NIBE's Basiswerk Milieuclassificaties Bouwproducten, which are books concerning all environmental and health effects of building products. With the help of the information of NIBE's data the most important environmental criteria which are: emissions, exhaustion, land utilization and remaining hindrance of the five already mentioned building materials are summarized in the table below.

Whenever different alternatives for the same application (for example an inner leave) are being compared to one another on environmental technical level, it is necessary to determine the functional unit. Besides the scale of the building component, which is to be compared (for example 1m2 floor) the concern lies also on equal technical performances. The term functional unit shows that products are being judged by the amount of delivered performance and not the amount of material.

The functional Units are described for all four materials; the materials are the same as the ones described above however timber is distinguished in a softwood type and a hardwood type:

- Reinforced concrete: For 1 m^2 wall (thickness 200mm) made of finished reinforced concrete there is about 473 kg concrete mortar necessary, 7 kg reinforcement steel and 4 kg plasterwork.
- Oak (hardwood): For 1 m^2 there is about 13,7 kg wood necessary. The fasteners and the lathing weigh about 0,9 kg.
- Whitewood (softwood): For 1 m^2 there is about 10,7 kg (preserved) wood necessary. De fasteners and lathing weigh about 0,9 kg.
- Steel galvanized & coated: For 1 m^2 facade material with a plate thickness of 0,7mm, there is about 6,5 kg steel necessary. The fasteners and lathing weigh about 1,1 kg.
- HR++ Insulating glass (aluminum frame): Height=2315mm and wide=938mm; per m2 0,8 m^2 glass and 0,2 m^2 aluminum. The aluminum frame accounts for 28% of the environmental load.

<u>Description of Units which are mentioned in table 3:</u>

Kg CO_2	= Kilogram carbon dioxide	mbp	=
Kg CFC	= Kilograms chlorofluorocarbon	PDF m^2 jr.	=
Kg 1,4-DB	=	OTV m^3	=
Kg C_2H_4	= Kilograms ethane	Kg PO_4	= kilograms phosphate
Kg SO_2	= kilograms sulfur dioxide		

In table 3 one can find information about the mentioned materials and their rate of sustainability with respect to emissions, exhaustion, land utilization and hindrance. The values are expressed in the above mentioned units and are taken from NIBE's database.

	Reinforced Concrete	Oak (Hardwood)	Whitewood (Softwood)	Steel galvanized & coated	HR++ Insulatingglass (Alu-frame)	Expression in Units
EMISSIONS						
Greenhouse Effect	91.6999	5.0044	17.0264	37.6435	543.423	kg CO_2 eq.
Ozone Depletion	7.42168E-6	7.17316E-7	3.04233E-6	6.93563E-6	7.211E-5	kg CFC-11 eq.
Human Toxicity	5.97848	0.617869	2.96962	4.25554	751.363	kg 1,4-DB eq.
Aquatic Toxicity	0.835177	0.0471059	0.287868	0.327322	24.1577	kg 1,4-DB eq.
Terrestrial Toxicity	0.0804893	0.0470711	0.100265	0.0781014	0.660492	kg 1,4-DB eq.
Photochemical Oxidant forming	0.0118926	-0.00541062	-0.00706427	0.0145465	0.138377	kg C2H4 eq.
Acidifaction	0.331049	0.0292402	0.109962	0.184781	2.73175	kg SO2 eq.
Eutrophication	0.0542541	0.00543281	0.0176161	0.0141768	0.219112	kg PO 4eq.
Exhaustion						
Biotic Resources	0.0	0.0	0.0	0.0	0.0221538	mbp
Abiotic Resources	16.8631	0.0349883	0.110204	1.75055	35.8702	mbp
Energy Carriers	3.74075	0.540893	1.54254	1.72844	27.292	mbp
Land utilization	10.3315	1.13978	1.85206	4.0505	37.3449	PDF.m^2.jr.
Hindrance due to						
Odour	800819.0	61220.7	146319.0	1597110	1468530.0	OTV m^3
Sound caused by road traffic	383052.0	45879.6	198254.0	337682.0	170324.0	DALY
Sound caused by production	603.334	-4.56196	-1.25614	147.906	607.159	mbp
Light	3.94015	0.567152	1.93415	2.90292	26.3373	mbp
Chance to calamities	4.20487	0.525306	1.49119	1.62966	26.0575	mbp

table 3 Environmental data of materials[20]

This table shows the values of all environmental aspects for each material separately. By considering the greenhouse effect one can see that concrete is the most environmentally unfriendly material in comparison to the other considered materials. Also the GreenCalc+ results showed that concrete is by far the most unfriendly material towards the environment.

[20] NIBE's Basiswerk, Milieuclassificaties Bouwproducten

3.7 Discussion

In chapter 3 several commonly applied materials within the facade industry were described. At first a description about their general properties and appliance as facade materials followed by two tables with information about their rate of sustainability. Both tables contain the same data to evaluate the environmental load. GreenCalc+ uses the TWIN2002 model which is created by NIBE (Dutch Institute for Building Biology and Ecology) to evaluate the environmental load. This model views the environmental load from materials from cradle to grave with the help of LCA's. When comparing concrete, steel, glass and timber with each other with respect to emissions and exhaustion, from the tables it becomes clear that concrete scores the lowest on environmental scale. However, when considering the general properties of concrete one can see that concrete does contain a lot of advantages as a material. Also with respect to sustainability concrete contains some properties which can be very advantageous. The high thermal mass and the strength of concrete which can make concrete elements multifunctional are to be considered very carefully and concrete should therefore not be considered as a material which cannot be applied for the museum, due to the results in GreenCalc+. GreenCalc+ does not take properties like strength, thermal mass and other building physical properties into account. For this reason the material concrete will be further researched and taken into account in chapter 7 and 8, where environmental benefits from concrete become clear and show that the appliance of concrete facades for the energy museum can be sustainable after all.

4. Renewable energy

Renewable energy can be defined as energy obtained from sources that are essentially inexhaustible. Such energy is generated from natural resources such as sunlight, wind, rain, tides and geothermal heat. For the energy museum, where several types of renewable energy will be exhibited, the appliance within the building is important. Obviously not all types can be applied; this depends on different factors. Below one can find a brief description of important types of renewable energy.

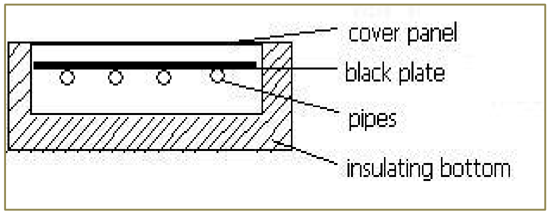
4.1 Solar energy

Solar energy is energy from the sun that is converted into electrical or thermal energy. This can be subdivided into two manners. In the first manner light coming from the sun is converted into heat by means of solar collectors. The second manner is about converting light coming from the sun directly into electricity by means of photovoltaic cells.

<u>4.1.1 Solar collectors</u>

Solar thermal energy is a technique where solar energy is being used to obtain thermal energy i.e. heat. With the help of solar collectors it is possible to convert sunlight (energy) into thermal energy. Unlike photovoltaic cells, solar collectors do not utilize the electromagnetic properties of sunlight. The warmth which is activated by the collector, can immediately be used to heat an object like a building.

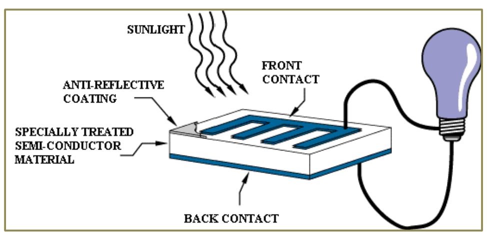
Nowadays there are quite some solar collectors available; the most common is the flat plate collector. The centre of the collector is a black plate, also recognized as the absorber. This plate is surrounded with insulation material and can absorb sun light very efficiently. To increase the temperature above the absorber one can find a transparent panel, this traps heat radiation from the absorber. This means that more heat is absorbed than emitted. On the bottom side of the absorber there are pipes where water runs trough. These pipes are placed in a certain manner, so that the heat which is absorbed by the absorber can easily be transferred to the water. The heated water can then be discharged and be used domestically. In image 2 one can find an impression of a solar collector.



Img. 2 Solar collector; this image shows the components of a solar collector which converts solar energy into thermal energy i.e. heat.

4.1.2 Photovoltaic cells

Electrical energy or solar power could be described as the generation of electricity from sunlight. This can be done with the help of photovoltaic cells (PV cells). Image 3 shows the components of a PV cell. The direct conversion of light into electricity at the atomic level can be called photovoltaic. Solar cells are made of semiconductor materials, such as silicon. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive at one side and negative at the other. When light energy strikes the solar cell, electrons are knocked loose. These move around in the desired direction. The movements from the loose electrons together generates the electric power which goes through the cell.



Img. 3 Photovoltaic cell; this image shows the components of a PV cell which provide for electricity. Electricity is generated by sunlight on atomic level.

Special attention is needed for the production of PV-cells. The production of these cells has the disadvantage of emitting toxic substances, for example hydrochloric acid, hydrogen bromide, phosphorus, hydrogen peroxide etc.

Important to consider is the fact that the Netherlands gains an amount of about 1000kWh/m^2 sunlight per year. The problem is not the amount of sunlight per year, but the large difference between summer and wintertime (factor 7 – 10) can be disadvantageous. It is therefore important in case solar energy is used, to make sure that the energy can be stored or that a secondary form of energy supply is present to compensate the differences.

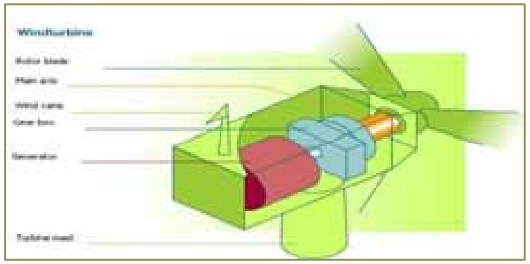
4.2 Tidal power

Tidal power which is also known as tidal energy relies on tides when it comes to generating energy. In image 4 one can find an impression of the tidal power construction in France. The difference in height between ebb and flow can drive a turbine which then on its turn generates power. The stronger the tide, no matter in water level height or tidal current velocities, the greater is the potential for generating electricity. Wherever there is enough difference in height in tides, it is possible to collect water when water is high behind a dam and then letting in flow back through turbines which are coupled to generators when low water occurs.

Img. 4 Tidal power construction; Dam of the tidal power plant on the estuary of the Rance River, Bretagne, France (source: climatelab.org)

4.3 Wind power

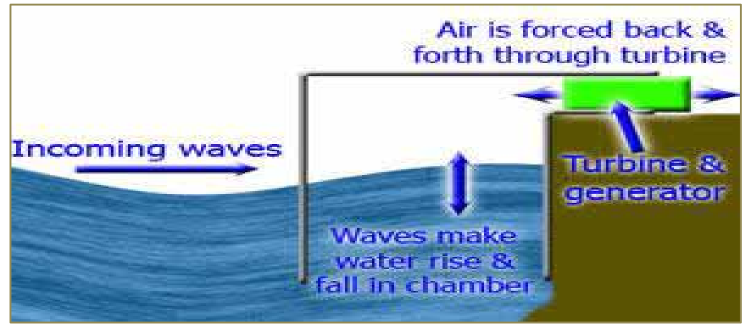
Wind power is the energy that is produced from kinetic energy from wind flows. For this purpose wind turbines are used. Wind turbines are available in various types and sizes, the components of a wind turbine are given in image 5. By means of a generator wind power is converted into electricity. The generator converts the movement form axis to electricity and provides the network of electricity.



Img. 5 Wind turbine; this image shows the components of a wind turbine which is a form of renewable energy commonly applied in the Netherlands

4.4 Wave power

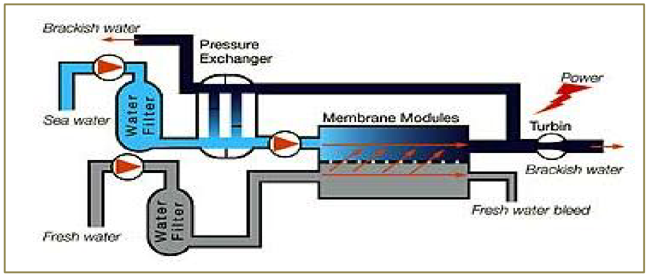
Wave power can be considered as the transport of energy by ocean surface waves. The electricity generators are placed on the surface of the ocean. The amount of energy is determined by the height of the waves, the speed of the waves, wavelengths and the density of the water. There is an energy transfer from the wind to the waves as long as the waves that are generated by wind propagate slower than the wind speed just above the waves, this principle is shown in image 6. The purpose of this obtained energy is mostly the desalination plants, power of plants and water pumps. It is not a technology which is widely used at this moment. However, there have been several attempts for using this principle since 1890.



Img. 6 Wave power; this image shows the operation of generating wave power

4.5 Osmotic power

Osmotic power also known as salinity gradient power is energy which is gained from the difference in salt concentration between seawater and riverwater. The process contains two solutions with different salt-concentrations (often freshwater and salt-water). A semi permeable membrane, which is an organic filter separates the solutions from each other. Only small molecules like water-molecules pass through the membrane. The water aspires to decrease the salt-concentration on the side of the membrane that contains most salt. The water therefore streams through the membrane and creates a pressure on the other side. This pressure can be utilized in order to gain energy, for example with the help of a turbine and a generator, the principle of the operation of osmotic power is shown in image 7.



Img. 7 Osmotic power; this image shows the operation of osmotic power. This principle is based on the differences in salt concentration between seawater and river water

4.6 Discussion

In this chapter several forms of renewable energy were considered. Wave, tidal and osmotic power are not used as often compared to solar and wind power. In the Netherlands the development of these forms of renewable energy has not yet reached the level we would like. The disadvantages which are summarized in the table 4 are quite important and as long as these forms of energy are not profitable within a certain amount of time the development will not take place. The question whether the form of renewable energy should be applied in the energy museum depends strongly on the efficiency. All forms of renewable power have a certain energy payback time. The energy payback time is the time which the power installation needs to obtain the same amount of energy as was used during manufacturing. There is also the financial payback time which is concerned about the amount of money which is invested in the production of the installation. Due to the fact that this thesis concerns only one single building it is not profitable to apply large scale expensive plants to generate power and where also very little experience is available for. This means that wave, tidal and osmotic power will not be applied in this research. This therefore leads automatically to the appliance of solar power as the method to generate renewable energy for the energy museum. In this specific case the solar energy will be applied in the form of electricity. Depending on the electricity demand of the building it might be possible that only solar energy in the form of electricity will not be sufficient. In that case also wind power will be applied, to meet the total electricity demand in combination with PV cells.

	Solar power	Wind power	Tidal power	Wave power	Osmotic power
Advantages	- Clean form of energy - Long life cycle - Low maintenance - No pollution with damaging gasses	- No waste is produced - Available in a range of sized - Off-grid decentralized system possible	- Non polluting - Predictable	- No emission of greenhouse gasses - Low noise pollution	- Minimal environmental impact - Clean process
Disadvantages	- Initial costs - Large area needed to achieve efficient results - No supply during nighttime - Supply negatively influenced by pollution and/ or clouds	- Noise pollution - Not continuous - Construction of wind turbines are expensive - Applied materials (polyurethane and polyester) are polluting to the environment	- Expensive construction - Limitations in location - Negative effect on fish migration - Power is only generated per 12 hours - Natural switch of ebb and flow could be disturbed	- Waves are not consistent - Salt water corrosion	- Costs - Problem protection of the marine organisms from the turbine and other machinery - Engineering problems; difficulties to built a plant and lower it in the sea

table 4 Summary of properties of the different forms of renewable energy. This table contains information about the most important disadvantages and advantages of the discussed forms of renewable energy.

5. Innovations on facades

Because of environmental imperatives intelligent buildings and intelligent facades are popular nowadays. It is clear that buildings have a major impact on the environment. Thus, to avoid environmental degradation, changes need to arise. The facade of a building can account for between 15% and 40% of the total building budget.[21]

Intelligent facades are a part of the intelligent buildings, which have become popular over the last years. The facade refers to the building element which performs as the envelope to the interior. The intelligent skin could be described as a skin which protects against weather and which adapts either manually or automatically to environmental variations, with using a minimum amount of energy.

5.1 Selected innovations

There are different methods available to achieve an intelligent façade. Some important ones are listed below with a brief description of the principle:

Building management systems
The BMS is a central processing unit which receives information from different stations and then determines the most favorable response. For example the BMS could monitor all kinds of weather conditions and then react to that.

Responsive Artificial Lighting/ Daylight controllers
In case that artificial lighting has the ability to control itself with respect to natural lighting, as in dimming itself or even deactivating itself, a daylighting system can be optimally effective.

[21] Hal, A; ARUP ENGINEERING, Advances in Cladding, 7 july 1997

Sun controllers
This system is about tracking the sun on its variable path throughout the day and year. Also computer controlled protective shades are a good manner of solar control.

Ventilation controllers
Automatically regulated ventilation methods.

Electricity generators
Electricity which is generated by PV-cells, wind turbines and combined heat and power systems.

The double skin
The double skin facade also known as the second skin facade is a system that consists of an external screen, a ventilated cavity and an internal screen. Solar shading is positioned in the ventilated cavity. The external and internal screens can be single glass or double glazed units, the depth of the cavity and the type of ventilation depend on environmental conditions, the desired envelope performance and the overall design of the building including environmental systems, according to Kragh[22].

The cavity is connected with the outside air so that the windows of the interior facade can be opened, even in tall buildings subject to wind pressures; this enables natural ventilation and night time cooling of the building's thermal mass. In the winter the cavity forms a thermal buffer zone which reduces heat losses and enables passive thermal gain from solar radiation. All types of double skin facades offer a protected place within the air gap to mount shading and daylight enhancing devices such as venetian blinds and louvers. Sheltered from wind, rain and snow, these shading devices are less expensive than systems mounted on the exterior. When solar radiation is high, the facade cavity has to be well ventilated,

[22] Kragh, M; Building envelopes and Environmental systems; www.permasteelisa.com/upload/docs/pub_TUD02001.pdf

to prevent overheating. The key criteria here are the width of the cavity and the size of the ventilation openings in the outer skin. The air change between the environment and the cavity is dependent on the wind pressure conditions on the buildings skin, the stack effect and the discharge coefficient of the openings.[23]

Smart solar shading

Solar shading is any device which excludes sunshine from a building. There is a wide variety of solar shading products available nowadays. Solar shading controls the amount of heat and light admitted to a building. They can reduce the cooling load and in that way reduce the amount of energy which is necessary for example for air conditioning. Solar shading can also reduce the amount of energy required for artificial lighting, for example by admitting more light during overcast conditions.

Solar shading on the outside keeps the heat outside, while solar shading on the inside does not. To optimally control the temperature in a building, it is a must to prevent the building for heating up. Solar shading on the outside is therefore most efficient. Radiation from the sun is absorbed and reflected by outside solar shading. Therefore the heat does not have to be abducted by means of a ventilation or cooling system

A few methods for smart solar shading are listed below:

- Fixed or controllable carrier systems
- Fixed or controllable external solar shading system that incorporates glass louvres
- Fixed or controllable external solar shading system that incorporates glass louvres with photovoltaic cells integrated into the glass

5.2 Discussion

In this chapter several innovative methods were described. At least one method will be applied in the energy museum and therefore to be further researched. The appliance of a second skin or smart solar shading are the most interesting methods of all the above describes methods, because aside the smart solar shading and the double skin facade. All other methods are more concerned with control engineering whereas the double skin facade is concerned with material and building physical benefits and the smart solar shading benefits the energy consumption, both very suitable for the sustainability part in this master thesis. In chapter 8, depending on the circumstances one of the two systems will be further researched.

[23] Uuttu, S; Study of current structures in double skin facades.
Msc thesis in structural engineering and building physics; Helsinky University Finland (HUT)
http://www.tkk.fi/Civil/Steel/Publications/TKK TER series/SINI2.PDF

6. Practice examples

As been said before sustainable construction at this moment is quite in interest. To obtain some knowledge on how this is done in the Netherlands a few practice examples are considered. In this part of the master thesis existing projects will be discussed. The first two projects were built by taking the cradle to cradle concept in consideration and

The following three projects are said to be the greenest buildings in the Netherlands according to measurements which were made with the help of the software GreenCalc+. A top ten of most the sustainable buildings at this moment in the Netherlands was made with the help of the software GreenCalc+. The MIG-value is the output of the lifecycle analysis of a building that comes from the software GreenCalc+. Environmental load with respect to material, water use and energy use are calculated with GreenCalc+. Energy use is determines the eventual results for 75 till 85%. Materials about 15 till 20% and water usage for 2 to 3%. The watertoren reached a value of 900, Rijkswaterstaat a value of 323 and the building of Wereld Natuur Fonds has a MIG value of 269.

It is clear that in a sustainable or green building measures are taken concerning different aspects. However in this review the interest goes to material use and energy; therefore only these measures will be discussed.

6.1 Office building Search

An example of a Building produced by the concept of cradle to cradle where possible is the Office building of the company Search in Amsterdam see image 8. The information below contains a description of several measures which concern either material or energy and are attempts to obtain a sustainable building.

- On the south side of the building the facade is made out of glass and on the north side it is completely closed. This way is an attempt for optimal use of solar heat and sunlight;
- Appliance of a massive timber structure except for the concrete foundation, along with the energy poles produced by the manufacturer Betonson, the whole building is erected out of crosswise fastened softwood;
- The deep foundation piles consist of vertical lamellas that provide heat and cold storage. The energy piles are prefabricated foundation piles with a synthetically element where water is being pumped through; the liquid is then heated or cooled by the earth;
- Hundred square meters of an energy-roof, which facilitates heating, cooling and hot water supply;
- Underneath concrete plates which lay on the foundation extra thick polystyrene insulation is applied;
- Windows are made out of triple layered glass;
- PV cells and windmills provide for electricity (see img 9 for the windmill on site).

Img. 8 Timber structure Search office; Office was built with respect to the C2C principle. The whole structure except for the foundation is erected out of crosswise fastened wood. *(sustainable measure on material part)*

Img. 9 Windmills on site; along with PV-cell these two windmills provide for the buildings electricity demand.
(sustainable measure on energy part)

Img. 10 Large window surfaces; the large window surfaces provide for optimal daylighting. Appliance of artificial light can be therefore reduced to a minimum, thus savings in energy.
(sustainable measure on material and energy part)

6.2 Nike European Headquarters

William MCDonough who is one of the founders of the Cradle to Cradle principles and his partners got the assignment to create a world-class innovation to the Nike European Headquarters in the Netherlands. The aim was to develop a human- and environmental friendly building. Measures that were met concerning energy and material use in attempt to fulfill the original aim are listed below.

- Large window surfaces which should enable maximum incoming daylight see image 10;
- Energy saving is quantified to be about 35% due to thermal storage in the soil energy;
- Appliance of FSC-checked hardwood with respect to the usage of natural materials;
- Use of low-VOC finishes in a virtually PVC-free environment.

6.3 Watertoren; Bussum

In 2010 the construction of the Watertoren in Bussum was finished, an impression of the watertoren in Bussum is shown in image 11. From that moment on this building can be called the most sustainable and green building in the Netherlands. According to the MIG-value of 900, which stands for Environmental-Building-Index, the Watertoren has reached a new record.

Measures that were met on behalf of materials are not necessary sustainable. The score on behalf of materials was not exceptional good. A relative simple prefabricated concrete structure was applies with glass facades for the pavilion behind the tower. For the tower itself a steel structure and a lot of glass was applied. Appearance and esthetics were on material part more important.

From the results it becomes clear that this particular building stands out on the energy usage. Measures that were met on behalf of energy:

- Heat-Cold:
  - Heat and cold storage;
  - Biotic-cogeneration (wkk) in combination with concrete core activation provides for the heating demand of the building;
  - Cooling of the building happens with the same biotic-cogeneration system, also in cooperation with concrete core activation (see image 12) and ventilation;
  - Electricity is provided by its own installation with the help of PV-cells, bio-wkk and wind power.
- The biotic cogeneration is stoked with vegetal oil, on behalf of the CO2 emissions this is a positive measure, due to the fact that it is part of the short cyclic CO2-cycle. This therefore has no contribution to the greenhouse effect.

Img. 11 Water toren; this building is at this moment the most sustainable building in the Netherlands, with a GreenCalc+ score of 900.

Img. 12 Concrete core activation applied in the floor, in combination with Biotic cogeneration the concrete core activation provides for the heating demand in the building.

6.4 TNT; Hoofddorp

The office building TNT which is located in Hoofddorp is Europe's second most sustainable building according to GreenCalc+. Some measures that were met are the following:

- Heat and cold storage; the remaining heat in the summer and the remaining cold in the winter are being stored in the water bearing layers in the soil by means of heat and cold storage. The stored heat is being used during wintertime for heating the building. The cold is used for cooling the building during summertime. It is an even more interesting concept when the whole surrounding of a building is involved in heat/cold storage.[24]

[24] De Ruiter, P; Technische gegevens; Project: TNT Green Office, Hoofddorp http://www.paulderuiter.nl/projects/sustainabilities/3_utiliteitsbouw/project/51_tnt_green_office,_hoofddorp/sustainability/41.html

- Chameleon skin; working under circumstances where there is sufficient daylight improves the health and performance of the users of the building. The 'chameleon skin' is a facade which adapts to the sun with lamellas (see image 13 and 14). Smart sun screening keeps the heat outside, so that less cooling is demanded, and daylight gets a chance to come in, so that less artificial lighting is demanded. The use of artificial lighting is connected to the amount of daylight coming in and the presence of people. Smart sun screening contributes to the consent of human beings and the reduction of energy consumption.[25]

Img. 13/14 Chamelion skin; this so called chameleon Skin façade adapts to the sun with lamellas. This is a Form of smart sun screening during the year.

[25] De Ruiter, P; Technische gegevens; Project: TNT Green Office, Hoofddorp http://www.paulderuiter.nl/projects/sustainabilities/3_utiliteitsbouw/project/51_tnt_green_office,_hoofddorp/sustainability/41.html

6.5 Rijkswaterstaat; Terneuzen

The company OpMaat is responsible for the design of the office building for the Rijkswaterstaat which is located in Terneuzen. Some of the methods and requirements that were met for the design of the building are described underneath[26].

The building has a surface area of about 1750 square meters and about 60 workplaces. The building has a trianglular form with in the middle a round atrium with a glass roof.

- The appliance of recycled materials and also natural materials are an attempt to use materials for as long as they can be used without damaging the environment. Two examples are the following:
  - Old mooring posts were saturated and used for facade coatings, for the galleries, staircases and balusters
  - Old basalt blocks and Clinker bricks were reused both inside and outside the building
- The structure is built out of timber except for the foundation which is made out of concrete (see image 15);
- The building does not have air conditioning: with the help of a chimney and wind pressure depending ventilation grid the building is ventilated naturally. Fresh air comes into the building via the ventilation grid, flows around openings in the inner façade in the atrium and leaves via the chimney of the building;
- A heat pump which retracts water from the canal makes sure the building can be heated by means of wall and floor heating;
- Above the atrium Solar photovoltaic's (PVs) are installed (see image 16). The panels also have a sun screening function. In this way the designers tried to combine renewable energy with intelligent sunscreening.

Img. 8 Smart shading

[26] opMaat; Projectbeschrijving: Rijkswaterstaat Kantoor Terneuzen; http://www.opmaat.info/

Img. 15 Timber structure; FSC wood is applied for the entire structure of the building

Img. 16 PV cells on the rooftop which provide for the electricity demand

6.6 Discussion

In this chapter several practise examples were discussed. All mentioned buildings were built with sustainable measures, which determine the rate of sustainability. The design of the energy museum will also contain several sustainable measures. With the help of the discussed practise examples the following measures will be taken into account for the design of the energy museum:

- Appliance of renewable energy by means of solar power;
- Appliance of renewable energy in form of wind;
- Large window surfaces for optimal incoming daylight;
- Appliance of concrete core activation;
- Appliance of smart solar shading.

It might be possible that other measures will be taken which are not mentioned in the list above, however during the further research there is a possibility that other sustainable measures arise and can work out very well for the energy museum. Thus, the above mentioned measures are just an indication of what kinds of measures are applicable for the energy museum and its function.

7. The energy museum

7.1 Conceptual design

In the previous chapters the history of sustainable construction and its developments, reviews on sustainable aspects and practical examples have been discussed. From this point on the gained information and knowledge will be translated to a conceptual design for the energy museum. Within the scope of sustainable construction and the design of a sustainable building, which will function as an energy museum, choices for sustainable measures will be made to optimize the rate of sustainability within the energy museum. As been mentioned before the main focus of this thesis lies in the facades of the museum. Therefore the aim is to integrate as many sustainable measures as possible in the facades.

7.1.1 Choice for the facade materials

While designing a sustainable building it is not necessarily the case to apply materials with the lowest environmental loads, like for example timber. All materials have certain properties which can be very advantageous with respect to sustainability.

For the materials it is important to take the following aspect into account while deciding for a facade material.

- The museum is located on see:
    - transportation over sea is therefore possible;
    - Material should be resistant to the circumstances of the location on sea;
- The material of the facades should contain the ability to be multifunctional;
- Ability to reuse materials after its lifecycle.

By taking the above mentioned facts into account where especially the location and exposure to the circumstances on sea are important for the life cycle and the maintenance of the building. Considering the material concrete it became clear in chapter 3 that concrete contains quite some advantages and can be applied as a facade material on the specific location on sea, while it is resistant to the exposures on the pier. However, in chapter 3 it also became clear that concrete scores lower than the other mentioned materials with respect to emissions. This does not mean that concrete is not a sustainable material for the energy museum on the pier. As been mentioned before, the fact that the importance lies in the facades and that the facades should be multifunctional, make concrete a good choice for the facade material. The following facts about concrete make the material an attractive choice for the appliance in the energy museum:

- Concrete elements can be prefabricated and therefore usable after the building lifecycle for other purposes;
- Large concrete elements can be transported over sea, this part also contributes to the environment;
- A concrete facade can take a structural function, where the floors rest on the facade and the load bearing walls of the facade can provide for stability, at the same time the facade functions as the intermediate between the inside and outside climate. By means of this double function, the amount of material can be reduced;
- Concrete has a high thermal mass, this is a property that enables building materials to absorb, store, and later release significant amounts of heat. Energy savings are made possible due to the thermal mass, concrete absorbs energy slowly and can hold it for longer periods of time;
- Concrete can be applied in a system which can provide for cooling and heating a building, by means of concrete core activation.

These facts show that concrete can be a sustainable material for the energy museum, in spite of its higher values for emissions, when all advantageous properties of concrete are applied and combined in a good way. The choice is therefore to apply concrete as the facade material of the energy museum.

The concrete facades will be performed as sandwich element, which consist of a concrete inner leave which also fulfills a structural function and a concrete outer leave separated by a layer of insulation material. The insulation layer will prevent that heat is lost to outside, heat losses are minimized by also applying insulation. The concrete elements are all prefabricated and fixed to one another on site. It must be clear that the inner leave has another thickness than the outer leave, because it is not load bearing.

Normally the application of concrete core activation takes place in concrete floors. However, the aim lies in creating sustainable facades and therefore the concrete core activation will be applied in the facades. By doing this another function has been added to the facades, thus the rate of sustainability increases by adding another function to the facade. In case concrete core activation is applied in the facade, the ducts of the concrete core activation lie in the core of the load bearing wall. In this case the load bearing wall is the inner leave of the concrete facade.

While designing the building for the energy museum one should also carefully take the function and the type of building into account. A museum is a public building with many visitors on a daily basis. A pleasant indoor climate is very well on its place within a museum. Besides the indoor climate one should take into account that in every museum art or experiments are exhibited. The type of lighting plays an important role for this matter. When considering the function and location of the building the following aspects should be taken into account:

- A relative constant temperature within the museum;
- Entrance of diffuse light and as less as possible sunlight, due to the visual effect of the exhibitions;
- Optimized amount of daylight with respect to humans psychology;

Considering the information in chapter 6 where practical examples were described, there are certain measures which can be taken to meet the requirements for the above mentioned aspects:

1. To gain a pleasant indoor climate with a relative constant temperature and at the same time an energy efficient system, concrete core activation is an application which fits in the energy museum.
2. To gain as much as possible diffuse light during the year and as less possible sunlight, window openings/ glass parts or a total glass facade on the North side is the most obvious choice.
3. To optimally use daylight either large glass facades or glass parts in the roof are advantageous.

Important is to acknowledge the fact that in this case where concrete core activation is applied in the inner leave of the concrete facade, it is most likely to use the total surface of the facades to provide with concrete core activation. This means that piping/ ducts are all over the surface of the facades, to gain maximum capacity. The consequence however is that the facades should therefore be opaque, no window openings are then allowed. When combining all the tools and measures, the fact that the facades should be closed don’t have to be necessarily a problem.

The building has the form of a cube, as been said before the architect decided to use this form because it is a pure form which offers a lot of possibilities. Because of the cubic form all facades are similar in dimensions and also the roof has the same dimensions.

Combining measures with respect to materials of the facade

From this point one could say that to create a building which can be called sustainable is a matter of putting all the right elements together. A specific combination of elements for a certain building which is optimal with respect to sustainability does not have to be optimal for another building. Now combining the measures which are described above to obtain an as good as possible solution for the facades the following will be done. Opaque concrete facades, which consist of a load bearing inner leave where concrete core activation will also be applied in. Prefabricated elements where the inner and outer leave are separated by an insulation layer, this is also called a sandwich construction, where the inner leave has a larger thickness due to the structural function and the fact that the concrete should be thick enough so that the piping of the concrete core activation fit in the inner leaves. To gain enough daylight in forms of diffuse light and keep as much as sunlight outside of the building, a glass facade will be situated on the North. The type of glass determines the heat losses, to minimize the heat losses and considering the fact that the dimensions of the museum facades are quite large a specific type of insulating glass will be applied. Triple glass can reach to very high insulation values due to a very low U-value and is often applied in passive building. For these reasons the glass facade will be performed in triple glass. This means that the other three facades will be opaque and made out of concrete.

7.1.2 Choice on energy level

Beside the sustainable measures on material level, within the design of the energy museum also ‘energy’ plays an important role. The main purpose on energy level is to create an energy zero building, this is a building which uses as much energy as it generates on an annual basis. It is common within the sustainable construction that on energy level, renewable forms of energy are applied. In chapter 6 where practical examples were described, this matter occurred several times. Also for the energy museum a renewable form of energy will be applied, namely in form of solar power to provide for electricity. To create an energy zero building it is common to do this with renewable energy. In this case if solar power is not sufficient to supply for the electricity demand of the energy museum, wind power will compensate.

7.1.3 Summary of the choices and considerations

From this point several consideration and choices for the energy museum have been made. Below one can find an enumeration of all choices and consideration which are made in this stage for the design of the energy museum:

- Appliance of concrete for the facade materials;
- Appliance of load bearing facades;
- Appliance of concrete core activation within the concrete facades;
- Appliance of a glass (triple glass) facade on the North side for optimal diffuse light and minimal solar irradiation;
- Creating an energy zero building with the help of renewable energy in forms of solar and wind power;
- Appliance of prefabricated concrete sandwich elements for the opaque facades;
- Transportation over sea with respect to the environment.

In the following paragraphs functional and general requirements are described which are to be considered for the energy museum. Subsequently drawings and images of the museum and the exact location of the museum is shown, this chapter then end with a structural concept for the energy museum. With all choices and consideration which are made in this chapter, in chapter 8 the actual research to certain choices and sustainable measures will take place.

7.2 Schedule of the general requirements

All functional and general requirements play a role in this thesis. Because of the fact that these requirements are specific for every building, designers should always consider all possible ways to create a sustainable building.

Within this thesis the requirements are divided in three schedules of requirements. At first the general requirements are listed, subsequently the requirements with respect to the facade are given and finally the requirements with respect to sustainability are listed.

Representation schedule of requirements

Location and Assignment

Location:

- The Pier of Scheveningen

Assignment:

Design of facades for the energy museum in relation to its function and with respect to sustainability and intelligent buildings.
Required spaces:

- Experience/ exhibition area
- Possibilities for the exchange of information and knowledge
- Restaurant
- Conference room

Boundary Conditions

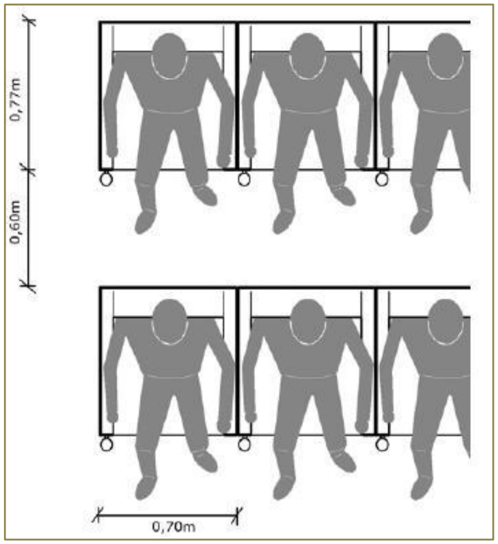
- The design should fit in its location
- The design should be integrated in the public space and its surroundings
- Influences from outside and environment should be taken into account

7.3 Spatial requirements

The dimensions of the spaces within the energy museum are based on the number of visitors per day. The assumed numbers of visitors per day is 100 at most. Dimensions of particular spaces are based on information from Neufert Architect's Data and existing buildings with similar functions. In table 6 one can find the spaces and their dimensions within the energy museum.

Filmroom

For the film room the dimensions of the chairs and the spaces between them are quite relevant (sea image17 for dimensions), the numbers of seats in the film room is set on 40, where the distance between the first row and the screen is 1,2 m. With the information below in the drawings the numbers of rows are set on 5, with 8 seats on each row.



Img. 17 Dimensions of seats and spaces in a film room

Toilets

On a surface of 125m^2 the demand according to the building decree is 1 toilet. The minimal dimensions for one toilet are 0,9*1,2m. Dividing the total surface area with 125m^2 a number of 11 toilets is required within the museum. This requirement is met, there are more than 11 toilets present in the museum (see table 6). Not only are there more toilets then required, both men's/ ladies and disabled toilets have bigger dimensions then required, this because of comfort for the visitors.

Café

For the dimensions of the café a value of 1,5m^2 per person is calculated. At maximum the numbers of visitors together in the restaurant is set on 70%. This means that at max there will be 56 people in the restaurant at the same time. A surface of 84m^2 is therefore required. However, an area of 100m^2 is reserved for the café.

Demonstration areas

Five forms of renewable energy, the way they are generated will be demonstrated. An area of 50m2 is reserved for all forms of renewable energy. On these 50m^2 the test facility is located and also the space where visitors can stand and watch.

The surface area of 50m^2 is based on surface areas in the NEMO (science centre) located in Amsterdam, where also scientific projects and phenomena are demonstrated.

Office rooms

According to Neufert depths of offices lie between 3,75 – 7,50m with a maximum of 9.25m. For the offices in the energy museum dimension of 4m*4m are chosen.

Conference room

Similar to the film room an area of 50m^2 is reserved for the conference room. 40 people can be in the conference room at the same time, this translates in 1,25m^2 per person

SPACE	NUMBER	DIMENSION in m^1 and m^2	TOTAL SURFACE AREA in m^2
Entrance	1	5 m1	
Ticket service	3	5	15
Wardrobe room	1	15	15
Storeroom (cleaning)	3	5	15
Café	1	100	100
Storeroom (restaurant)	1	16	16
Sanitary room lady's	3 units (each unit contains 2 toilets and 1 general space for 3 washbasins)	10	30
Sanitary room Gentleman	3 units (each unit contains 2 toilets and 1 general space for 3 washbasins)	10	30
Disabled toilets	3	5	15
Conference room	2	52 (7.2x7.2)	104
Museum shop	1	50 (10x5)	50
Film/ theatre room	1	52 (7.2x7.2)	52
Office	2	16 (4x4)	32
Demonstration Solar Energy	1		50
Demonstration Biomass	1		50
Demonstration Osmotic Energy	1		50
Demonstration Tidal Energy	1		50
Demonstration Wave Energy	1		50
			Total: **725 m^2**

Table 6 Dimensions of spaces and functions within the museum

The original idea of the architect was to apply a cubic form with dimensions of 30*30*30m for the energy museum. However considering the above mentioned surface areas a cube with smaller outer dimensions is also sufficient to fit in all the required spaces, therefore the museum will have the outer dimensions of 24*24*24m.

7.4 Functional requirements of the facade

1. Intermediate between indoor and outdoor climate
2. Structural function
3. Form and esthetics
4. Safety
5. Maintenance

All the above mentioned requirements consider different aspects. These aspects and a description on what is important concerning these aspects are given below. Influence of all mentioned aspects should be considered before and during the design process.

1. Separation between indoor and outdoor climate
   - Temperature
     - The facade functions as the skin between the inside and outside temperature.
     - R-value (thermal resistance); the higher this value for the facade the better the insulation of the facade.
     - Thermal conductivity coefficient (λ): this value is specific for each material, the higher the value the lower the R-value.
     - Sandwich panels can contribute positively to thermal resistance and inertia.
   - Relative humidity
     - Appliance of a vapor barrier
     - Vapor buffering; absorbing vapor in case of high relative humidity and emitting in case of low relative humidity
   - Acoustics
     - Building mass
     - Air-tightness
   - Wind
     - Structural stability
     - Air-tightness
   - Light
     - Window openings
     - Opaque parts
     - Sun screening
     - Building orientation

2. Structural function
   - (non) load bearing façade
     - Reinforcement in case of load bearing
     - Extra mass in case of load bearing
     - Fire resistance
   - (non) self supporting façade
     - Connection to structure

3. Form/ esthetics
   - Surroundings
     - Energy museum should fit in the surrounding area
   - Appearance
     - Function should be noticeable in the appearance of the museum
   - Relation form and function
     - Form follows function

4. Safety
    - Fire safety
        - For the structure of the building the prescription for fire safety:
          Building height > 13m → 120 minutes fire resistant
    - Burglary safety
        - The building should be protected against burglary
    - Structural safety
        - Strength
        - Stability
        - Stiffness

5. Maintenance
    - Minimal maintenance during life cycle
    - Easy to maintain

7.4 Architectural Design of the energy museum

As been said before the form of the energy museum is cubic and the outer dimensions from the cube are 24*24*24m. The facades which will mainly be the sustainable elements of the building are built up as following: three facades are made out of concrete sandwich panels and one facade will be completely made out of glass. The glass facade is the one which will be performed with triple glass. By taking into account the museum function of the building, it is not desirable to receive a lot of sunlight in the building where several objects will be exhibited. A maximum amount of daylight however is desirable; the amount of artificial light could then be reduced to a minimum. At this moment for the above mentioned reasons the glass facade is situated on the north.

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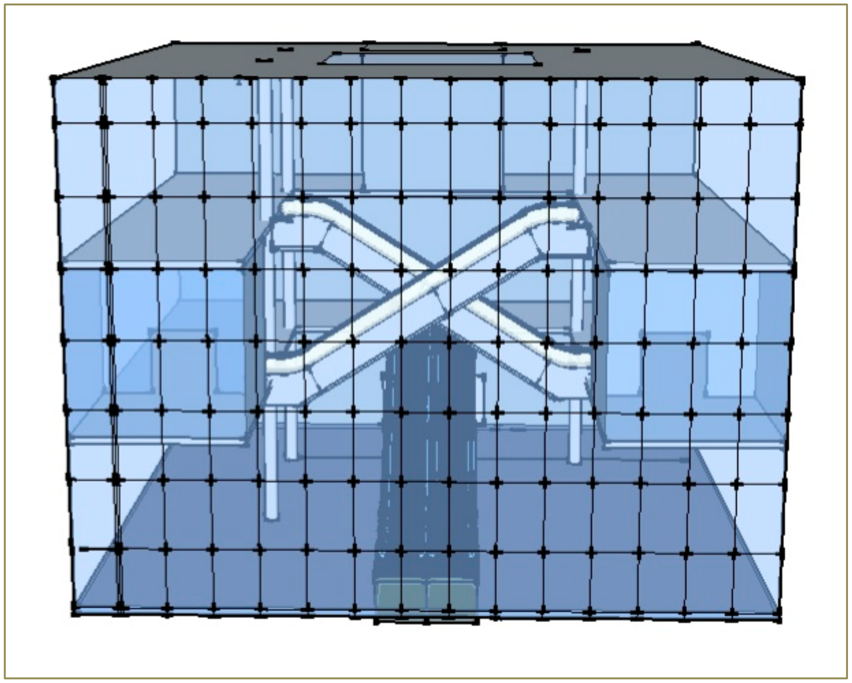
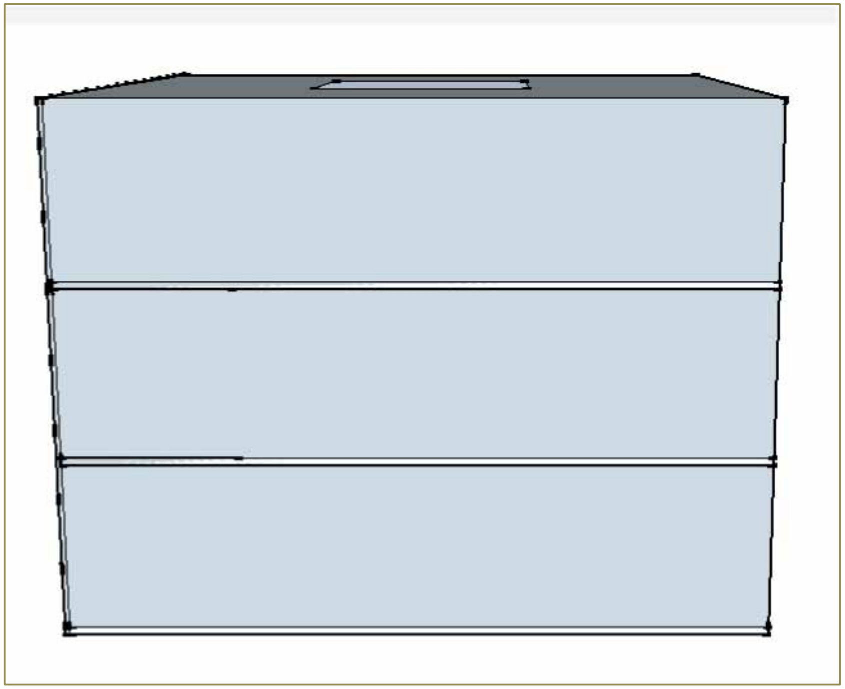
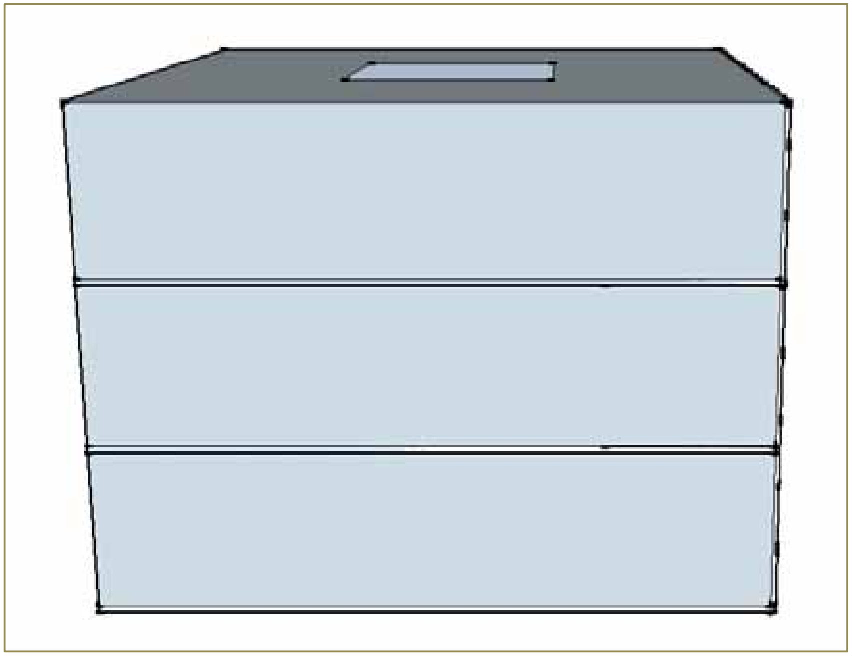


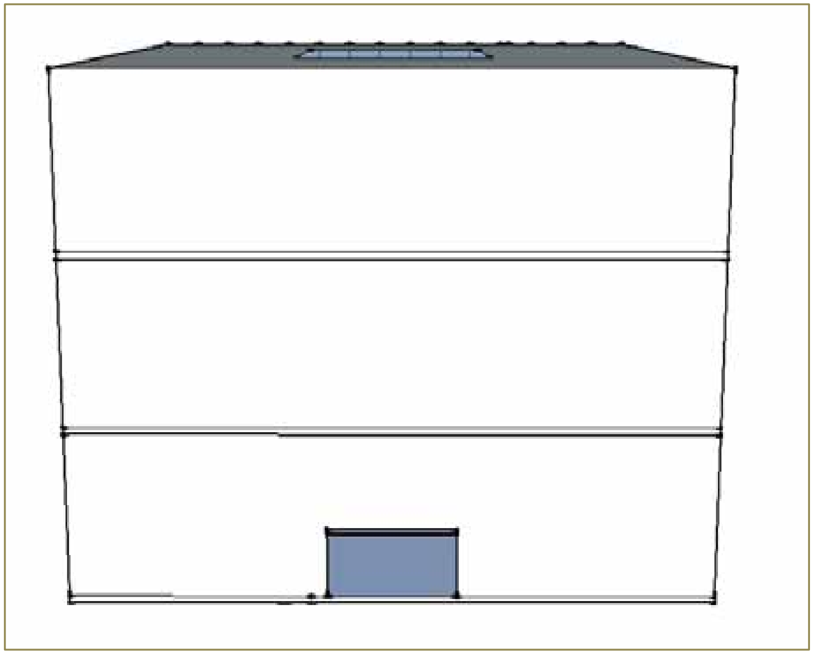
Img. 18 North Facade; Complete north facade is built out of triple glazing



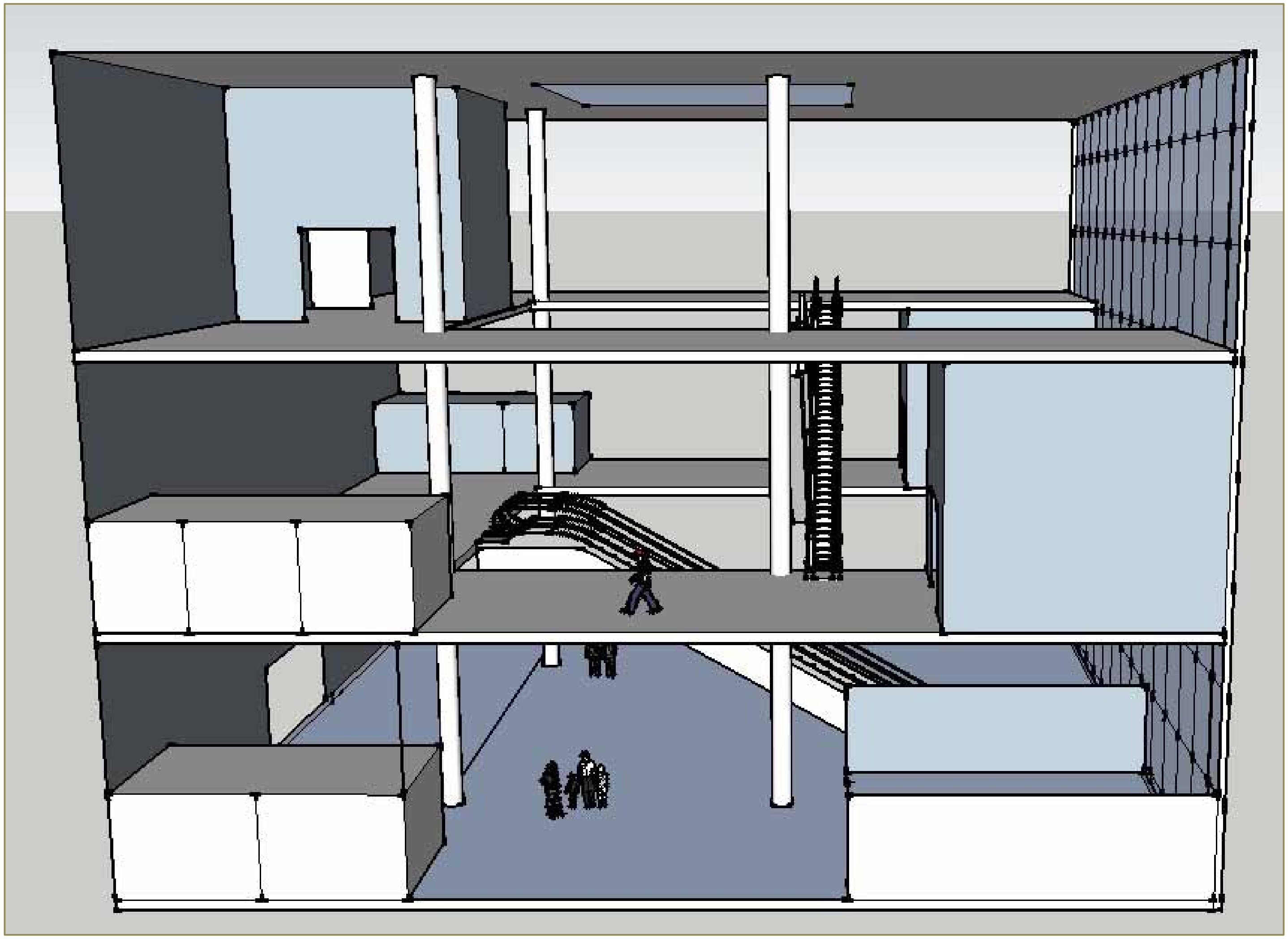
Img. 19 South facade; Opaque south facade made out of concrete sandwich panels



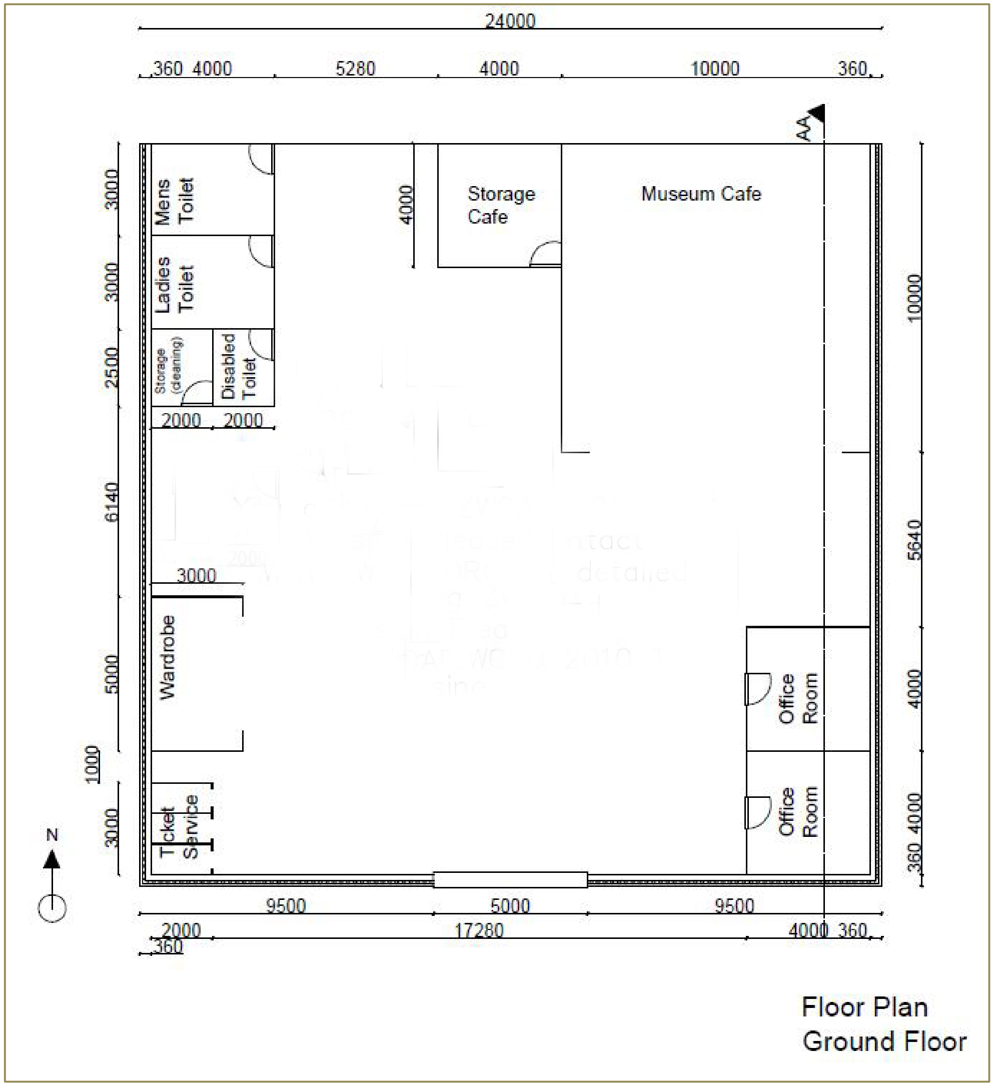
Img. 20 East facade; Opaque east facade made out of concrete sandwich panels



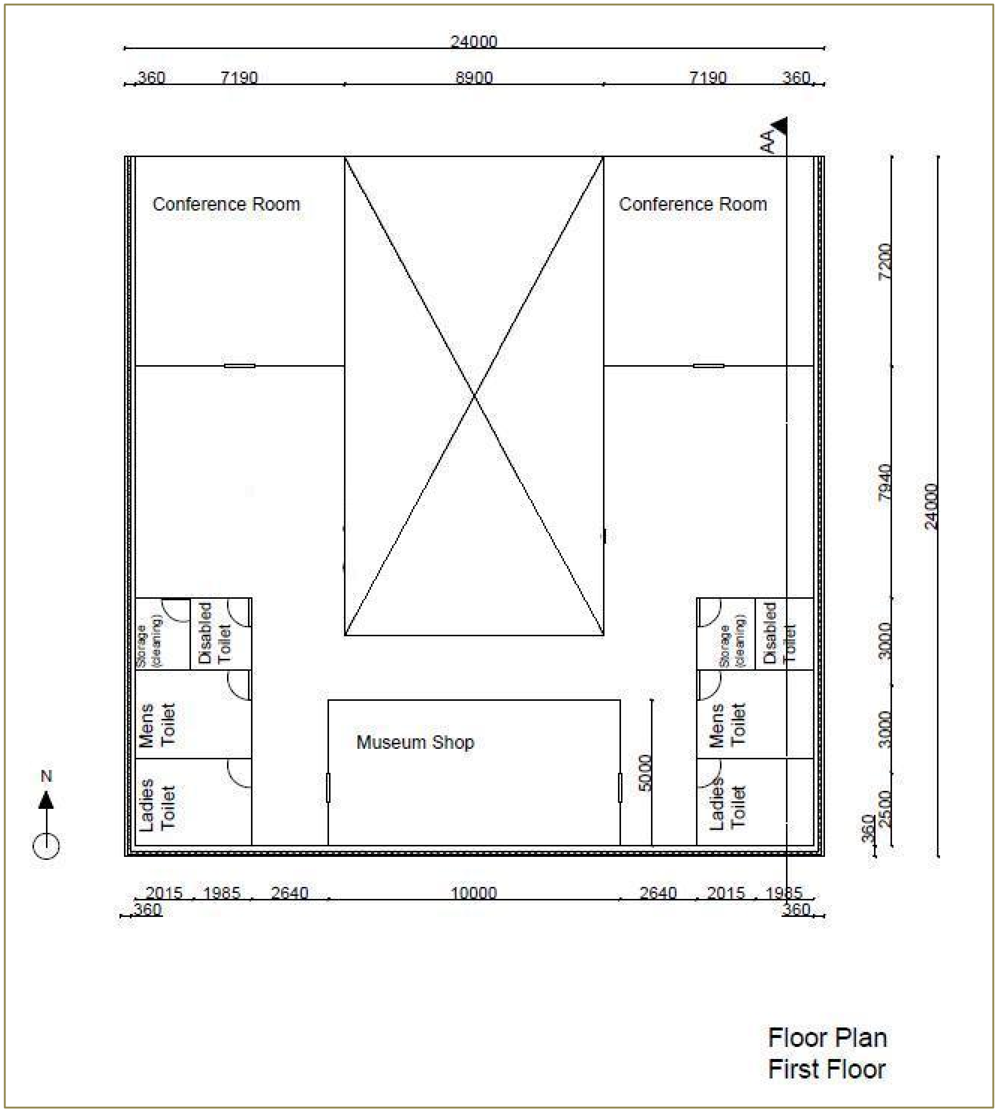
Img. 21 West facade; Opaque west facade made out of concrete sandwich panels



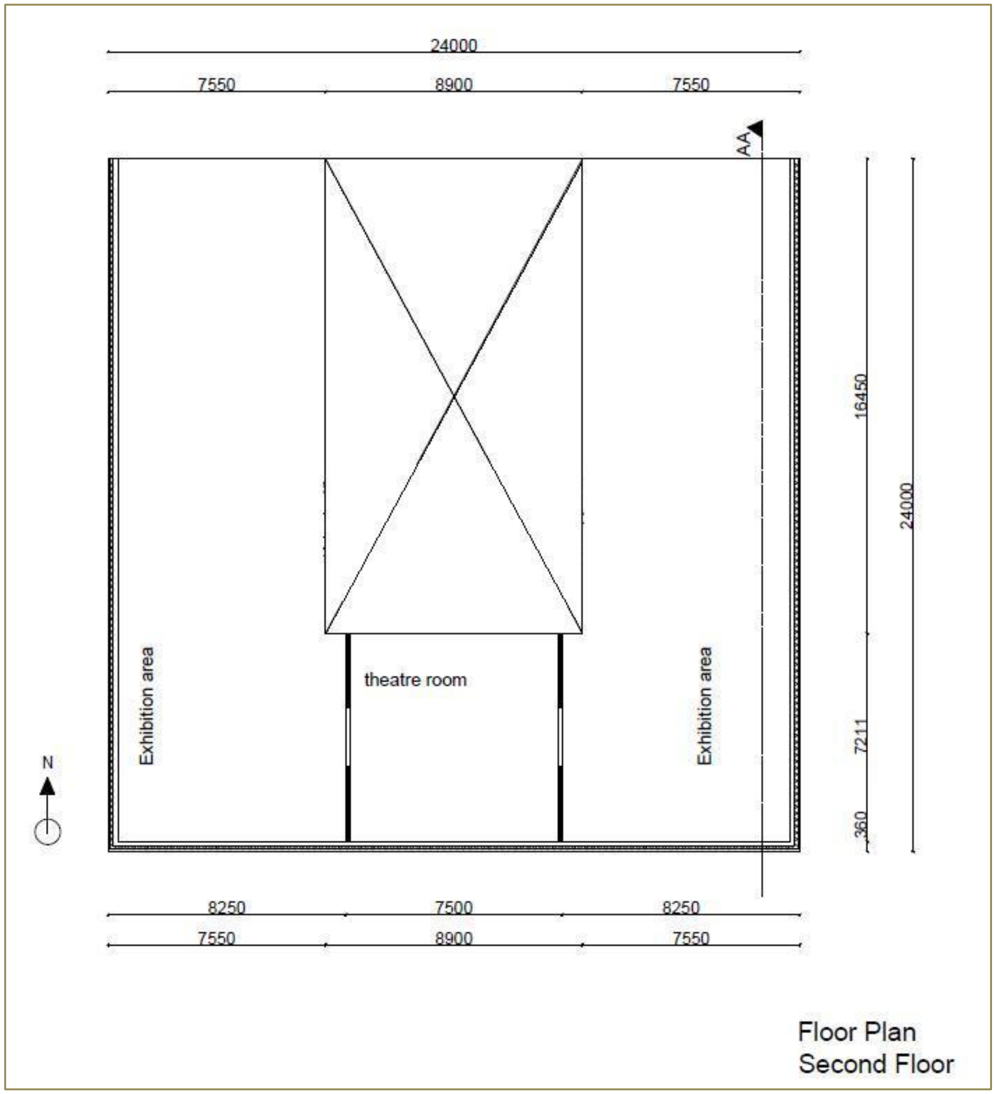
Img. 22 Cross Section AA; this cross section illustrates the interior of the museum



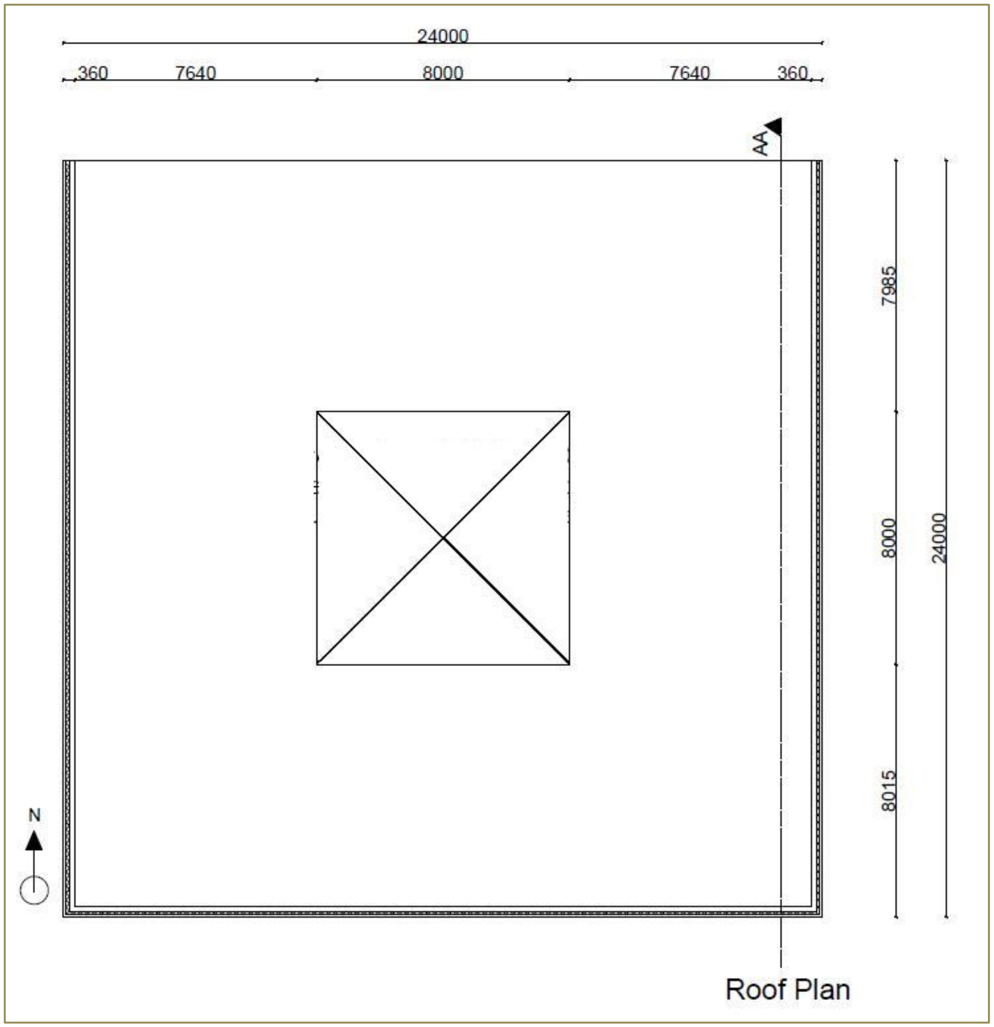
Img. 23 Floor plan ground floor; space division of the ground floor



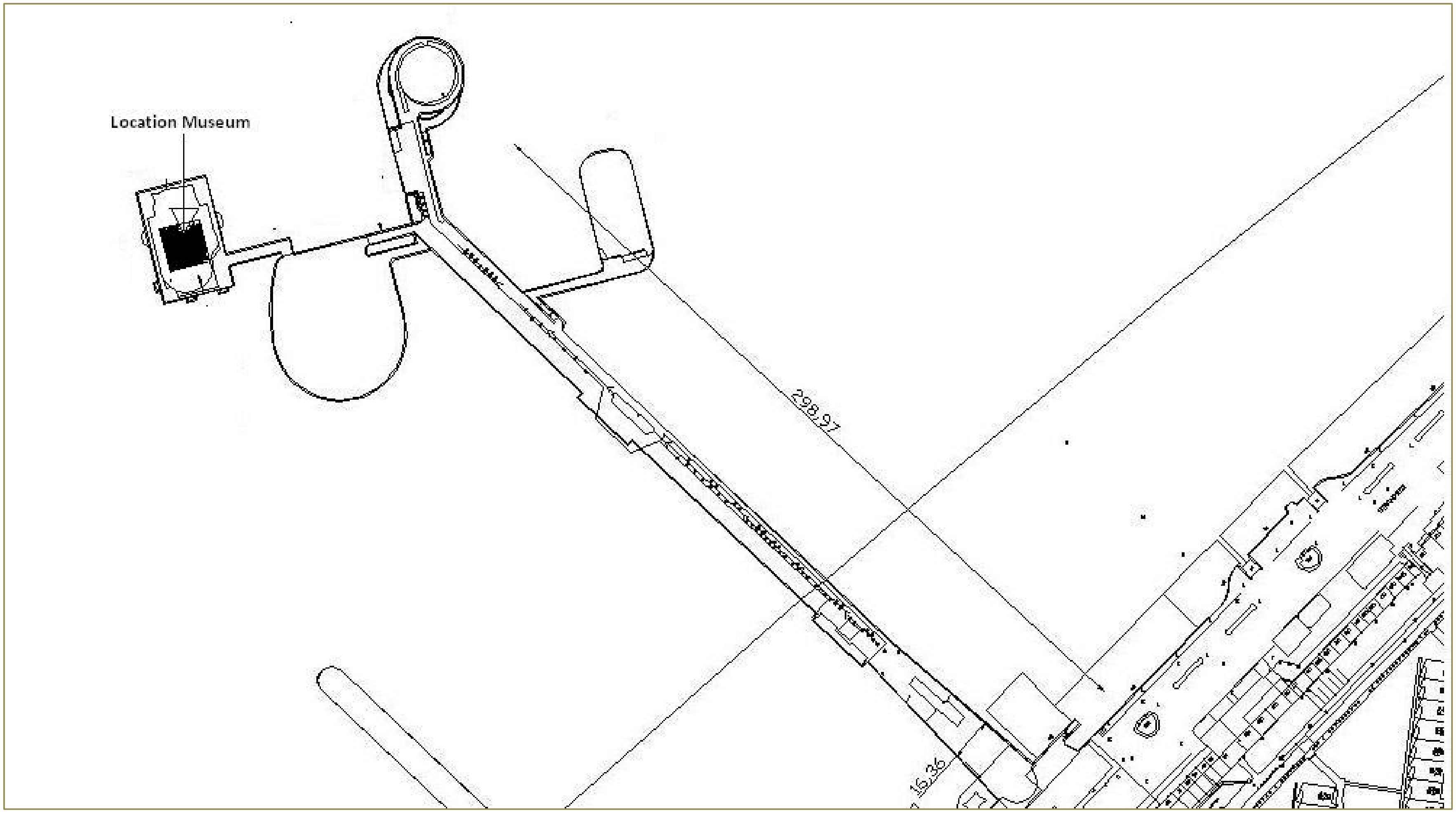
Img. 24 Floor plan first floor; space division first floor



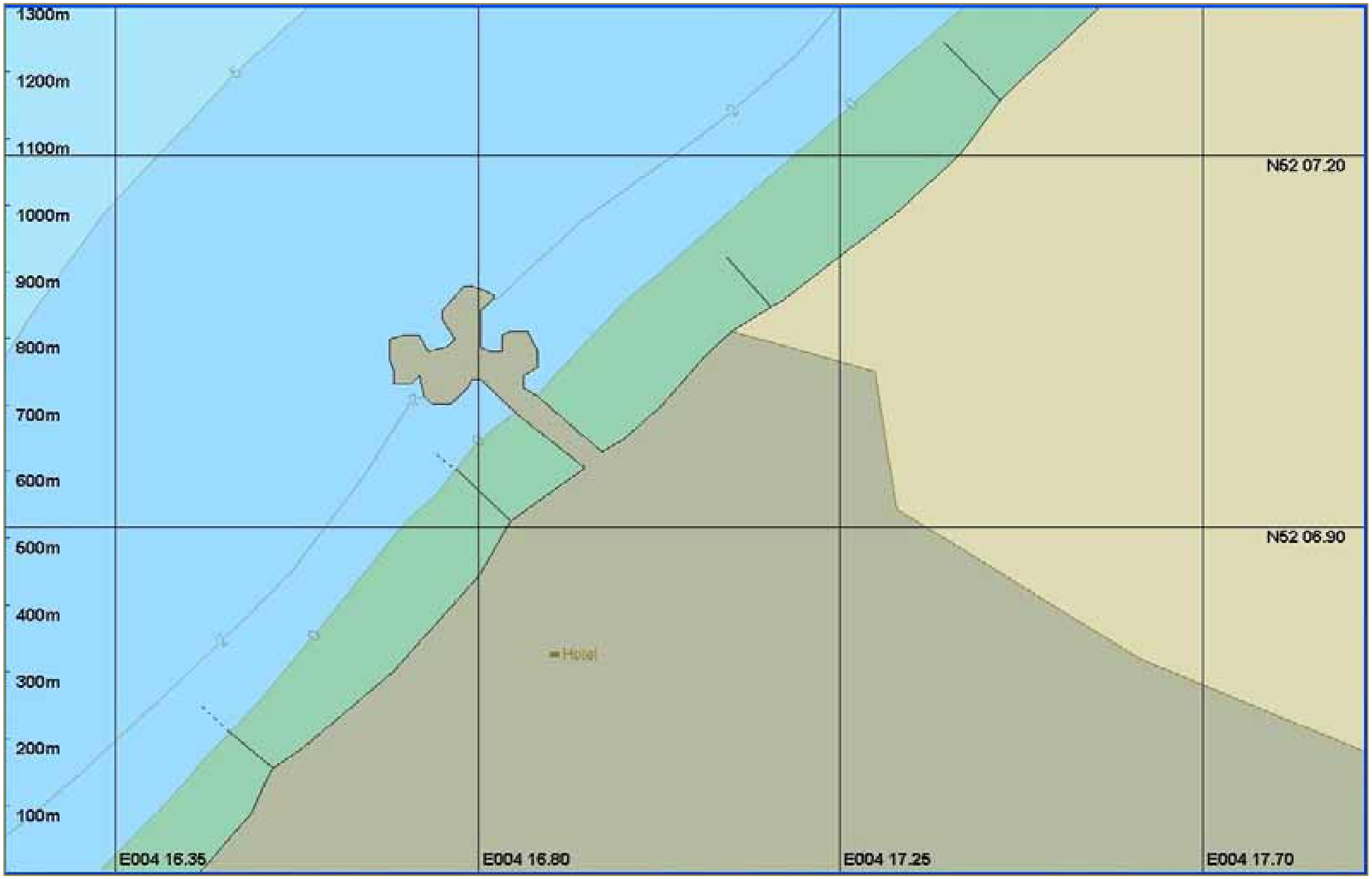
Img. 25 Floor plan second floor; space division of the second floor



Img. 26 Roofplan; opaque concrete roof with a glass part in the middle



Img. 27 Location of the energy museum on the Pier of Scheveningen



Img. 28

Location of the energy museum

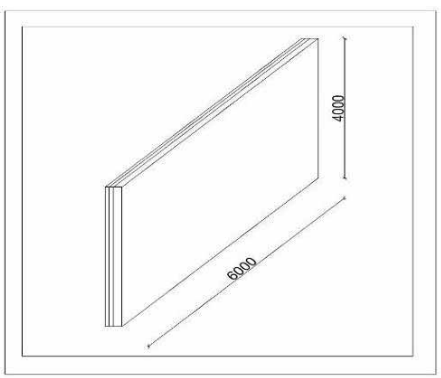
7.5 Structural concept

In this part of the thesis a few structural elements will be discussed. Because of the fact this thesis is not concerned about the structural design of the energy museum, only the concrete elements within the building which contain a structural function will be discussed. The energy museum is located on one of the existing island of the pier where there is already a foundation, assuming the foundation can carry the loads of the energy museum, there will be no further research to the foundation. The structure of the energy museum is made out of prefabricated concrete elements. The dimensions of the elements are determined with the help of rules of thumbs.

7.5.1 Load bearing walls

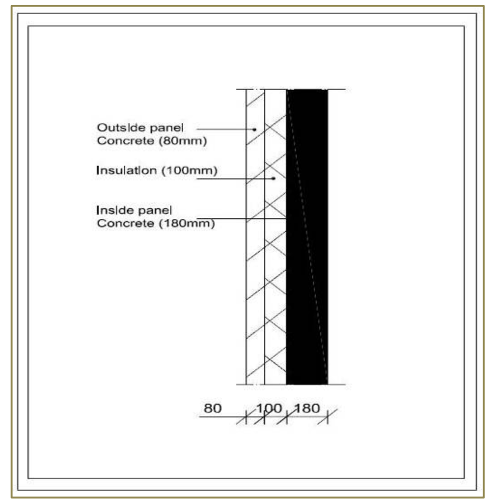
The building structure consists of load bearing facades, which carry the floors on one side. The facade is built up with two concrete layers separated by an insulating layer (see image 30). The load bearing facades are prefabricated concrete sandwich elements of 6*4m where the inner leave is the load bearing leave (see image 29).

Rule of thumb:



Img. 29 Sandwich panel; the opaque facades consist of concrete sandwich panels with dimensions of 6X4m

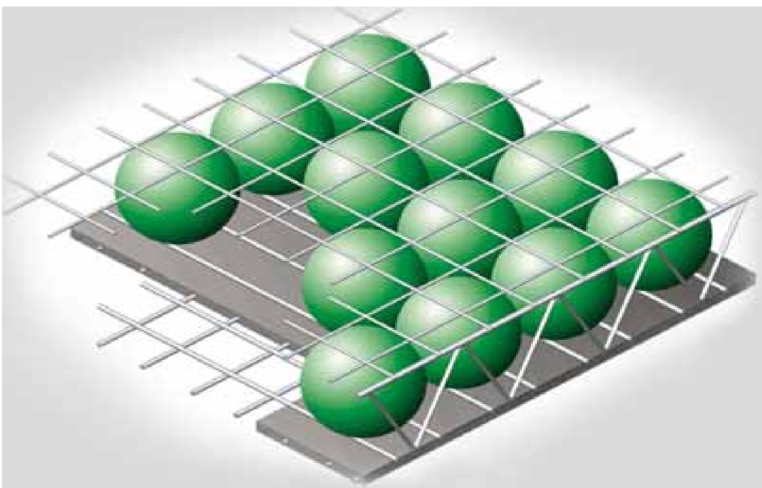
Load bearing wall: number of floors <8; minimal wall thickness 180mm. Keeping in mind that the less material is used, the better it is for the environment, the minimum thickness of 180mm will be applied. With respect to sustainability the facade is not only the intermediate between in- and outside, but fulfills also a structural function. In this way optimum material use is pursued.



Img. 30 Cross section sandwich panel; panel consist of an insulation layer between two concrete leaves, where the inner leave is load bearing

7.5.2 Floor system

With respect to reduce the material volume which is profitable for the environment, concrete bubble deck floors (see image 31) are a good option to apply as floors in the museum. The main advantages of the bubble deck floor is the reduction in weight with about 25 till 30% in comparison with a traditional concrete floor and the fact that the bubble deck floor is load bearing in two directions. On one side the bubble deck floors are carried by the load-bearing facade, on the other side one row of bubbles will be removed to create an invincible beam, which is supported by concrete columns.



Img. 31 Concrete bubble deck floor; this floor will be applied for all floors in the museum. Due to the bubbles the weight is reduced to a minimum, besides that the floor is load bearing in two directions

Floor thickness: 1/25 * l = 1/25 * 7500 = 300mm

7.5.3 Columns

The columns which support the floors on one side and transfer loads to the foundation are prefabricated concrete columns.

Dimensionering Kolom												
E.g. Vloer	0,3	*	75%	*	24	=	5,4	kN/m2	*	1,2	6,48	kN/m2
dekvloer	0,05				20	=	1	kN/m2	*	1,2	1,2	kN/m2
Plafond/inst.							0,25	kN/m2	*	1,2	0,3	kN/m2
V.b.							4	kN/m2	*	1,5	6	kN/m2
										totaal:	13,98	kN/m2
Te dragen opp door kolom begane grond =	3	*	64	=	192	m2						
					192	m2	*	13,98	=	2684,16	kN	

Rule of thumb

Prefabricated column: A= F/15

F=2684,16kN, we assume a further value of 3000kN

$$A = \frac{3000 * 10^3}{15} = 200000mm$$

$$r = \sqrt{200000/\pi} = 252mm$$

$$\varnothing = 2 * 252 = 504mm$$

We choose concrete columns with a diameter of 400mm, this diameter is less than the actual needed diameter, but the columns will be made out of high strength concrete and so the diameter can be reduced for that matter.

8. Research

In this chapter the three sustainable measures which will be applied in the energy museum will be researched. At first the measure with respect to materials will be further researched, followed by the measure on renewable energy, subsequently a research to the second skin facade.

According to the values in the table 3, concrete is almost in every category the most harmful material towards the environment, especially when emissions like Greenhouse effects are considered. However concrete is one of the most important and most commonly applied construction materials, besides that concrete contains several environmental and general properties which are very advantageous in the building industry. Because of this it is a challenge and also necessary to increase the development of sustainable facades in concrete. Therefore in this particular case for the energy museum the further purpose is to develop sustainable facades in concrete for as far as. Combining properties in the right way. In this master thesis the aim is to take advantage of these properties of concrete, so that for this matter the goal to develop a sustainable facade in concrete will be accomplished.

In the second part of this chapter research to renewable energy that will be applied in the form of solar energy and perhaps wind power to compensate if necessary will be done. The main purpose to cover the electricity demand with renewable energy.

In the third part of this chapter the research to the second skin facade and the smart solar shading which will be take place.

8.1 Sustainable measure with respect to material

In this part of the master thesis the construction material concrete is discussed. For this thesis the importance lies in the relationship between concrete and sustainability, thus in the way concrete acts towards the environment. To apply the material for this purpose it is necessary to understand the construction material. Components, production process, properties, transport, recycle abilities are aspects that need to be taken into account carefully; therefore this part starts with a research to concrete.

8.1.1 Resources and composition of concrete

Concrete is composed of cement, water and aggregates. Roughly speaking for the production of one m^3 concrete there is 300 kilo of cement, 150 liter water and 2000 kilo of aggregates necessary. The most important resource for cement is marl, which is a variation on limestone. Important aggregates are sand and gravel.

Portland cement

Portland cement is produced mainly with marl, which is extracted in South Limburg. The extraction has led to deterioration of the landscape and its ecosystems.

Blast furnace cement

This type of cement mainly consist of grinded blast furnace clinker; these are slags which are leftovers from the blast furnace process. In fact they are rest materials which would have had no other destination otherwise. Blast furnace slag is also a ‘binder’: therefore less cement is necessary. The radioactivity of blast furnace cement is a bit higher and it contains tracks from heavy metals coming from the slag, which can release during recycling or during drilling in the usage. For flyash the same issues occur. Appliance in dwellings is not advisable, because flyash slags contain also heavy metals and is quite radioactive.

Sand

Sand can be extracted in two ways; as seasand coming from the bottom of the sea and as landsand coming from layers in the soil and out of rivers. For concrete the most applied sand is landsand, because seasand has the disadvantage that the surface is not adhesive enough and the sand is contaminated with chlorides. In principle the extraction from sand is not deteriorating the landscape for a great deal, because the extraction takes place in deep layers. Occasionally it creates new watery areas. However the deep extraction can also be disturbing towards the water management because areas in the water could subside.

Gravel

Gravel is extracted from rivers and deep soil layers. Extracting from rivers damages the soil and ecosystems. Gravel is not as easily available as sand, however it is possible to use rubblegranule, grinded stony building or demolition rubble, instead of gravel. Up to about 20% replacement with granule there are no disadvantages with respect to the strength of the concrete. Whenever concrete is not applied for structural purposes and thus its strength plays a limiting role, one could replace all gravel with granule. In this case concrete can at least reach a strength C25.

Clay

There is also the possibility to apply sintered clay particles instead of gravel, but it does take more energy to produce these particles. The concrete does get lighter by this replacement, the same case occurs by replacing with granule.

In the table 4 one can find information about the extraction amounts of marl, gravel and sand in the Netherlands[27].

Resource	**Area**	**supply**	**supply**	**usage (mln tonne/year)**	**Supply period (year)**	**Supply period (year)**
		category 1	category 2		category 1	category 2
Marl	St.Pietersberg	75	low	1.3	40	low
	Margraten	500	low	-	300	low
Gravel	Limburg	2.500	1.000	10.0	250	100
Sand	Netherlands	40.000	35.000	10.0	4.000	3.500

table 4 Availability of materials in the Netherlands which are needed to produce concrete

* Category 1 In principle no extraction; under conditions extraction is permitted
* Category 2 In principle extraction is permitted

[27] Source: Scheme surface minerals. Design planology decisions. Ministry of Transport, Public Works and Water Management and Ministry of Housing, Spatial Planning and the Environment, the Hague, 7th march 1994

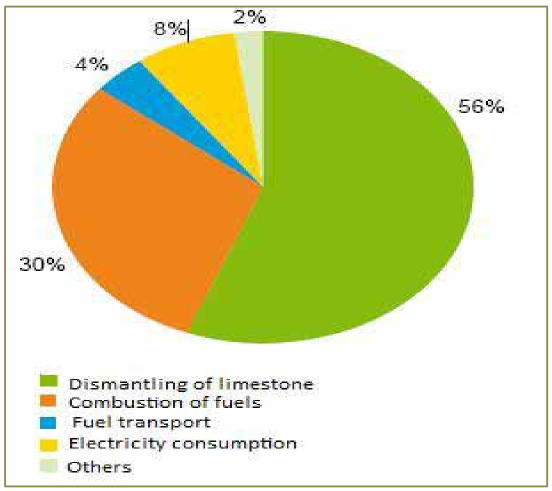
The infestation of the environment due to the extraction of sand, gravel and marl is a combination of deterioration of the landscape and the energy consumption during transport and extraction itself. Besides that emissions are released because of the use of fuel and electricity during extraction and transport, noise and dust can also cause hindrance.

8.1.2 Environmental aspects of concrete and CO_2 emissions

There are several environmental problems with concrete. In the following paragraphs the most important ones are discussed.

Cement

The largest source of concrete related CO_2 emissions is cement. One ton cement which is produced in the European union causes subsequently 865 kg CO_2-equivalents. In the image below one can see how the ratio between the several factors is determined.



Img. 32 Average percentages of CO_2 production in European cement

There is an assumption that the cement industry is world widely responsible for 5% of the CO_2 emissions on earth[28]. There are two important CO_2 sources: fuels and limestone. To reduce the CO_2 emission within the cement industry there are some measures which can be met:

- Fossil fuels could be replaced by secondary fuels or biomass.
- Reducing the amount of clinker of cement; Clinker is the solid material produced by the cement kiln stage, fused into an irregular lump, that remains after the combustion of coal. The less clinker is used in cement, the less limestone needs to be dismantled, the less CO_2 gets emitted in the air. This can be done by adding fly ash, silica fume, slag, pozzolana or crushed limestone. Transport needs to be taken into account for this matter, because not all regions contain these sources.
- For the electricity use one could consider using power coming from renewable forms of energy which are described in the following chapter.

Nitrous oxide emissions

When burning gasoline or other fuels nitrous oxide is emitted. Ozone is formed when nitrogen oxides and volatile organic compounds mix in sunlight. The volatile organic compounds come from sources ranging from industrial solvents to volatile resins in trees. Ozone near the ground can cause many health problems.

By reducing the burning temperature or injecting ammonia compounds into the high temperature exhaust stream the amount of nitrous oxides can be reduced[29]. However the side effect of this principle is that it affects the quality of the produced fly ash. This on its turn means that the fly ash

[28] World Business Council for sustainable development; publication2007

[29] Klein, M; Rose, D; Development of CME National Emission Guidelines for Cement Kilns in CANMET/ACZ International Symposium on Sustainable Development of the Cement and Concrete Industry, editor V.M.Malhotra, Ottawa, October 1998, pp. 16-30.

needs to be treated to remove the unburned coal and ammonia gas before it can be used in concrete mixtures.

Transport

A very important source of CO_2 emissions in the concrete industry is the transport. The amounts of cement and concrete which need to be transported are large after all. Obviously not only transport of cement and concrete should be taken into account for this matter, but also the raw materials which are used for cement and concrete play a role. According to the CBS (Central bureau for statistics) on a yearly basis 132 Mt of construction materials are transported on roads; 40 Mt is concrete. Transportation from construction materials over water represents about 54Mt. These numbers were approximately close to reality in the year 2007. The inland transport of goods through roads causes 7 % of the yearly emission of CO_2 in the Netherlands.

The positive side is that the Netherlands contains quite a number of waterways; canals, rivers and lakes. This makes it possible that a large part of the transport from for instance sand, gravel and cement can take place on water. This costs a lot less energy than the transport through roads.

Reinforcement and prestressing

Steel contains about 7 to 10 times more energy than cement per kilo. However whenever concrete is used for structural purposes it needs to be reinforced or prestressed with steel.

Carbonization

Carbonization is a chemical process where CO_2 in the air reacts with calcium dihydroxide $Ca(OH)_2$ in the concrete. This then together forms $CaCO_3$ (limestone). This phenomenon can be damaging for the concrete and for as far as possible this reaction should be delayed. Steel in the concrete which serves as reinforcement can be affected negatively, because carbonization opens up the concrete barrier to penetration of unwanted compounds and it also lowers the pH-value in the concrete[30] and for that matter the structure could lose its safety. The rate of carbonization depends strongly on the CO_2 concentration in the air.

Advantage of carbonization: Some environmentalists consider this phenomenon as a positive one, due to the fact that the CO_2 in the air gets admitted.

In the usage phase carbonization occurs very slowly, however the process increases in speed after concrete is dismantled and is crushed and grinded into concrete granulate.

8.1.3 Environmental benefits of concrete

Besides all the mentioned negative issues that come along with the usage of concrete there are also several benefits. The environmental benefits of concrete are discussed in the following paragraphs.

Reuse

Whenever a building is made out of concrete or partly made out of concrete, the concrete is reusable. In case of reinforced concrete, reinforcing bars are removed after crushing the concrete. Depending on its future purpose concrete is crushed into particles of a certain size. The reuse of elements in its original form is only possible if structures are built up demountable with prefabricated elements.

Material savings

In case of pretensioning or applying high strength concrete it is possible to use slim elements, in this way less material is used, thus less resources are necessary.

[30] Burström P. G.; Byggnadsmaterial Uppbyggnad, tillverkning och egenskaper, Chapter 12, Studentlitteratur

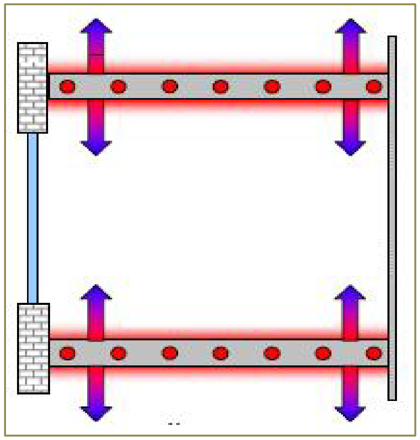
The concrete industry also contains concrete floors which are built up with bubbles and/ or cores which reduce the weight and the amount of concrete. Bubble deck floors, where the weight is reduced with about 30% in comparison with a traditional concrete floor.

Thermal mass

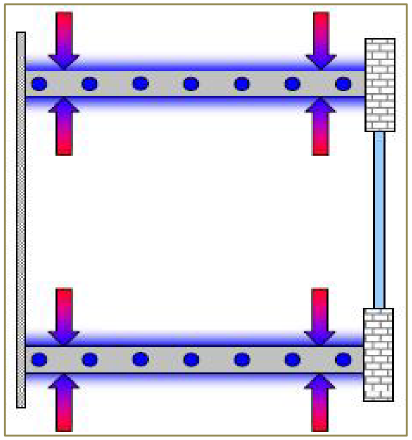
The thermal mass of a building is a function of the physical mass (density kg/m3) of the building, the specific heat capacity (J/kgK) and the ratio between the area and thickness. The energy content of building increases when the mass increases. The thermal mass of a building increases when the physical mass increases. This is favorable for the energy consumption of a building in the usage phase and also for the indoor thermal comfort. From this point of view concrete does have some advantages. Concrete insulates well, mass is high and the ability to accumulate heat is good. These properties work in the advantage for concrete with respect to the indoor climate of a building. It is quite stable, without extreme heating and cooling. Thermal mass can be used actively or passively. In the last case scenario the mass of concrete does all the work. No extreme temperatures and temperature differences will occur when seasons change or during day and nighttime. An early application using thermal mass actively is the intentioned airflow trough canals in hollow core slabs.

Concrete core activation

The principle of concrete core activation is that a room within a building can be heated or cooled by means of the circulation of water in pipes that lay in the core of a concrete floor slab. Concrete core activation uses the building mass and uses the ability to accumulate thermal energy. The building structure is capable to store thermal energy and release it whenever it is required. As the water flows through the pipes, it transfers heating capacity or cooling capacity to
the slab, thus heating or cooling it, depending on the water temperature.
The heat or cold which is stored in the concrete is transferred to the rooms by means of convection and radiation. The capacity to emit is influenced by a few factors; the heat transfer coefficient between the surfaces and the rooms, the dimensions of the surfaces and the thermal storage capacity of the structure.



Img.33 Heating with cca; hot air rises down



Img. 34Cooling with cca; cold air flows

By applying concrete core activation to cool and/ or to heat a space is based on a low level of heating or a high level of cooling temperatures in combination with a large surface (ceiling, wall and/or floor).

Advantages of concrete core activation:

- A pleasant inside climate can be obtained; because the concrete mass releases heat and cold gradually one can obtain a relative constant temperature.
- The combination with low temperature heating contributes to energy savings, for example compared to a heating system with radiators.
- Concrete core activation can be easily combined with a heat pump which contributes to energy savings.
- Esthetics; there are no radiators or piping necessary in the spaces

Low temperature heating
The principle of low temperature heating (LTH) systems is that the distributing temperature of the water in the system is closer to room temperature than other systems. Where in other systems the water temperature is around 90 °C, the water in the LTH systems is around 50 °C; in this way LTH-systems lead to energy savings.

Concrete core activation with air

Normally concrete core activation is done with the help of a liquid floating trough the pipes. However it is also a possibility to apply concrete core activation with air flowing through ducts. The diameter of these pipes is larger when applying air instead of a liquid like water. Aluminum ducts with a diameter of about 60 or 80mm are applied. The air is blown into the ducts with a temperature of around 12 degrees and a relative humidity of 95%. While the air is flowing through the ducts the concrete absorbs the heat of the concrete and on its turn the air can be blown into a room. The air which is supplied for ventilation is reheated without using extra energy and is used in an efficient way. In practice it seems that the relative humidity reduces to a value of about 50-60%, this value is according to Fanger a pleasant one for office buildings.

Advantages that come along with concrete core activation on air basis are the following:

- A system with water needs a larger heat content and besides that it is more difficult to switch over from cooling to heating, thus a system with the use of air needs a smaller capacity
- There is no need for another system to ventilate. For thermal comfort dehumidifying is more important than cooling.

Disadvantages that come along with concrete core activation on air basis are the following:

- For the application of concrete core activation on air basis the diameter of the pipes increases, construction elements where the pipes are laid in should therefore have minimum dimensions.
- Cleaning is difficult and with respect to health effects this could be disadvantageous.

8.1.4 Discussion

There are several sustainable benefits that come along with the usage of concrete. First of all by just considering the fact that using as less material as possible is in advantage of the environment. The less material there is used, the less energy will be used during production and transportation. The great advantage of concrete for this matter is that it can fulfill more than one function at the same time. The facade will be the intermediate between inside and outside, but also function as a part of the structure.

Like every other building the energy museum needs to be cooled during the summer period and heated during the winter period, to apply one more function to the facade, the described form of heating and cooling by means of concrete core activation will be applied in the facades of the museum. Because of the fact that concrete core activation will be applied in the energy museum the system will be further analyzed and researched in the following paragraphs.

The application of concrete core activation is a combination of a measure on material and energy part. However, the largest source of concrete related CO_2 emissions is cement and in this thesis all concrete elements, most importantly the facades, will be made with a new type of cement which is more environmental friendly. In the paragraph 8.1.6 this item will be further considered.

8.1.5 Concrete core activation

The application of concrete core activation depends strongly on the cooling and heating demand. This on its turn is dependent on the building and its dimensions and function. It is important that the condition of mind that expresses satisfaction with the thermal environment is taken into account in buildings. The term 'thermal comfort' describes a person's psychological state of mind and is usually referred to in terms of whether someone is feeling too hot or too cold. Within the energy museum the concrete core activation would be the system that takes care of the thermal comfort for its visitors and employers by means of cooling during the summer and heating during the winter.

In the following paragraphs the total heating and cooling demand for the energy museum are calculated. These values need to be determined in order to find out whether the concrete core activation contains enough capacity to meet the heating and cooling demand of the building. If not than another system for heating and cooling needs to be added to meet the requirements for the total demand.

8.1.5.1 Cooling demand

For the summer situation the cooling demand is to be determined. In this thesis the calculation sheet from the Kennisbank Bouwfysica, made by ir.P. van den Engel was applied to determine the cooling demand. There are three calculations done, one for each floor. For each floor then separately there will be a calculation which will show if cooling with concrete core activation within the facades is sufficient. The calculation sheet contains information and numbers, beforehand the values in the several steps of the calculation will be explained:

Explanation of values in the calculation sheets:
In step 2 the total surface of the floor in given.

In step 3 the height is added to obtain the value of the volume from that particular floor.

In step 4 the temperature outside and the temperature inside is determined. For the summer situation we assume an outside temperature of 28 Celsius and inside a temperature of 24 Celsius. The outside temperature is based on an extreme situation and the inside temperature is set on 24 Celcius degrees.

In step 5 the total surfaces of the transparent elements are calculated and the specific G-value of the applied glass is given. The G-value of 0,3 is the value for insulating sun-screening glass. Also the average most unfavorable solar heat load is gives. For the ground and first floor, by taken into account that the glass facade is on the north side a value of 150W/m2 is determined. For the second floor a value of 300 is used, due to the fact the roof is horizontal and partially made out of glass with solar shading.

In step 6 the numbers of persons at its max is set on 100, the capacity of the lighting and computers are average values from the Kennisbank Bouwfysica

In step 7 the ventilation rate according to the building decree for a museum is 0,9dm^3/sm^2. The heat recovery percentage is set on 0% in the summer situation, the infiltration rate is set on 0,2 and the volumic mass of air is 1,2kg/m3

All floors should be considered separately when it comes to the cooling demand. In the first sheet the cooling demand of the ground floor is determined, in the second sheet the cooling demand for the first floor, subsequently in the third sheet the cooling demand of the second floor is determined.

Ground Floor								
Steps					**Results and characterstic numbers**			
1	Choose a building, part of a building or a room which should be calculated							
2	Calculate the net floor area							
	length	24	m					
	width	24	m		576	m^2		
3	Calculate the net volume (between floor and ceiling)							
	Avarage height between floor and ceiling							
		8	m		4608	m^3		
4	Choose a design indoor and outdoor temperature							
		24	°C					
	T_{buiten} =	28	°C					
5	Calculate external heat load							
	Area transparant parts building envelope							
	A_{glass} =	202	m^2	ca 90% of glass + frame				
	Average g-value							
	ZTA (g) =	0,3						
	Average most unfavourable solar heat load (literature: bouwfysisch tabellarium)							
	Q_{sun} =	150	W/m^2					
	External heat load = A_{glass} * ZTA * Qsun				9090	W	16	W/m^2
6	Determine internal heat load							
	Number of persons							
		100			8000	W	14	W/m^2
	Capacity lighting							
		10	W/m^2		5760	W	10	W/m^2
	Capacity computers							
		10	W/m^2		5760	W	10	W/m^2
7	Calculate ventilation cold loss							
	Air change rate						See Building Code	
	n =	0,9			4147	m^3/h	2,0	dm^3/sm^2
	Ventilation flow Q_{vent}				1,152	m^3/s		
	Heat recovery percentage (sensible heat) hrp							
		0%						
	Infiltration rate							
	n =	0,2			922	m^3/h	0,4	dm^3/sm^2
	Infiltration flow Q_{inf}				0,256	m^3/s		
	Volumic mass air ρ			specific heat capacity air c = 1.000 J/kgK				
		1,2	kg/m^3	depends on outside temperature				
	Ventilation cold loss = (Q_{vent} * ((1- hrp) + Q_{inf})) * ρ * c * ($T_{outside}$ - T_{inside})							
				without dehumidification	6.758	W	12	W/m^2
				with dehumidification	17549	W	30	W/m^2
				24°C, 50%RV inside; 28°C, 60%RV outside				
8	Determine total cold demand			without dehumidification	35.368	W	61	W/m^2
				with dehumidification	46.159	W	80	W/m^2
	Exclusive:							
	More cooling capacity necessary due to cold loss by transmission via the building envelope							
	More cooling capacity necessary due to cold loss to the surrounding spaces							
	Less cooling capacity necessary by free cooling, such as night time ventilation with cooling down of the building mass, 20-30 W/m^2							

Calculation sheet 1. Cooling demand for the ground floor

First Floor								
Steps					**Results and characterstic numbers**			
1	Choose a building, part of a building or a room which should be calculated							
2	Calculate the net floor area							
	length	**24**	m					
	width	**24**	m		**576**	m^2		
3	Calculate the net volume (between floor and ceiling)							
	Avarage height between floor and ceiling							
		8	m		**4608**	m^3		
4	Choose a design indoor and outdoor temperature							
		24	°C					
	T_{buiten} =	**28**	°C					
5	Calculate external heat load							
	Area transparant parts building envelope							
	A_{glass} =	**192**	m^2	ca 90% of glass + frame				
	Average g-value							
	ZTA (g) =	**0,3**						
	Average most unfavourable solar heat load (literature: bouwfysisch tabellarium)							
	Q_{sun} =	**150**	W/m^2					
	External heat load = A_{glass} * ZTA * Qsun				**8640**	W	**15**	W/m^2
6	Determine internal heat load							
	Number of persons							
		100			**8000**	W	**14**	W/m^2
	Capacity lighting							
		10	W/m^2		**5760**	W	**10**	W/m^2
	Capacity computers							
		10	W/m^2		**5760**	W	**10**	W/m^2
7	Calculate ventilation cold loss							
	Air change rate						See Building Code	
	n =	**0,9**			**4147**	m^3/h	**2,0**	dm^3/sm^2
	Ventilation flow Q_{vent}				**1,152**	m^3/s		
	Heat recovery percentage (sensible heat) hrp							
		0%						
	Infiltration rate							
	n =	**0,2**			**922**	m^3/h	**0,4**	dm^3/sm^2
	Infiltration flow Q_{inf}				**0,256**	m^3/s		
	Volumic mass air ρ			specific heat capacity air c = 1.000 J/kgK				
		1,2	kg/m^3	depends on outside temperature				
	Ventilation cold loss = (Q_{vent} * ((1- hrp) + Q_{inf})) * ρ * c * ($T_{outside}$ - T_{inside})							
				without dehumidification	**6.758**	W	**12**	W/m^2
				with dehumidification	**17549**	W	**30**	W/m^2
				24°C, 50%RV inside; 28°C, 60%RV outside				
8	Determine total cold demand			without dehumidification	**34.918**	W	**61**	W/m^2
				with dehumidification	**45.709**	W	**79**	W/m^2
	Exclusive:							
	More cooling capacity necessary due to cold loss by transmission via the building envelope							
	More cooling capacity necessary due to cold loss to the surrounding spaces							
	Less cooling capacity necessary by free cooling, such as night time ventilation with cooling down of the building mass, 20-30 W/m^2							

Calculation sheet 2 Cooling demand for the first floor

Second Floor								
Steps					**Results and characterstic numbers**			
1	Choose a building, part of a building or a room which should be calculated							
2	Calculate the net floor area							
	length	24	m					
	width	24	m		576	m^2		
3	Calculate the net volume (between floor and ceiling)							
	Avarage height between floor and ceiling							
		8	m		4608	m^3		
4	Choose a design indoor and outdoor temperature							
		24	°C					
	T_{buiten} =	28	°C					
5	Calculate external heat load							
	Area transparant parts building envelope							
	A_{glass} =	256	m^2	ca 90% of glass + frame				
	Average g-value							
	ZTA (g) =	0,3						
	Average most unfavourable solar heat load (literature: bouwfysisch tabellarium)							
	Q_{sun} =	200	W/m^2					
	External heat load = A_{glass} * ZTA * Qsun				15360	W	27	W/m^2
6	Determine internal heat load							
	Number of persons							
		100			8000	W	14	W/m^2
	Capacity lighting							
		10	W/m^2		5760	W	10	W/m^2
	Capacity computers							
		10	W/m^2		5760	W	10	W/m^2
7	Calculate ventilation cold loss							
	Air change rate						See Building Code	
	n =	0,9			4147	m^3/h	2,0	dm^3/sm^2
	Ventilation flow Q_{vent}				1,152	m^3/s		
	Heat recovery percentage (sensible heat) hrp							
		0%						
	Infiltration rate							
	n =	0,2			922	m^3/h	0,4	dm^3/sm^2
	Infiltration flow Q_{inf}				0,256	m^3/s		
	Volumic mass air ρ			specific heat capacity air c = 1.000 J/kgK				
		1,2	kg/m^3	depends on outside temperature				
	Ventilation cold loss = $(Q_{vent} * ((1-hrp) + Q_{inf})) * \rho * c * (T_{outside} - T_{inside})$							
				without dehumidification	6.758	W	12	W/m^2
				with dehumidification	17549	W	30	W/m^2
				24°C, 50%RV inside; 28°C, 60%RV outside				
8	Determine total cold demand			without dehumidification	41.638	W	72	W/m^2
				with dehumidification	52.429	W	91	W/m^2
	Exclusive:							
	More cooling capacity necessary due to cold loss by transmission via the building envelope							
	More cooling capacity necessary due to cold loss to the surrounding spaces							
	Less cooling capacity necessary by free cooling, such as night time ventilation with cooling down of the building mass, 20-30 W/m^2							

Calculation sheet 3 Cooling demand for the second floor

8.1.5.2 Heating demand

For the winter situation the heating demand is to be determined. In this thesis the calculation sheet from the Kennisbank Bouwfysica, made by ir. P. van den Engel was applied to determine the heating demand. Similar to the determination if the cooling demand, there are 3 calculations, one for each floor is done to determine the heating demand.

The heating demand must be determined just like the cooling demand in order to find out whether the concrete core activation as a heating system is enough to heathen the energy museum during the year. For all three floors the heating demand is determined and the used values which eventually determine the heating demand are explained below:

Explanation of values in the calculation sheets:

In step 2 the total surface of the floor in given.

In step 3 the height is added to obtain the value of the volume from that particular floor.

In step 4 the temperature outside and the temperature inside is determined. For the summer situation we assume an outside temperature of -10 Celsius and inside a temperature of 20 Celsius. Once again we assumed an extreme outside temperature and a pleasant indoor temperature for during the wintertime.

In step 5 the total surface of the opaque facades are given and the U-value, which is determined and set on 0,22 (see table 5). The total surfaces of the transparent elements are calculated and the specific U-value of the applied glass is given. The U-value is set on 0,6 for triple glazing, in this value also the frame around the glass is taken into account. The U-value describes how well a building element conducts heat and measures the rate of heat transfer through a building element over a given area.

In step 6 the air change rate for a museum is given, the heat recovery percentage is set on 40%, the infiltration rate is set on 0,2 and the volumic mass of air is 1,2kg/m^3. These values are similar for the cooling demand, except for the heat recovery, whereas it is not necessary in the summer situation.

All floors should be considered separately.

The first calculation sheet consist of the calculation of the heating demand of the ground floor, the second sheet is the calculation for the heating demand of the first floor and in the third sheet the heating demand of the second floor is determined.

The U-value for Insulation sun –screening triple glazing is 0.6W/m^{2}K, for the other three facades the U value has to be calculated and depends on the different layers. In the table below one can find the calculation and information of the south/ north and east facade, which are all identical.

Layers	Thickness (m)	λ (W/mK)	R (m^{2}K/W)	U (W/m^{2}K)
			Ri= 0.13	
Concrete inside	0.180	1.8	0.1	
Insulation	0.10	0.024	4.16	
Concrete	0.04	1.7	0.01	
			Re= 0.04	
			Tot: 4.4	(1 / 4.4)= 0.22W/m^{2}K

Table 5 U-Value sandwich construction; *coefficient of heat transmission*, a measure of the rate of non-solar heat loss or gain through a material or assembly

Ground Floor											
Steps								**Results and characterstic numbers**			
1	Choose a building, part of a building or a room which should be calculated										
2	Calculate the net floor area										
	length	24	m								
	width	24	m					576	m^2		
3	Calculate the net volume (between floor and ceiling)										
	Avarage height between floor and ceiling										
		8	m					4608	m^3		
4	Choose a design indoor and outdoor temperature										
	T_{indoor} =	20	°C								
	$T_{outdoor}$ =	-10	°C								
5	Calculate transmisson heat loss										
	Area closed parts building envelope										
	A_{closed} =	576	m^2								
	Average U-value closed parts building envelope										
	U_{closed} =	0,22	W/m^2K								
	Area transparant parts building envelope										
	A_{window} =	202	m^2								
	Average U-value window building envelope										
	U_{window} =	0,6	W/m^2K								
	Transmission loss = (A_{closed} * U_{closed} + A_{window} * U_{window}) * (T_{inside} - $T_{outside}$)							7437,6	W	13	W/m^2
6	Calculate ventilation heat loss										
	Air change rate									See Building Code	
	n =	0,9						4147	m^3/h	0,9	dm^3/sm^2
	Ventilation flow Q_{vent}							1,152	m^3/s		
	Heat recovery percentage (sensible heat) hrp										
		40%									
	Infiltration rate										
	n =	0,2						922	m^3/h	0,4	dm^3/sm^2
	Infiltration flow Q_{inf}							0,256	m^3/s		
	Volumic mass air ρ			specific heat capacity air c = 1.000 J/kgK							
		1,2	kg/m^3	depends on outside temperature							
	Ventilation heat loss = (Q_{vent} * (1-hrp) + Qinf) * ρ * c * (T_{inside} - $T_{outside}$)							34.099	W	59	W/m^2
7	Determine total heat demand							41.537	W	72	W/m^2
	Exclusive:										
	More heating capacity necessary due to cooled down building mass after a night, weekend or holiday, 5 - 20 W/m^2										
	More heating capacity necessary due to heat loss to the surrounding spaces										
	Less heating capacity necessary due to Internal heat gains										
	Less heating capacity necessary due to solar gains										

Calculation sheet 1 Heating demand ground floor

First Floor											
Steps								**Results and characterstic numbers**			
1	Choose a building, part of a building or a room which should be calculated										
2	Calculate the net floor area										
	length	24	m								
	width	24	m					576	m^2		
3	Calculate the net volume (between floor and ceiling)										
	Avarage height between floor and ceiling										
		8	m					4608	m^3		
4	Choose a design indoor and outdoor temperature										
	T_{indoor} =	20	°C								
	$T_{outdoor}$ =	-10	°C								
5	Calculate transmisson heat loss										
	Area closed parts building envelope										
	A_{closed} =	576	m^2								
	Average U-value closed parts building envelope										
	U_{closed} =	0,22	W/m^2K								
	Area transparant parts building envelope										
	A_{window} =	192	m^2								
	Average U-value window building envelope										
	U_{window} =	0,6	W/m^2K								
	Transmission loss = $(A_{closed} * U_{closed} + A_{window} * U_{window}) * (T_{inside} - T_{outside})$							7257,6	W	13	W/m^2
6	Calculate ventilation heat loss										
	Air change rate									See Building Code	
	n =	0,9						4147	m^3/h	0,9	dm^3/sm^2
	Ventilation flow Q_{vent}							1,152	m^3/s		
	Heat recovery percentage (sensible heat) hrp										
		40%									
	Infiltration rate										
	n =	0,2						922	m^3/h	0,4	dm^3/sm^2
	Infiltration flow Q_{inf}							0,256	m^3/s		
	Volumic mass air ρ			specific heat capacity air c = 1.000 J/kgK							
		1,2	kg/m^3	depends on outside temperature							
	Ventilation heat loss = $(Q_{vent} * (1\text{-}hrp) + Q_{inf}) * \rho * c * (T_{inside} - T_{outside})$							34.099	W	59	W/m^2
7	Determine total heat demand							41.357	W	72	W/m^2
	Exclusive:										
	More heating capacity necessary due to cooled down building mass after a night, weekend or holiday, 5 - 20 W/m^2										
	More heating capacity necessary due to heat loss to the surrounding spaces										
	Less heating capacity necessary due to Internal heat gains										
	Less heating capacity necessary due to solar gains										

Calculation sheet 2 Heating demand first floor

Steps	Second Floor	Value	Unit		Results and characterstic numbers			
1	Choose a building, part of a building or a room which should be calculated							
2	Calculate the net floor area							
	length	24	m					
	width	24	m		576	m^2		
3	Calculate the net volume (between floor and ceiling)							
	Avarage height between floor and ceiling							
		8	m		4608	m^3		
4	Choose a design indoor and outdoor temperature							
	T_{indoor} =	20	°C					
	$T_{outdoor}$ =	-10	°C					
5	Calculate transmisson heat loss							
	Area closed parts building envelope							
	A_{closed} =	1088	m^2					
	Average U-value closed parts building envelope							
	U_{closed} =	0,22	W/m^2K					
	Area transparant parts building envelope							
	A_{window} =	256	m^2					
	Average U-value window building envelope							
	U_{window} =	0,6	W/m^2K					
	Transmission loss = (A_{closed} * U_{closed} + A_{window} * U_{window}) * (T_{inside} - $T_{outside}$)				11788,8	W	20	W/m^2
6	Calculate ventilation heat loss							
	Air change rate						See Building Code	
	n =	0,9			4147	m^3/h	2,0	dm^3/sm^2
	Ventilation flow Q_{vent}				1,152	m^3/s		
	Heat recovery percentage (sensible heat) hrp							
		40%						
	Infiltration rate							
	n =	0,2			922	m^3/h	0,4	dm^3/sm^2
	Infiltration flow Q_{inf}				0,256	m^3/s		
	Volumic mass air ρ			specific heat capacity air c = 1.000 J/kgK				
		1,2	kg/m^3	depends on outside temperature				
	Ventilation heat loss = (Q_{vent} * (1-hrp) + Qinf) * ρ * c * (T_{inside} - $T_{outside}$)				34.099	W	59	W/m^2
7	Determine total heat demand				45.888	W	80	W/m^2
	Exclusive:							
	More heating capacity necessary due to cooled down building mass after a night, weekend or holiday, 5 - 20 W/m^2							
	More heating capacity necessary due to heat loss to the surrounding spaces							
	Less heating capacity necessary due to Internal heat gains							
	Less heating capacity necessary due to solar gains							

Calculation sheet 3 Heating demand second floor

8.1.5.3 Heating and cooling capacity CCA

With concrete core activation within this building water pipes for heating and cooling are integrated in the concrete load bearing facade. The system shall be connected to a heat pump. Due to the fact that water temperatures in the wall usually only slightly differs from the average room temperature, a high energetic efficiency is possible. Concrete core activation uses the energy of the water flow through the wall and of the cooled or heated thermal mass of the wall as well. About 60% of the heat transport is by means of radiation and the other 40% of heat transport is trough convection. Because of the high radiation part of the energy flow, the velocities in a room heated or cooled with concrete core activation are generally low.

To check whether the concrete core activation is able to cool or heat in W/m^2 within the expected range there are a few steps that need to be followed.

General approach for the heating and cooling capacity

$$\phi_{c;sp} = \alpha_i * \Delta\theta$$

$\phi_{c;sp}$ = Specific cooling flow in W/m2

α_i = Heat transfer coefficient (radiation and convection) in W/m2K

$\Delta\theta$ = Temperature difference between the air and the surface in K

** For wall heating and wall cooling heat transfer coefficient according to NEN-EN 15377 has a value of 8W/m2K*

Summer situation; cold air flows down

$T_{concrete}$= 18˚C

T_{space}= 24˚C

$$\phi_{c;sp} = 8 * 6 = 48W/m^2$$

Winter situation; Hot air rises

$T_{concrete}$= 30˚C

T_{space}= 20˚C

$$\phi_{c;sp} = 8 * 10 = 80W/m^2$$

In the winter situation one can increase the temperature difference between the concrete and the space. A temperature of 30˚C of the concrete is not too high for heating; it will not lead to discomfort according to ir. P. van den Engel. This means that the heating capacity increases for that matter.

8.5.1.4 Conclusions

Summer situation:

When considering the capacity of the concrete core activation when applied in the opaque concrete facades it becomes clear for each floor the concrete core activation can provide for 48W/m^2 of cooling capacity.

For the ground floor the cooling demand is 80 W/m^2, this means that for the ground floor a capacity of 80 – 48 = 32 W/m^2 needs to be compensated. This should not be a problem, because of the appliance of concrete walls and concrete floors which cool down. So the thermal mass for example during nighttime can compensate the 32W/m^2. This is also a note on the calculation sheet.

For the first floor the cooling demand is 78 W/m^2, this means that for the first floor a capacity of 78 – 48 = 30 W/m^2 needs to be compensated. This should not be a problem, because of the appliance of concrete walls and concrete floors which cool down. So the thermal mass for example during nighttime can compensate the 30W/m^2. This is also a note on the calculation sheet.

For the second floor the cooling demand is 81 W/m^2, this means that for the first floor a capacity of 81 – 48 = 33 W/m^2 needs to be compensated. This should not be a problem, because of the appliance of concrete walls and concrete floors which cool down. So the thermal mass for example during nighttime can compensate the 33W/m^2. This is also a note on the calculation sheet.

Winter situation:

When considering the capacity of the concrete core activation when applied in the opaque concrete facades it becomes clear for each floor the concrete core activation can provide for 80W/m^2 of heating capacity.

For the ground floor the heating demand is 72 W/m^2, this means that for the ground floor the concrete core activation is sufficient to heathen this floor.

For the first floor the heating demand is 72 W/m^2, this means that for the first floor the concrete core is just like the ground floor sufficient to heathen the first floor.

For the second floor the heating demand is 80 W/m^2, this means that for the second floor concrete core activation can compensate this value. taking into the calculation sheet produce heat. For this matter the 8 W/m2 will be compensated at any time.

The thermal capacity of the water flow

In order to calculate the pump energy one should first calculate the velocity of the water. Underneath one can find the calculations to determine the pump energy:

$$\phi_c = q_v * \rho * c * \Delta\theta$$

ϕ_c = cooling flow in W
q_v = volume flow in m^3/s
ρ = volume mass of water in kg/m^3
c = specific heat of water in J/(kg*K)
$\Delta\theta$ = temperature difference between supply and runoff in K

A cold supply of 48W/m2 (calculated in 8.1.5.3) for an area of 24m^2 (this area is the area of one sandwich element where the concrete core activation will be applied in) $(\phi_c = 1152W)$ and a temperature difference of1 K between supply and runoff water will lead to the following water volume flow:

$$q_v = \frac{\phi_c}{\rho * c * \Delta\theta} = \frac{1152}{1000 * 4200 * 1} = 1{,}4 * 10^{-4} m^3 / s = 0{,}14 l / s = 504 l / h$$

For an area of 24m2 this is 33l/hm^2. Assuming a pipe with a diameter of 18mm the velocity becomes:

$$u = \frac{q_v}{A} = \frac{1{,}4 * 10^{04}}{\pi * (\frac{0{,}018}{2})^2} = 0{,}55 m/s$$

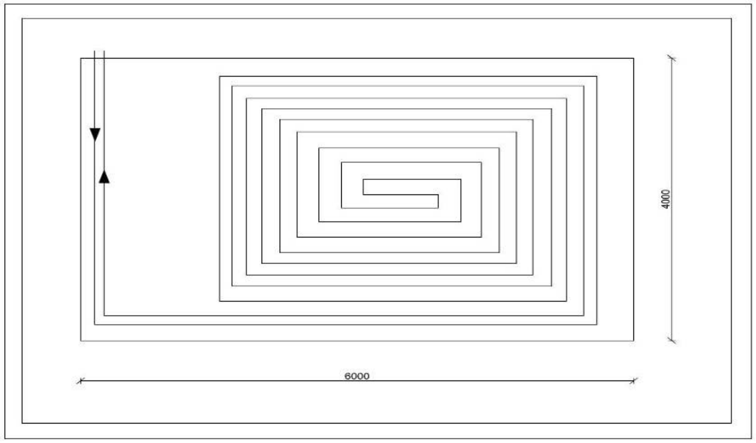
$$A = \pi * (\frac{r}{2})^2$$

Velocity should remain below 1m/s in order to reduce pump energy.[31]

<u>Schematization of the piping</u>

The pipes which are laid down in the sandwich panels and in the concrete floor have a diameter of 18mm and have a centre-to-centre distance of 20 cm. The maximum length of the piping on a surface of 20m^2 is 100m. However, the surface of one sandwich panel is 24m^2. Even so the length of the piping will be 100m. In order to prevent temperature differences in a floor the pipes should be positioned in a snail's shell shaped way[32].

[31] Concrete core activation; dr. Ir. P. van den Engel, dr. Regina Bokel and ir. Leo de Ruijsscher
[32] Concrete core activation; dr. Ir. P. van den Engel, dr. Regina Bokel and ir. Leo de Ruijsscher



Img. 35

Schematization of the piping in a snail's shell shaped way in order to prevent temperature differences in the wall.

<u>Heat pump</u>

Concrete core activation needs to be combined with a system to heathen and to cool the water that runs through the pipes. For the energy museum c.c.a. will be connected to a heat pump. A heat pump uses less energy, thus produces less emission and on its turn contributes to a better environment.

<u>Principle of a heat pump</u>

In this case the heat pump system abstracts heat from the outside air. This process takes place in the evaporator, where outside air runs over. There is a flow of a refrigerant inside the evaporator which takes on the heat from the air. The liquid refrigerant then evaporates to a gaseous condition. The compressor primes the gas and transports it to the condenser. The pressure and the temperature increase strongly due to this. In the condenser the gas condensates back to liquid and all the taken heat from the outside air and from the compressor is again released in favor of the heating system. Because of heat exchange the water in the c.c.a. rises in temperature. The refrigerant flows under high pressure back to the expansion valve where it strongly decreases in pressure and the process starts right back from the top.

A heat pump has three or four connections:

1. On the source system which delivers free warmth (outside air)
2. On the electricity network (400V) to make the pump work
3. On the heating and/ or cooling system
4. Possibly to waterworks for heating of the DHW

Adding all heating demands from the calculation sheets a total value of 48 + 46 + 58 = 152 kW is obtained. This value will be taken to the following part of the research with respect to renewable energy where the electricity demand will be calculated.

8.1.6 CEMroc cement

As been mentioned before in this report cement and its CO_2 production is by far the largest source of concrete related CO_2 emissions. However the chosen material for the facades and the rest of the structure is concrete. Concrete is worldwide the most applied building material and therefore the concrete industry is also trying to find ways in reducing the environmental loads.

The company Holcim; one of the world's leading suppliers of cement and aggregates developed a new type of cement which can be called an eco-efficient product. CEMroc has very low CO_2 emissions during production and the concrete in which it is applied shows exceptional resistance to chemical agents and aggressive environmental conditions.

CEMroc is a hydraulic binder and consists of granulated blast furnace slag, secondary constituents, calcium sulphate and additives. The properties of the constituents of CEMroc correspond to EN 197-1, section 5, constituents.[33]

CEMrocis intended to be used as cement for production of concrete, including in particular cast-in- situ or prefabricated structural concrete conforming to EN 206-1. Cement according to this standard may also be used in mortars and grouts.[34]

De cementindustrie is op wereldvlak immers verantwoordelijk voor 5% van de schadelijke broeikasgassen. Bij de productie van CEMROC*, het ternair slakcement dat bij de renovatie gebruikt werd, komt 80 tot 95% minder CO2 vrij. CEMROC* bestaat bovendien voor 95% uit gegranuleerde hoogovenslak, een bijproduct van de staalindustrie dat na recyclage als nieuwe grondstof gebruikt kan worden.

Type of cement	**Amount of Kilograms CO_2 emitted per tone**
ordinary Portland cement	865 kg CO_2/tone
CEMroc	45 kg CO_2/tone

Table 6 Comparison of CO_2 emissions between tradition cement[35]

[33] Holcim; European Technical Approval; 21-4-2008;P.4

[34] Holcim; European Technical Approval; 21-4-2008;P.10

[35] Bruno Vanderborght; Holcim; Four good reasons for Cement benchmarking; 8-6-2009, p.3

8.1.6.1 Application CEMroc for the energy museum

The main focus lies on the concrete facades in this master thesis. By applying CEMroc cement for the production of the concrete facades the CO_2 emissions for that matter can be reduced enormously. The following calculation gives an impression of the amount of CO_2 emitted with the appliance of ordinary Portland cement and then the amount of CO_2 emissions when applying CEMroc cement.

Thickness sandwich panels inner leave = 180mm
Facade surface = 24000 * 24000 = 576000*10^3 mm^2
Volume concrete outer leave = 180 * 576000*10^3 = 103,68*10^9 mm^3
Volume concrete inner leave = 40* 576000*10^3= 23,04*10^9 mm^3
Volume of all four facades together
4 * 103,68*10^9 + 4 * 23,04*10^9 = 506,88*$10^9$$mm^3$

This equals 506,88m^3 concrete

For the production on 1m3 concrete there is 300 kg of cement required.
For 506,88m^3 there is 152064 kg of cement required.

CO_2 emission Portland cement: $\frac{152064*865}{1000}=131525{,}36kg$

CO_2 emission CEMroc cement: $\frac{152064*45}{1000}=6842{,}88kg$

This is a total reduction of 95% of CO_2 emission for the application of CEMroc cement within the facades of the energy museum.

8.2 Sustainable measure with respect to renewable energy

In this part of the thesis the measure which will be applied in the energy museum with respect to renewable energy will be researched. In paragraph 4.6 it became clear that solar energy is the form of renewable energy which is best applicable for the museum. In the requirements with respect to sustainability one of the requirements is to create an energy zero building. An energy zero building can be defined as a building which uses as much energy as it generates on an annual basis, normally in combination with renewable forms of energy. This means that all energy which is necessary for the building to heat, cool, lighten and all other applications of electricity are coming from renewable energy sources. For that reason an energy zero building is very environmental friendly and is also called a CO_2 neutral building.

In this master thesis a renewable form of energy will be applied to provide for electricity. As been mentioned in paragraph 4.6, solar energy in the form of electricity will provide for the total electricity demand of the energy museum if this is possible. If the amount of produced electricity by the PV cells turns out to be not enough wind power will be applied to compensate and create an energy zero building after all. At first a research to the important factors about PV cells will be done followed by an overview of the different types of PV cells and its properties. With the help of GreenCalc+ the electricity demand for the energy museum will be determined and with that information it is possible to determine which solar cells are best applicable and if they can or cannot provide for the determined electricity demand.

8.2.1 Operation of a photovoltaic cell

PV's are arrays of cells that convert solar radiation into electricity. PV cells consist of an atomic structure and because of that an electrical charge moves around in the crystal, but in a random manner. By joining two types of silicon together; one acting as a positive terminal (p-type) and the other acting as a negative terminal (n-type), the current can be encouraged to flow in one direction. At the p-n junction, an electric field is then built up which leads to the separation of the charge carriers (electrons and holes). As with all electrical devices, connections are required to pick up and channel the available electricity. The back of the crystal has a copper layer deposited on to it to make up the lower terminal. The upper terminal sits on the side of the semiconductor facing the sun. To avoid the entire face to be covered in copper and thus the crystal would be shaded form the sun, the upper terminal is made out of a network of extremely fine wires deposited onto the surface. Sunlight can pass between the gaps in the wire grid and hit the crystal. The amount of semiconductor obscured from the sun by the upper terminal is one of the factors that reduce photovoltaic efficiency. The whole cell is protected by being encased in a glass sandwich.

8.2.2 Types of photovoltaic cells

There are three main types which can be distinguished, namely the monocrystalline silicon, the polycrystalline silicon and the amorphous silicon.
According to SenterNovem the types the market share at this moment in the Netherlands is as following:

- Monocrystalline silicon cell (30% market share)
- Polycrystalline silicon cell (50% market share)
- Amorphous silicon cell (10% market share)

Monocrystalline silicon cells

These types of photovoltaic cell consist of one single crystal. This type of cell is easily identifiable; it is made up of uniformly stacked rounded cells. The structure of the silicium consists of one single crystal, not multiple crystals fused together. The process of making this substance to a useful cell is very complex and expensive. However, the higher costs do pay back in efficiency. It produces more power than the lower priced ones. At this moment the highest efficiency of all photovoltaic cells wit a value of 15 to 17%. The lifespan of a monocrystalline cell depends on the quality, but has a minimum of twenty-five years and can be reach to more than fifty years. The panels are extremely fragile though; this could lead to a breakdown of the cell. The dimensions of the cells are variable. Most common dimensions are 10*10cm and 12,5*12,5cm.

Polycrystalline silicon cells

With polycrystalline cells the structure of the silicium consists of crystals with variable sizes. Because of this structure these cells are less efficient in converting solar heat into power in comparison to monocrystalline cells. The material is actually a residual of the monocrystalline semiconductor industry. These panels are relatively cheap, but offer less efficiency per square meter. The life span is the same as the lifespan of the monocrystalline silicon cells. The efficiency lies between 13 to 15%. The dimensions of the cells are mostly 10*10cm or 15*15cm.

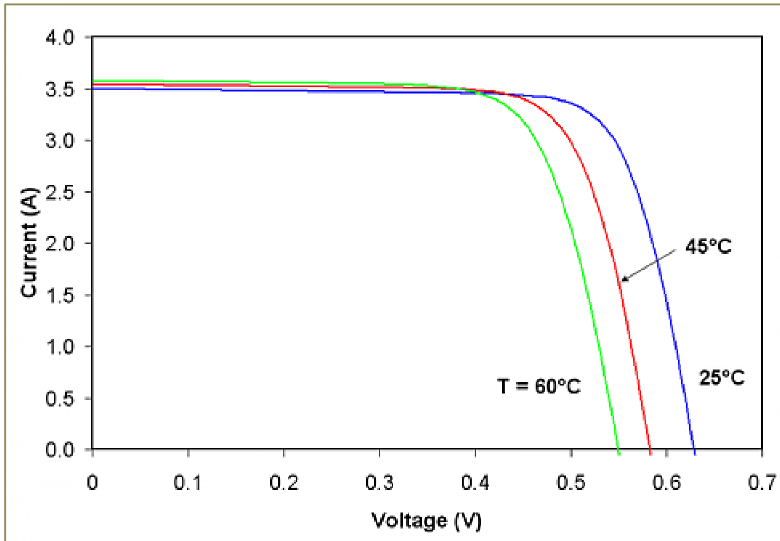
Amorphous silicon cells

Photovoltaic cells made out of amorph silicium are mostly applied in the thin-film modules. Due to the fact that these cells do not contain crystals, they are very flexible. In comparison with the other two types they are relatively cheap, but the efficiency is a lot less. The efficiency lies between 6 to 10%. The lifespan of the older techniques are limited to a few years. However, with the latest technology the lifespan can incur to 15 years.

8.2.3 Capacity of PV cells

The capacity of PV cells can be expressed in the unit watt peak (Wp). The actual capacity depends on several factors that are listed below:

- Intensity of the sun; the brighter the sun is, the more electricity van be generated. For that reason only PV cells are most efficient during the summer and spring. In colder seasons there are less free electrons which decreased the current in the circuit.
- Resistance of the circuit; in case a PV-system is not connected to the grid it is important to keep the resistant of the circuit as low as possible. The total yield decreases in case the resistance of the circuit increases.
- Shadow; shadow should be avoided beforehand under any circumstances. In case solar panels are formed in a series circuit, the cell with the lowest current is decisive. Shadow for one single cell could decrease the yield of the entire system. To solve this issue it is possible to choose for a parallel circuit.
- Material of the cell; as mentioned in the previous paragraph the material of the cell determines also the efficiency, thus the capacity of the PV cell.
- Temperature; it appears to be that efficiency decreases with 0,5% for every increasing degree Celsius in temperature above 25°C (see image 36)



Img. 36 In this picture one can see that the yield of a PV cell decreases with increasing temperatures. When temperature increases the conductivity does increase, thus increasing movements of the electrons, its then easier to fill up wholes elsewhere in the material. Because the electrical balance in the cell improves, the electrical field at the boundary layer disappears, which leads to the fact that loading is hard to separate. Result is a decreasing voltage between layers.

8.2.4 Electricity demand

With the help op GreenCalc+ the total electricity demand of the energy museum will be determined. Besides that the EPC (energy performance coefficient) will be determined with the help of GreenCalc+. The aim is to compensate the electricity demand by means of PV cells and if necessary with wind power. In case that the building supplies its own energy demand the EPC becomes zero. The input in GreenCalc+ is added in Appendix 3

The results are as follows:

Overzicht energieprestatieberekening:

Rekenmethode: GreenCalc+ methodiek gebaseerd op NEN 2916:2004

	Primair energiegebruik in MJ	
	Ontw.	**Ref.**
Qprim;verw	128974	0
Qprim;pomp	28382	0
Qprim;vent	140969	0
Qprim;tap	11826	0
Qprim;koel	16589	0
Qprim;bev	0	0
Qprim;vl	161538	0
Qprim;pv	0	0
Qprim;wkk	0	0
Qpres;tot	488277	0
Qpres;toel	751183	0
EPC	**0,71**	**0**

Img. 37 EPC calculation; the output of the EPC calculation according to GreenCalc+ is 0,71

Overzicht milieukosten energiegebruik

<Nieuw gebouw>	Milieukosten per jaar		Elektriciteitgebruik per jaar [kWh]	
Energiegebruik per jaar	Ontw.	Ref.	Ontw.	Ref.
Verwarming	€ 1664,-	€ 0,-	16205	0
Pompen	€ 316,-	€ 0,-	3075	0
Ventilatoren	€ 1568,-	€ 0,-	15272	0
Tapwater	€ 132,-	€ 0,-	1281	0
Koeling	€ 57,-	€ 0,-	552	0
Bevochtiging	€ 0,-	€ 0,-	0	0
Verlichting	€ 1725,-	€ 0,-	16800	0
Apparatuur	€ 960,-	€ 0,-	9353	0
Opbrengst PV-cellen	€ 0,-	€ 0,-	0	0
Opbrengst WKK	€ 0,-	€ 0,-	0	0
Opbrengst Wind	€ 0,-	€ 0,-	0	0
Correctiepost elektrisch	€ 0,-	€ 0,-	0	0
Correctiepost gas	€ 0,-	€ 0,-	0	0
Correctiepost warmte	€ 0,-	€ 0,-	0	0
Totaal			62538	0
Totaal	**€ 6421,-**	**€ 0,-**		
Eigen-index	-	-		

Img. 38 The total electricity demand for the energy museum per year in kWh. This sum needs to be compensated with renewable energy.

To evaluate the amount of electricity which can be generated with the PV cells the average sum of global irradiation from the sun per square meter received needs to be determined.

PVGIS estimates of solar electricity generation

Location: 52°7'0" North, 4°16'45" East, Elevation: 0 m a.s.l.,

Nominal power of the PV system: 1.0 kW (crystalline silicon)
Estimated losses due to temperature: 6.9% (using local ambient temperature)
Estimated loss due to angular reflectance effects: 4.4%
Other losses (cables, inverter etc.): 14.0%
Combined PV system losses: 23.5%

Fixed system: inclination=0°, orientation=0°				
Month	E_d	E_m	H_d	H_m
Jan	0.45	14.1	0.62	19.3
Feb	1.08	30.2	1.39	39.0
Mar	1.80	55.8	2.26	70.1
Apr	2.96	88.9	3.77	113
May	3.78	117	4.92	153
Jun	3.78	113	5.00	150
Jul	3.74	116	4.99	155
Aug	3.18	98.5	4.21	131
Sep	2.13	63.9	2.79	83.7
Oct	1.23	38.1	1.61	50.0
Nov	0.60	18.1	0.82	24.7
Dec	0.33	10.3	0.47	14.6
Yearly average	**2.09**	**63.7**	**2.75**	**83.5**
Total for year		**764**		**1000**

E_d: Average daily electricity production from the given system (kWh)
E_m: Average monthly electricity production from the given system (kWh)
H_d: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)
H_m: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)

Img. 39 Solar irradiation in Scheveningen during the year[36]

This means that for a year a total of 1000 kWh/m^2 is available in Scheveningen. The roof has a total surface of 576m2, where 64m2 is made out of glass.

576 – 64 = 512m^2 where 12 m^2 is reserved for wind power installations. This means that on the roof there is 500m^2 available to apply PV cells. The type which is most efficient will be applied. This means that for these 500m^2 mono crystalline silicon PV cells will be applied.

However there are certain losses which need to be taken into account, these losses together are about 25%:

1000 kWh/m2 * 500 = 500.000 kWh

15% - 17% efficiency gives: 500.000 * 15 % = 75.000 kWh

This value might be to optimistic, therefore we assume that the total efficiency of the PV cells is 13% and not between 15%-17%

This gives a value of: 500.000 * 13 % = 65.000 kWh

When the losses of 25% are taken into account, the output becomes:

65.000 – 16.250 = 48750

Looking at the value of the electricity demand which is 62.538 kWh one can see that the PV cells are not sufficient.

For this reason wind power needs to compensate for:
62.538 – 48.750 = 13.788 kWh

[36] PVGIS © European Communities, 2001-2008; http://re.jrc.ec.europa.eu/pvgis/apps3/pvest.php

Wind Power

When applying a wind turbine the location plays an important role. Wind speeds for a particular location determine the amount of electricity which can be generated with a wind turbine. The higher the wind speed the more electricity can be generated. The wind speed in Scheveningen where the museum is located has an average of about 8 m/s.[37]

The wind turbine which will be applied for the energy museum has an output of about 10000kWh with a wind speed of 8 m/s. The wind speed on the museum's location has the average of 8 m/s. However, this can be lower during summer period and higher during colder period where there is more wind. So we calculate further with an output value of 8000kWh

(Technical data about the wind turbine is showed in appendix 4)

On the roof 2 wind turbines will be applied to compensate for the remaining needed power.

48.750 + 2 * 8000 = 64.750 kWh

The total demand was 62.538 – 64.750 = -2212 kWh

According to this calculation the wind power and the PV cells on the roof can meet the requirement for the electricity demand. This means that the total demand is compensated completely with renewable energy and even more so, there is more energy produced than necessary. Al extra electricity will be given back to the grid and than in the end of the year it will be settled with the grid.

Img. 40 Urban Green Energy's UGE-4K vertical axis wind turbine;
two of these turbines will be placed on the roof to provide for electricity

[37] Windkaart van Nederland op 100m hoogte; Senternovem; p.24

Inclination of the PV cells

In the following table one can see what effect the inclination of the PV cells has with respect to efficiency.

Inclination	Usable solar area	Specific inclination radiation in %	Usable incident radiation in %
0	100	100	100
10	75	106	80
20	61	111	68
30	53	113	60
40	48	113	54

Table 7 This table contains information about the inclination of the PV-cells in relation with their total efficiency. For the Energy museum no inclination is most profitable, because the total roof surface can be used. Looking at the last column it becomes clear that when no inclination is applied the usable radiation is at its max.

8.3 Sustainable measure with respect to innovations

As been mentioned in chapter 5, there have been quite some innovations on facades. The choice to apply either a double skin facade or a smart solar shading system in the energy museum will be made in this part of the thesis.

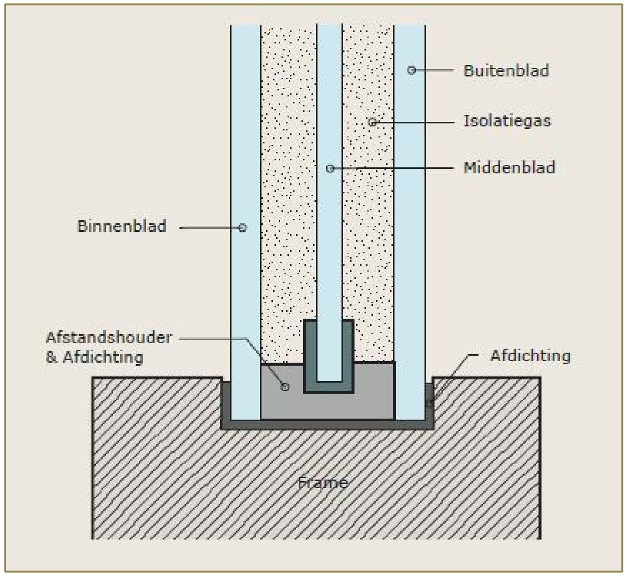
8.3.1 The glass facade

The double skin facade is only applicable for a glass facade. The glass facade of the energy museum is situated on the north. This means that there will be diffuse radiation all year long and direct radiation between end of March till the end of September, however minimal when compared to facades on other all other orientations.

One of the functions of the double skin facade is to reduce the cooling demand during the summer period. However, there is no solar irradiation on the north side. Thus this function of the double skin facade is not of value in the museum. During wintertime the double skin facade provides for higher insulation values. However, in the calculation sheet triple glazing is applied to meet this requirement. Triple glazing is also a relative new type of glass which can is applied in passive buildings. Therefore very suitable for the energy museum to insulate well and reduce heat losses through the glass facade to a minimum.

Triple glazing

Triple glazing exists in several forms. A commonly applied form is the one in image x. Three glass plates and two cavities form the unit. Triple glazing can therefore realize higher insulation values. Heat transfer in cavities takes place by means of convection, because of the extra glass plate convection is reduced cavities. Triple glazing does weigh more than double glass units, this can be disadvantageous during transport and construction.



mg. 41 This image gives an impression of the way a triple glazing units Is built.

Research to trice glass showed that the CO2 reduction which can be obtained by applying trice glass instead of double glass is 200 kg per year. This equals 5.5% which is about 1/40 of the environmental load of an average car.

Due to the high degree of air tightness and the application of triple glazing, the outdoor noise level is very low. Because of this low noise-level, indoor noise of installations is can be noticed easily. Low sound levels below 30 dB(A) are recommended. During the night even lower, below 25 dB(A).

Besides the application of triple glazing units on the glass facade which is situated on the North, the fact that because of the situation on the north optimal daylight is used within the energy museum. In a museum it is not desirable to let sunlight enter the building, due to exhibitions and paintings which are then not clear because of the sun. However, daylight is very much desirable. Not only for humans psychology, but also because it can reduce the appliance of artificial lighting. Solar shading is also not necessary to apply on the glass facade. With respect to esthetics this is a positive fact. Creating an optimal glass facade for the energy museum is realized by several matters which are again summarized below:

1. Optimal daylight due to a complete glass facade on the North
2. Application of triple glazing on the glass facade
3. No solar shading necessary

8.3.2 The roof

Similar to the facade the roof is also a part of the building envelope. Also the roof consists of concrete and glass. However the glass part of the roof is exposed to solar irradiation unlike the north facade. This could cause too much heating within the museum if there are no measures met.

To reduce solar irradiation there are several methods available. With respect to sustainability a particular measure which fits in the term sustainability will be met.

It is a possibility to integrate PV modules in the sun shading system. Such a solution may provide for:

- good shading of the building in summer;
- optimal solar gain;
- diffusion of daylight.

Translucency of the BIPV modules depends on the glass type and the distance between the cells. The translucency can take a value between 25 till 50%.

Besides panels where PV cells are integrated it is also a possibility to apply a solar shading system where the PV cells function as the louvers. In this case the PV cells also convert solar irradiation into power and as louvers which provide for sun shading. These so called system louvres are automatically positioned with respect to the sun. The result of this matter is an optimal protection against the solar heating and optimal light entrance. Because the louvers are made out of glass, contact with outside remains. There are several cells available, also the amount of translucency can be chosen by designers. Therefore a lot of freedom in design is made possible.

Img. 42 BIPV ProSol; Building integrated PV cells produced by Schuco, they can perform the same function as conventional infill units. Properties demanded like protection against weather, direct sun, fire safety and noise reduction can be fulfilled with building integrated PV cells.

Img. 43 PV cells functioning as louvers; can either be a fixed or controllable external glazed solar shading system.

Decision

The choice for the glass part of the roof is the

9. Conclusions

IK HEB WAT TEKST UIT DE THESIS GEKOPIEERD EN HIER GEPLAKT OM TE VERWERKEN IN DE CONCLUSIE….DIT IS ZEKER NIET MIJN EINDCONCLUSIE! NO WORRIES!!!

In this chapter the general conclusions of this thesis are given. The conclusions are divided in the same order of the thesis outline and are discussed point wise.

- There are many different ways to contribute to 'Sustainable Development'; one of those ways is by Sustainable Construction. Sustainable construction can be defined as a manner of constructing where environmental- and health effects due to constructing, usage, restoration or dismantling will be reduced to a minimum. Because of this global environmental thinking the concept Cradle to Cradle (C2C), created by Michael Braungart and William McDonough was introduced to the world. eco-effectiveness is about maximizing the positive effects of the industry. Cradle to Cradle is covering the concept of eco-effectivity. LCA's, manuals and software tools take part as sources which contribute to sustainable design.

- When comparing concrete, steel, glass and timber with each other with respect to emissions and exhaustion, from the tables it becomes clear that concrete scores the lowest on environmental scale. However, GreenCalc+ does not take properties like strength, thermal mass and other building physical properties into account

- several forms of renewable energy thesis concerns only one single building it is not profitable to apply large scale expensive plants to generate power and where also very little experience is available for. This therefore leads automatically to the appliance of solar power as the

- method to generate renewable energy for the energy museum. In this specific case the solar energy will be applied in the form of electricity. Depending on the electricity demand of the building it might be possible that only solar energy in the form of electricity will not be sufficient. In that case also wind power will be applied, to meet the total electricity demand in combination with PV cells

- Because of environmental imperatives intelligent buildings and intelligent facades are popular nowadays. The intelligent

- skin could be described as a skin which protects against weather and which adapts either manually or automatically to environmental variations, with using a minimum amount of energy. The appliance of a second skin or smart solar shading are the most interesting methods of all the above describes methods.

- practise examples
- buildings were built with sustainable measures, which determine the rate of sustainability
- measures will be taken into account for the design of the energy museum:
- Appliance of renewable energy by means of solar power;

- Appliance of renewable energy in form of wind;
- Large window surfaces for optimal incoming daylight;
- Appliance of concrete core activation;
- Appliance of smart solar shading.
-

Appendices

Appendix 1 Personal data and graduation committee

Personal Data

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Appendix 2 GreenCalc+ results

In paragraph 3.6 a summary of the GreenCalc+ results is gives. However, the input and all the results in forms of tables from each material separately is summarized in this appendix.

Concrete facade

Totaal € 740,42

Code	Bouwproduct	Aantal	Eenh.	Maat	Begrenzing	Milieukosten
S00594	PIB aluminium versterkt[1a][slabben]	210,7	m1		n.v.t.	5,66
S10010	Deur (zachthout massief (met boskeur)/ zachthout kozijn(met boskeur))[samengestelde buitenwandopening (deur)]	1,6	m2		noord	0,04
S10009	Raam (Eur. zachth. kozijn , HR+-glas - met boskeur)[samengestelde buitenwandopening (raam)]	134,5	m2		noord	29,38
S10010	Deur (zachthout massief (met boskeur)/ zachthout kozijn(met boskeur))[samengestelde buitenwandopening (deur)]	0,9	m2		west	0,02
S10009	Raam (Eur. zachth. kozijn , HR+-glas - met boskeur)[samengestelde buitenwandopening (raam)]	79,7	m2		west	17,41
S10010	Deur (zachthout massief (met boskeur)/ zachthout kozijn(met boskeur))[samengestelde buitenwandopening (deur)]	1,6	m2		zuid	0,04
S10009	Raam (Eur. zachth. kozijn , HR+-glas - met boskeur)[samengestelde buitenwandopening (raam)]	134,5	m2		zuid	29,38
S10010	Deur (zachthout massief (met boskeur)/ zachthout kozijn(met boskeur))[samengestelde buitenwandopening (deur)]	0,9	m2		oost	0,02
S10009	Raam (Eur. zachth. kozijn , HR+-glas - met boskeur)[samengestelde buitenwandopening (raam)]	79,7	m2		oost	17,41
S00006	Beton - gewapend (20% granulaat)[5b][buitenspouwblad]	91,5	m2	200 mm	n.v.t.	39,69
S00006	Beton - gewapend (20% granulaat)[5b][buitenspouwblad]	155,4	m2	200 mm	n.v.t.	67,43
S00006	Beton - gewapend (20% granulaat)[5b][buitenspouwblad]	70,6	m2	200 mm	n.v.t.	30,64
S00006	Beton - gewapend (20% granulaat)[5b][buitenspouwblad]	54,2	m2	200 mm	n.v.t.	23,52
S00006	Beton - gewapend (20% granulaat)[5b][buitenspouwblad]	92,1	m2	200 mm	n.v.t.	39,96
S00006	Beton - gewapend (20% granulaat)[5b][buitenspouwblad]	41,8	m2	200 mm	n.v.t.	18,15
S00006	Beton - gewapend (20% granulaat)[5b][buitenspouwblad]	91,5	m2	200 mm	n.v.t.	39,69
S00006	Beton - gewapend (20% granulaat)[5b][buitenspouwblad]	155,4	m2	200 mm	n.v.t.	67,43
S00006	Beton - gewapend (20% granulaat)[5b][buitenspouwblad]	70,6	m2	200 mm	n.v.t.	30,64
S00006	Beton - gewapend (20% granulaat)[5b][buitenspouwblad]	54,2	m2	200 mm	n.v.t.	23,52

Overzicht milieukosten materialengebruik

concrete		
MIG	Milieukosten per jaar	
Bouwdeel	Ontw.	Ref.
Fundering	€ 0,-	€ 1789,-
Gevels	€ 740,-	€ 2435,-
Binnenwanden	€ 0,-	€ 2721,-
Vloeren	€ 0,-	€ 3288,-
Daken	€ 0,-	€ 1184,-
Installaties	€ 1286,-	€ 1282,-
Inrichting	€ 148,-	€ 364,-
Totaal	**€ 2174,-**	**€ 13064,-**
Milieu-index	**601**	**100**

	Milieukosten [euro]		**Milieu-effecten**		
	Ontw.	**Ref.**	**Ontw.**	**Ref.**	
Emissies	**€ 1583,-**	**€ 9283,-**			
Broeikaseffect (100j)	€ 1010,-	€ 6128,-	11132,0	67516,3	kg CO2 eq.
Ozonlaagaantasting	€ 9,-	€ 41,-	0,0016	0,0071	kg CFC-11 eq.
Humane toxiciteit	€ 72,-	€ 328,-	1478,9	6782,7	kg 1.4-DB eq.
Aquatische toxiciteit (zoet water)	€ 5,-	€ 28,-	111,9	570,4	kg 1.4-DB eq.
Terrestische toxiciteit	€ 1,-	€ 4,-	19,4	79,5	kg 1.4-DB eq.
Fotochemische oxidantvorming	€ 17,-	€ 99,-	3,8	22,5	kg C2H4 eq.
Verzuring	€ 185,-	€ 751,-	68,0	276,0	kg SO2 eq.
Eutrofiering	€ 284,-	€ 1905,-	5,2	35,0	kg PO4 eq.
Uitputting	**€ 126,-**	**€ 576,-**			
Biotische grondstoffen	€ 0,-	€ 113,-	0,0	2673,3	mbp
Abiotische grondstoffen	€ 105,-	€ 327,-	2483,1	7754,0	kg Sb eq
Energiedragers	€ 21,-	€ 136,-	507,4	3213,3	kg Sb eq
Landgebruik	**€ 381,-**	**€ 2919,-**			
Landgebruik	€ 381,-	€ 2919,-	1862,3	14251,0	PDF.m2.jr
Hinder t.g.v.	**€ 84,-**	**€ 286,-**			
Stank	€ 7,-	€ 26,-	293204259,7	1109932373,0	OTV m3
Geluid door wegtransport	€ 7,-	€ 59,-	0,0226	0,1819	DALY
Geluid door productieprocessen	€ 0,-	€ 1,-	64526,6	363554,1	mbp
Licht	€ 57,-	€ 123,-	2388,0	5112,5	mbp
Kans op calamiteiten	€ 12,-	€ 78,-	508,5	3269,3	mbp

Steel facade

Totaal € 351,15

Code	Bouwproduct	Aantal	Eenh.	Maat	Begrenzing	Milieukosten
S00594	PIB aluminium versterkt[1a][slabben]	210,7	m1		n.v.t.	5,66
S10010	Deur (zachthout massief (met boskeur)/ zachthout kozijn(met boskeur))[samengestelde buitenwandopening (deur)]	1,6	m2		noord	0,04
S10008	Raam (aluminium kozijn, HR+-glas)[samengestelde buitenwandopening (raam)]	134,5	m2		noord	68,38
S10010	Deur (zachthout massief (met boskeur)/ zachthout kozijn(met boskeur))[samengestelde buitenwandopening (deur)]	0,9	m2		west	0,02
S10008	Raam (aluminium kozijn, HR+-glas)[samengestelde buitenwandopening (raam)]	79,7	m2		west	40,52
S10010	Deur (zachthout massief (met boskeur)/ zachthout kozijn(met boskeur))[samengestelde buitenwandopening (deur)]	1,6	m2		zuid	0,04
S10008	Raam (aluminium kozijn, HR+-glas)[samengestelde buitenwandopening (raam)]	134,5	m2		zuid	68,38
S10010	Deur (zachthout massief (met boskeur)/ zachthout kozijn(met boskeur))[samengestelde buitenwandopening (deur)]	0,9	m2		oost	0,02
S10008	Raam (aluminium kozijn, HR+-glas)[samengestelde buitenwandopening (raam)]	79,7	m2		oost	40,52
S00674	Staal verzinkt en gecoat (trapezium)[4a][gevelafwerking]	91,5	m2	0,7 mm	n.v.t.	7,44
S00674	Staal verzinkt en gecoat (trapezium)[4a][gevelafwerking]	155,4	m2	0,7 mm	n.v.t.	12,64
S00674	Staal verzinkt en gecoat (trapezium)[4a][gevelafwerking]	70,6	m2	0,7 mm	n.v.t.	5,74
S00674	Staal verzinkt en gecoat (trapezium)[4a][gevelafwerking]	54,2	m2	0,7 mm	n.v.t.	4,41
S00674	Staal verzinkt en gecoat (trapezium)[4a][gevelafwerking]	92,1	m2	0,7 mm	n.v.t.	7,49
S00674	Staal verzinkt en gecoat (trapezium)[4a][gevelafwerking]	41,8	m2	0,7 mm	n.v.t.	3,40
S00674	Staal verzinkt en gecoat (trapezium)[4a][gevelafwerking]	91,5	m2	0,7 mm	n.v.t.	7,44
S00674	Staal verzinkt en gecoat (trapezium)[4a][gevelafwerking]	155,4	m2	0,7 mm	n.v.t.	12,64
S00674	Staal verzinkt en gecoat (trapezium)[4a][gevelafwerking]	70,6	m2	0,7 mm	n.v.t.	5,74
S00674	Staal verzinkt en gecoat (trapezium)[4a][gevelafwerking]	54,2	m2	0,7 mm	n.v.t.	4,41

Overzicht milieukosten materialengebruik

concrete		
MIG	Milieukosten per jaar	
Bouwdeel	Ontw.	Ref.
Fundering	€ 0,-	€ 1789,-
Gevels	€ 351,-	€ 2435,-
Binnenwanden	€ 0,-	€ 2721,-
Vloeren	€ 0,-	€ 3288,-
Daken	€ 0,-	€ 1184,-
Installaties	€ 1286,-	€ 1282,-
Inrichting	€ 148,-	€ 364,-
Totaal	**€ 1785,-**	**€ 13064,-**
Milieu-index	**732**	**100**

	Milieukosten [euro]		**Milieu-effecten**		
	Ontw.	**Ref.**	**Ontw.**	**Ref.**	
Emissies	**€ 1281,-**	**€ 9283,-**			
Broeikaseffect (100j)	€ 771,-	€ 6128,-	8497,3	67516,3	kg CO2 eq.
Ozonlaagaantasting	€ 9,-	€ 41,-	0,0015	0,0071	kg CFC-11 eq.
Humane toxiciteit	€ 127,-	€ 328,-	2623,2	6782,7	kg 1.4-DB eq.
Aquatische toxiciteit (zoet water)	€ 6,-	€ 28,-	125,3	570,4	kg 1.4-DB eq.
Terrestische toxiciteit	€ 1,-	€ 4,-	18,4	79,5	kg 1.4-DB eq.
Fotochemische oxidantvorming	€ 17,-	€ 99,-	3,8	22,5	kg C2H4 eq.
Verzuring	€ 167,-	€ 751,-	61,3	276,0	kg SO2 eq.
Eutrofiering	€ 183,-	€ 1905,-	3,4	35,0	kg PO4 eq.
Uitputting	**€ 105,-**	**€ 576,-**			
Biotische grondstoffen	€ 0,-	€ 113,-	0,0	2673,3	mbp
Abiotische grondstoffen	€ 88,-	€ 327,-	2086,1	7754,0	kg Sb eq
Energiedragers	€ 17,-	€ 136,-	407,0	3213,3	kg Sb eq
Landgebruik	**€ 325,-**	**€ 2919,-**			
Landgebruik	€ 325,-	€ 2919,-	1586,2	14251,0	PDF.m2.jr
Hinder t.g.v.	**€ 74,-**	**€ 286,-**			
Stank	€ 7,-	€ 26,-	294601452,7	1109932373,0	OTV m3
Geluid door wegtransport	€ 2,-	€ 59,-	0,0072	0,1819	DALY
Geluid door productieprocessen	€ 0,-	€ 1,-	43993,3	363554,1	mbp
Licht	€ 55,-	€ 123,-	2304,0	5112,5	mbp
Kans op calamiteiten	€ 9,-	€ 78,-	394,6	3269,3	mbp

Timber facade

Totaal € 407,51

Code	Bouwproduct	Aantal	Eenh.	Maat	Begrenzing	Milieukosten
S00594	PIB aluminium versterkt[1a][slabben]	210,7	m1		n.v.t.	5,66
S10010	Deur (zachthout massief (met boskeur)/ zachthout kozijn(met boskeur))[samengestelde buitenwandopening (deur)]	1,6	m2		noord	0,04
S10009	Raam (Eur. zachth. kozijn , HR+-glas - met boskeur)[samengestelde buitenwandopening (raam)]	134,5	m2		noord	29,38
S10010	Deur (zachthout massief (met boskeur)/ zachthout kozijn(met boskeur))[samengestelde buitenwandopening (deur)]	0,9	m2		west	0,02
S10009	Raam (Eur. zachth. kozijn , HR+-glas - met boskeur)[samengestelde buitenwandopening (raam)]	79,7	m2		west	17,41
S10010	Deur (zachthout massief (met boskeur)/ zachthout kozijn(met boskeur))[samengestelde buitenwandopening (deur)]	1,6	m2		zuid	0,04
S10009	Raam (Eur. zachth. kozijn , HR+-glas - met boskeur)[samengestelde buitenwandopening (raam)]	134,5	m2		zuid	29,38
S10010	Deur (zachthout massief (met boskeur)/ zachthout kozijn(met boskeur))[samengestelde buitenwandopening (deur)]	0,9	m2		oost	0,02
S10009	Raam (Eur. zachth. kozijn , HR+-glas - met boskeur)[samengestelde buitenwandopening (raam)]	79,7	m2		oost	17,41
S10059	Spouwconstr.(HSB(met boskeur)184/keram. elem./vlaspl.110)[samengestelde buitenwand]	91,5	m2		n.v.t.	19,08
S10059	Spouwconstr.(HSB(met boskeur)184/keram. elem./vlaspl.110)[samengestelde buitenwand]	155,4	m2		n.v.t.	32,41
S10059	Spouwconstr.(HSB(met boskeur)184/keram. elem./vlaspl.110)[samengestelde buitenwand]	70,6	m2		n.v.t.	14,73
S10059	Spouwconstr.(HSB(met boskeur)184/keram. elem./vlaspl.110)[samengestelde buitenwand]	54,2	m2		n.v.t.	11,30
S10059	Spouwconstr.(HSB(met boskeur)184/keram. elem./vlaspl.110)[samengestelde buitenwand]	92,1	m2		n.v.t.	19,21
S10059	Spouwconstr.(HSB(met boskeur)184/keram. elem./vlaspl.110)[samengestelde buitenwand]	41,8	m2		n.v.t.	8,73
S10059	Spouwconstr.(HSB(met boskeur)184/keram. elem./vlaspl.110)[samengestelde buitenwand]	91,5	m2		n.v.t.	19,08
S10059	Spouwconstr.(HSB(met boskeur)184/keram. elem./vlaspl.110)[samengestelde buitenwand]	155,4	m2		n.v.t.	32,41
S10059	Spouwconstr.(HSB(met boskeur)184/keram. elem./vlaspl.110)[samengestelde buitenwand]	70,6	m2		n.v.t.	14,73
S10059	Spouwconstr.(HSB(met boskeur)184/keram. elem./vlaspl.110)[samengestelde buitenwand]	54,2	m2		n.v.t.	11,30

Overzicht milieukosten materialengebruik

hout		
MIG	Milieukosten per jaar	
Bouwdeel	Ontw.	Ref.
Fundering	€ 0,-	€ 1789,-
Gevels	€ 408,-	€ 2435,-
Binnenwanden	€ 0,-	€ 2721,-
Vloeren	€ 0,-	€ 3288,-
Daken	€ 0,-	€ 1184,-
Installaties	€ 1286,-	€ 1282,-
Inrichting	€ 148,-	€ 364,-
Totaal	**€ 1841,-**	**€ 13064,-**
Milieu-index	**710**	**100**

	Milieukosten [euro]		**Milieu-effecten**		
	Ontw.	**Ref.**	**Ontw.**	**Ref.**	
Emissies	**€ 1289,-**	**€ 9283,-**			
Broeikaseffect (100j)	€ 762,-	€ 6128,-	8397,6	67516,3	kg CO2 eq.
Ozonlaagaantasting	€ 8,-	€ 41,-	0,0014	0,0071	kg CFC-11 eq.
Humane toxiciteit	€ 112,-	€ 328,-	2306,6	6782,7	kg 1.4-DB eq.
Aquatische toxiciteit (zoet water)	€ 5,-	€ 28,-	103,0	570,4	kg 1.4-DB eq.
Terrestische toxiciteit	€ 1,-	€ 4,-	18,3	79,5	kg 1.4-DB eq.
Fotochemische oxidantvorming	€ 16,-	€ 99,-	3,7	22,5	kg C2H4 eq.
Verzuring	€ 167,-	€ 751,-	61,3	276,0	kg SO2 eq.
Eutrofiering	€ 218,-	€ 1905,-	4,0	35,0	kg PO4 eq.
Uitputting	**€ 149,-**	**€ 576,-**			
Biotische grondstoffen	€ 0,-	€ 113,-	0,0	2673,3	mbp
Abiotische grondstoffen	€ 131,-	€ 327,-	3099,2	7754,0	kg Sb eq
Energiedragers	€ 19,-	€ 136,-	440,3	3213,3	kg Sb eq
Landgebruik	**€ 324,-**	**€ 2919,-**			
Landgebruik	€ 324,-	€ 2919,-	1582,6	14251,0	PDF.m2.jr
Hinder t.g.v.	**€ 79,-**	**€ 286,-**			
Stank	€ 6,-	€ 26,-	264411571,5	1109932373,0	OTV m3
Geluid door wegtransport	€ 6,-	€ 59,-	0,0201	0,1819	DALY
Geluid door productieprocessen	€ 0,-	€ 1,-	43881,1	363554,1	mbp
Licht	€ 55,-	€ 123,-	2311,0	5112,5	mbp
Kans op calamiteiten	€ 11,-	€ 78,-	440,8	3269,3	mbp

<u>Curtain wall (aluminum frame) facade</u>

Totaal € 2284,94

Code	Bouwproduct	Aantal	Eenh.	Maat	Begrenzing	Milieukosten
S00594	PIB aluminium versterkt[1a][slabben]	210,7	m1		n.v.t.	5,66
S10084	Deur (HR++ isolatieglas in aluminium frame en alumium kozijn)[samengestelde buitenwandopening (deur)]	1,6	m2		noord	0,56
S10008	Raam (aluminium kozijn, HR+-glas)[samengestelde buitenwandopening (raam)]	134,5	m2		noord	68,38
S10084	Deur (HR++ isolatieglas in aluminium frame en alumium kozijn)[samengestelde buitenwandopening (deur)]	0,9	m2		west	0,33
S10008	Raam (aluminium kozijn, HR+-glas)[samengestelde buitenwandopening (raam)]	79,7	m2		west	40,52
S10084	Deur (HR++ isolatieglas in aluminium frame en alumium kozijn)[samengestelde buitenwandopening (deur)]	1,6	m2		zuid	0,56
S10008	Raam (aluminium kozijn, HR+-glas)[samengestelde buitenwandopening (raam)]	134,5	m2		zuid	68,38
S10010	Deur (zachthout massief (met boskeur)/ zachthout kozijn(met boskeur))[samengestelde buitenwandopening (deur)]	0,9	m2		oost	0,02
S10008	Raam (aluminium kozijn, HR+-glas)[samengestelde buitenwandopening (raam)]	79,7	m2		oost	40,52
S10006	Vliesgevel (Aluminium/PUR/Aluminium stijl Rc 2,5)[samengestelde vliesgevel]	91,5	m2		n.v.t.	120,10
S10006	Vliesgevel (Aluminium/PUR/Aluminium stijl Rc 2,5)[samengestelde vliesgevel]	155,4	m2		n.v.t.	204,05
S10006	Vliesgevel (Aluminium/PUR/Aluminium stijl Rc 2,5)[samengestelde vliesgevel]	70,6	m2		n.v.t.	92,71
S10006	Vliesgevel (Aluminium/PUR/Aluminium stijl Rc 2,5)[samengestelde vliesgevel]	54,2	m2		n.v.t.	71,17
S10006	Vliesgevel (Aluminium/PUR/Aluminium stijl Rc 2,5)[samengestelde vliesgevel]	92,1	m2		n.v.t.	120,92
S10006	Vliesgevel (Aluminium/PUR/Aluminium stijl Rc 2,5)[samengestelde vliesgevel]	41,8	m2		n.v.t.	54,94
S10006	Vliesgevel (Aluminium/PUR/Aluminium stijl Rc 2,5)[samengestelde vliesgevel]	91,5	m2		n.v.t.	120,10
S10006	Vliesgevel (Aluminium/PUR/Aluminium stijl Rc 2,5)[samengestelde vliesgevel]	155,4	m2		n.v.t.	204,05
S10006	Vliesgevel (Aluminium/PUR/Aluminium stijl Rc 2,5)[samengestelde vliesgevel]	70,6	m2		n.v.t.	92,71
S10006	Vliesgevel (Aluminium/PUR/Aluminium stijl Rc 2,5)[samengestelde vliesgevel]	54,2	m2		n.v.t.	71,17

Overzicht milieukosten materialengebruik

concrete		
MIG	Milieukosten per jaar	
Bouwdeel	Ontw.	Ref.
Fundering	€ 0,-	€ 1789,-
Gevels	€ 2285,-	€ 2435,-
Binnenwanden	€ 0,-	€ 2721,-
Vloeren	€ 0,-	€ 3288,-
Daken	€ 0,-	€ 1184,-
Installaties	€ 1286,-	€ 1282,-
Inrichting	€ 148,-	€ 364,-
Totaal	**€ 3718,-**	**€ 13064,-**
Milieu-index	**351**	**100**

	Milieukosten [euro]		**Milieu-effecten**		
	Ontw.	**Ref.**	**Ontw.**	**Ref.**	
Emissies	**€ 3050,-**	**€ 9283,-**			
Broeikaseffect (100j)	€ 1323,-	€ 6128,-	14582,7	67516,3	kg CO2 eq.
Ozonlaagaantasting	€ 26,-	€ 41,-	0,0045	0,0071	kg CFC-11 eq.
Humane toxiciteit	€ 966,-	€ 328,-	19955,3	6782,7	kg 1.4-DB eq.
Aquatische toxiciteit (zoet water)	€ 33,-	€ 28,-	676,8	570,4	kg 1.4-DB eq.
Terrestische toxiciteit	€ 2,-	€ 4,-	35,9	79,5	kg 1.4-DB eq.
Fotochemische oxidantvorming	€ 70,-	€ 99,-	16,0	22,5	kg C2H4 eq.
Verzuring	€ 284,-	€ 751,-	104,4	276,0	kg SO2 eq.
Eutrofiering	€ 346,-	€ 1905,-	6,3	35,0	kg PO4 eq.
Uitputting	**€ 118,-**	**€ 576,-**			
Biotische grondstoffen	€ 0,-	€ 113,-	0,6	2673,3	mbp
Abiotische grondstoffen	€ 87,-	€ 327,-	2066,5	7754,0	kg Sb eq
Energiedragers	€ 31,-	€ 136,-	735,7	3213,3	kg Sb eq
Landgebruik	**€ 461,-**	**€ 2919,-**			
Landgebruik	€ 461,-	€ 2919,-	2248,5	14251,0	PDF.m2.jr
Hinder t.g.v.	**€ 90,-**	**€ 286,-**			
Stank	€ 7,-	€ 26,-	297481001,2	1109932373,0	OTV m3
Geluid door wegtransport	€ 3,-	€ 59,-	0,0081	0,1819	DALY
Geluid door productieprocessen	€ 0,-	€ 1,-	48498,1	363554,1	mbp
Licht	€ 63,-	€ 123,-	2610,5	5112,5	mbp
Kans op calamiteiten	€ 17,-	€ 78,-	721,1	3269,3	mbp

Curtain wall (timber frame) facade

Totaal € 410,87

Code	Bouwproduct	Aantal	Eenh.	Maat	Begrenzing	Milieukosten
S00594	PIB aluminium versterkt[1a][slabben]	210,7	m1		n.v.t.	5,66
S10084	Deur (HR++ isolatieglas in aluminium frame en alumium kozijn)[samengestelde buitenwandopening (deur)]	1,6	m2		noord	0,56
S10008	Raam (aluminium kozijn, HR+-glas)[samengestelde buitenwandopening (raam)]	134,5	m2		noord	68,38
S10084	Deur (HR++ isolatieglas in aluminium frame en alumium kozijn)[samengestelde buitenwandopening (deur)]	0,9	m2		west	0,33
S10008	Raam (aluminium kozijn, HR+-glas)[samengestelde buitenwandopening (raam)]	79,7	m2		west	40,52
S10084	Deur (HR++ isolatieglas in aluminium frame en alumium kozijn)[samengestelde buitenwandopening (deur)]	1,6	m2		zuid	0,56
S10008	Raam (aluminium kozijn, HR+-glas)[samengestelde buitenwandopening (raam)]	134,5	m2		zuid	68,38
S10010	Deur (zachthout massief (met boskeur)/ zachthout kozijn(met boskeur))[samengestelde buitenwandopening (deur)]	0,9	m2		oost	0,02
S10008	Raam (aluminium kozijn, HR+-glas)[samengestelde buitenwandopening (raam)]	79,7	m2		oost	40,52
S10007	Vliesgevel (Vuren(met boskeur)/Cellulose/Vuren stijl Rc 2,5)[samengestelde vliesgevel]	91,5	m2		n.v.t.	10,84
S10007	Vliesgevel (Vuren(met boskeur)/Cellulose/Vuren stijl Rc 2,5)[samengestelde vliesgevel]	155,4	m2		n.v.t.	18,42
S10007	Vliesgevel (Vuren(met boskeur)/Cellulose/Vuren stijl Rc 2,5)[samengestelde vliesgevel]	70,6	m2		n.v.t.	8,37
S10007	Vliesgevel (Vuren(met boskeur)/Cellulose/Vuren stijl Rc 2,5)[samengestelde vliesgevel]	54,2	m2		n.v.t.	6,42
S10007	Vliesgevel (Vuren(met boskeur)/Cellulose/Vuren stijl Rc 2,5)[samengestelde vliesgevel]	92,1	m2		n.v.t.	10,91
S10007	Vliesgevel (Vuren(met boskeur)/Cellulose/Vuren stijl Rc 2,5)[samengestelde vliesgevel]	41,8	m2		n.v.t.	4,96
S10007	Vliesgevel (Vuren(met boskeur)/Cellulose/Vuren stijl Rc 2,5)[samengestelde vliesgevel]	91,5	m2		n.v.t.	10,84
S10007	Vliesgevel (Vuren(met boskeur)/Cellulose/Vuren stijl Rc 2,5)[samengestelde vliesgevel]	155,4	m2		n.v.t.	18,42
S10007	Vliesgevel (Vuren(met boskeur)/Cellulose/Vuren stijl Rc 2,5)[samengestelde vliesgevel]	70,6	m2		n.v.t.	8,37
S10007	Vliesgevel (Vuren(met boskeur)/Cellulose/Vuren stijl Rc 2,5)[samengestelde vliesgevel]	54,2	m2		n.v.t.	6,42

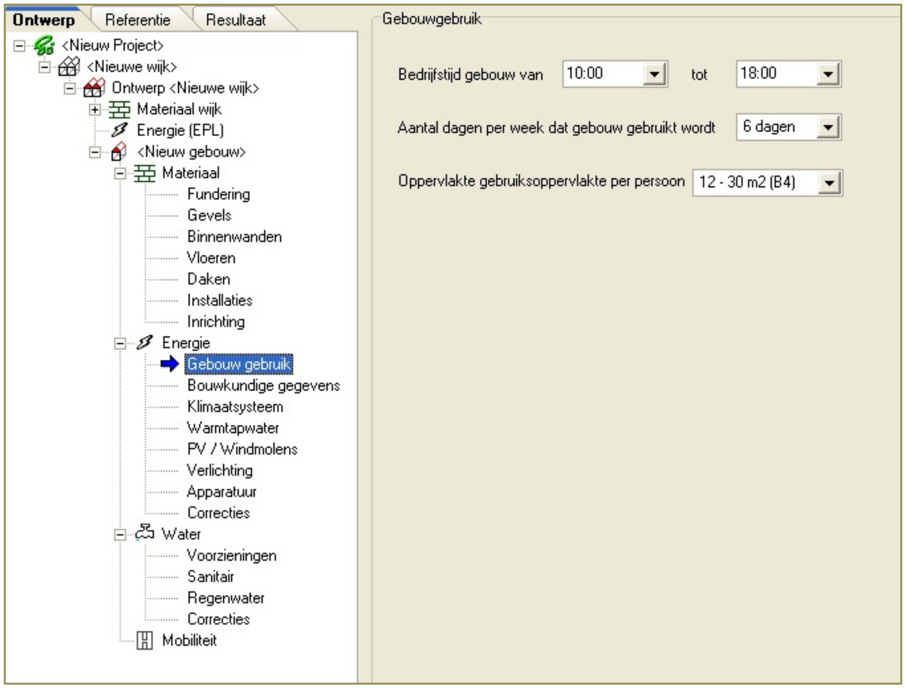
	Milieukosten [euro]		Milieu-effecten		
	Ontw.	Ref.	Ontw.	Ref.	
Emissies	**€ 1330,-**	**€ 9283,-**			
Broeikaseffect (100j)	€ 795,-	€ 6128,-	8758,1	67516,3	kg CO2 eq.
Ozonlaagaantasting	€ 9,-	€ 41,-	0,0015	0,0071	kg CFC-11 eq.
Humane toxiciteit	€ 129,-	€ 328,-	2657,3	6782,7	kg 1.4-DB eq.
Aquatische toxiciteit (zoet water)	€ 6,-	€ 28,-	129,4	570,4	kg 1.4-DB eq.
Terrestische toxiciteit	€ 1,-	€ 4,-	21,9	79,5	kg 1.4-DB eq.
Fotochemische oxidantvorming	€ 13,-	€ 99,-	3,0	22,5	kg C2H4 eq.
Verzuring	€ 171,-	€ 751,-	62,8	276,0	kg SO2 eq.
Eutrofiering	€ 206,-	€ 1905,-	3,8	35,0	kg PO4 eq.
Uitputting	**€ 106,-**	**€ 576,-**			
Biotische grondstoffen	€ 0,-	€ 113,-	0,1	2673,3	mbp
Abiotische grondstoffen	€ 87,-	€ 327,-	2050,6	7754,0	kg Sb eq
Energiedragers	€ 19,-	€ 136,-	449,8	3213,3	kg Sb eq
Landgebruik	**€ 326,-**	**€ 2919,-**			
Landgebruik	€ 326,-	€ 2919,-	1592,4	14251,0	PDF.m2.jr
Hinder t.g.v.	**€ 83,-**	**€ 286,-**			
Stank	€ 6,-	€ 26,-	271531553,3	1109932373,0	OTV m3
Geluid door wegtransport	€ 10,-	€ 59,-	0,0318	0,1819	DALY
Geluid door productieprocessen	€ 0,-	€ 1,-	40726,6	363554,1	mbp
Licht	€ 56,-	€ 123,-	2325,5	5112,5	mbp
Kans op calamiteiten	€ 11,-	€ 78,-	442,7	3269,3	mbp

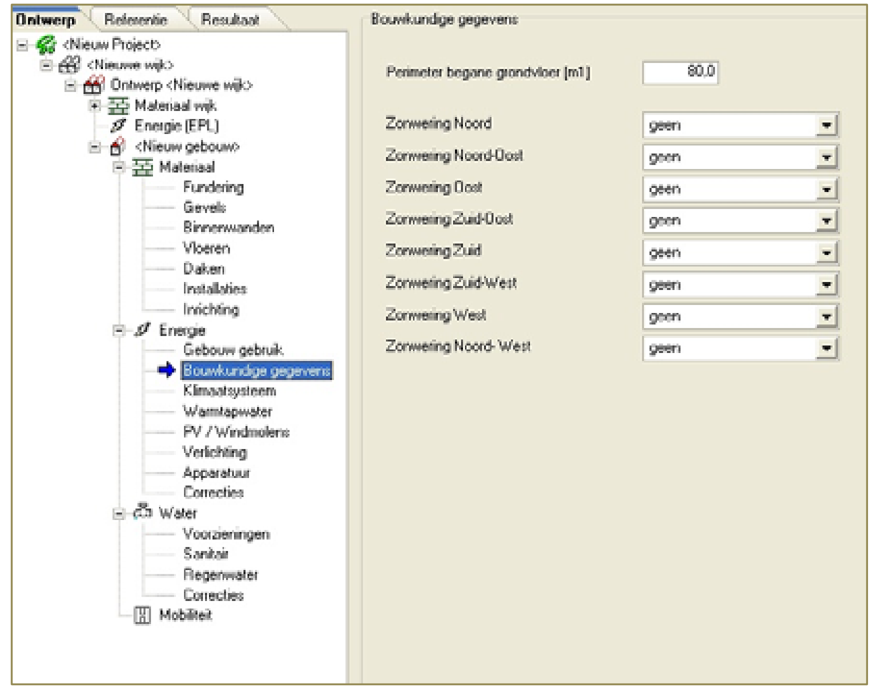
Overzicht milieukosten materialengebruik

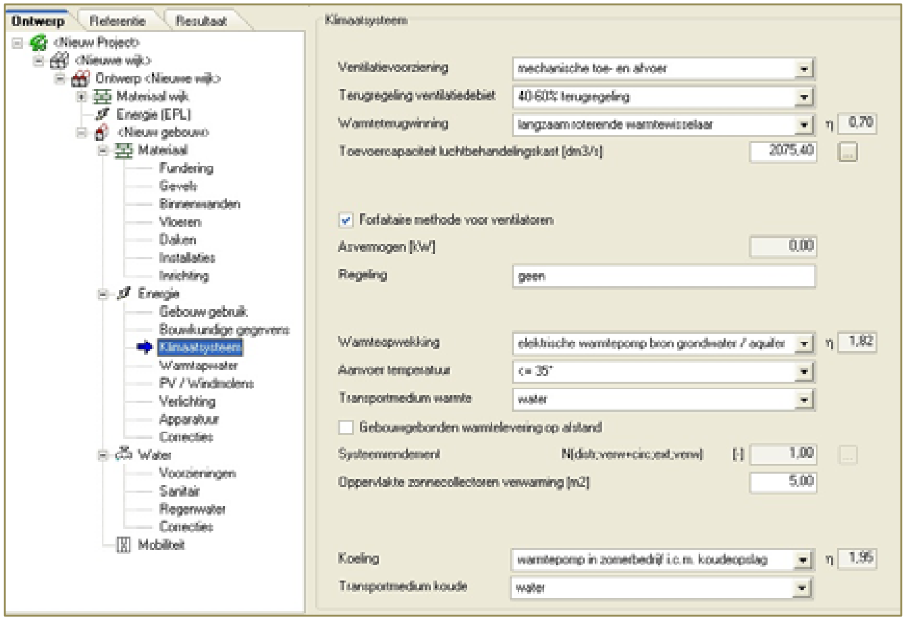
concrete		
MIG	Milieukosten per jaar	
Bouwdeel	Ontw.	Ref.
Fundering	€ 0,-	€ 1789,-
Gevels	€ 411,-	€ 2435,-
Binnenwanden	€ 0,-	€ 2721,-
Vloeren	€ 0,-	€ 3288,-
Daken	€ 0,-	€ 1184,-
Installaties	€ 1286,-	€ 1282,-
Inrichting	€ 148,-	€ 364,-
Totaal	**€ 1844,-**	**€ 13064,-**
Milieu-index	**708**	**100**

Appendix 3 Input GreenCalc+ for the electricity demand

This appendix contains the input in GreenCalc+ to determine the total electricydemand



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Energie (EPL)
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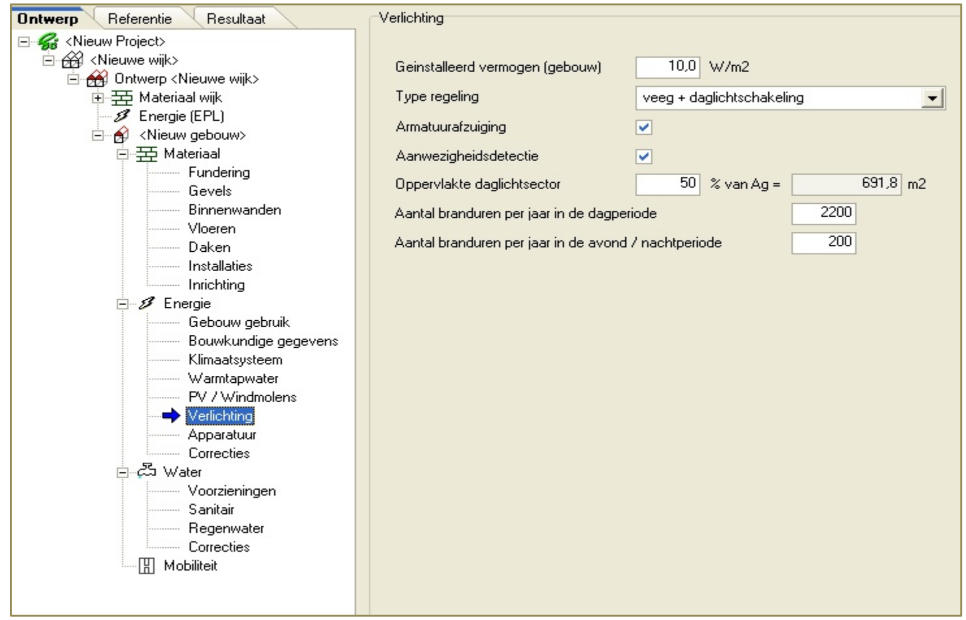
Fundering
Gevels
Binnenwanden
Vloeren
Daken
Installaties
Inrichting
Energie
Gebouw gebruik
Bouwkundige gegevens
Klimaatsysteem
Warmtapwater
PV / Windmolens
Verlichting
Apparatuur
Correcties
Water
Voorzieningen
Sanitair
Regenwater
Correcties
Mobiliteit
Klimaatsysteem
Ventilatievoorziening
mechanische toe- en afvoer
Terugregeling ventilatiedebiet
40-60% terugregeling
Warmteterugwinning
langzaam roterende warmtewisselaar
η 0,70
Toevoercapaciteit luchtbehandelingskast [dm3/s]
2075,40
Forfaitaire methode voor ventilatoren
Aanvermogen [kW]
0,00
Regeling
geen
Warmteopwekking
elektrische warmtepomp bron grondwater / aquifer
η 1,82
Aanvoer temperatuur
<= 35°
Transportmedium warmte
water
Gebouwgebonden warmtelevering op afstand
Systeemrendement
N(distr,verw+circ,ext,verw)
[-] 1,00
Oppervlakte zonnecollectoren verwarming [m2]
5,00
Koeling
warmtepomp in zomerbedrijf i.c.m. koudeopslag
η 1,95
Transportmedium koude
water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Gevels
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Installaties
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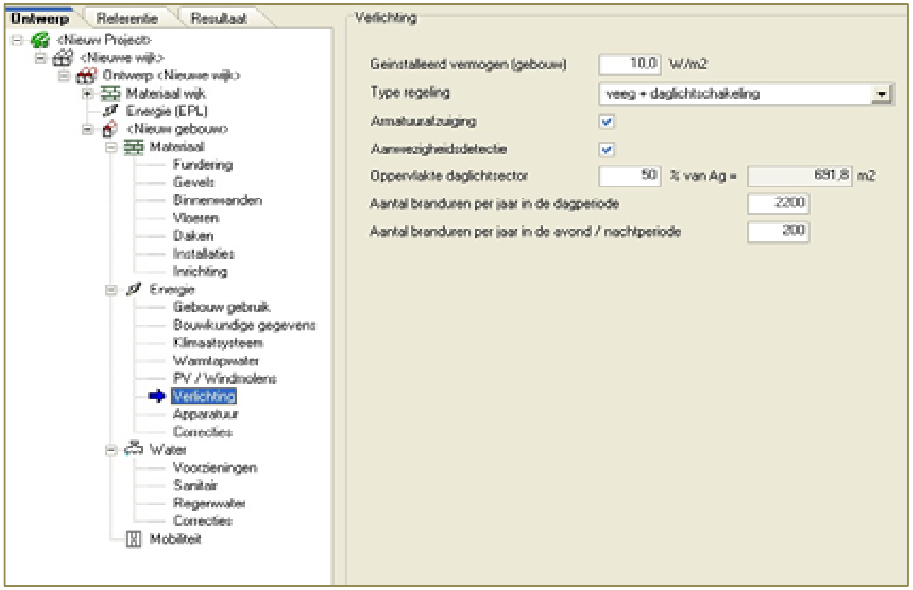
Gebouw gebruik
Bouwkundige gegevens
Klimaatsysteem
Warmtapwater
PV / Windmolens
Verlichting
Apparatuur
Correcties
Water
Voorzieningen
Sanitair
Regenwater
Correcties
Mobiliteit
Verlichting
Geinstalleerd vermogen (gebouw)
10,0
W/m2
Type regeling
veeg + daglichtschakeling
Armatuurafzuiging
Aanwezigheidsdetectie
Oppervlakte daglichtsector
50
% van Ag =
691,8
m2
Aantal branduren per jaar in de dagperiode
2200
Aantal branduren per jaar in de avond / nachtperiode
200



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Gevels
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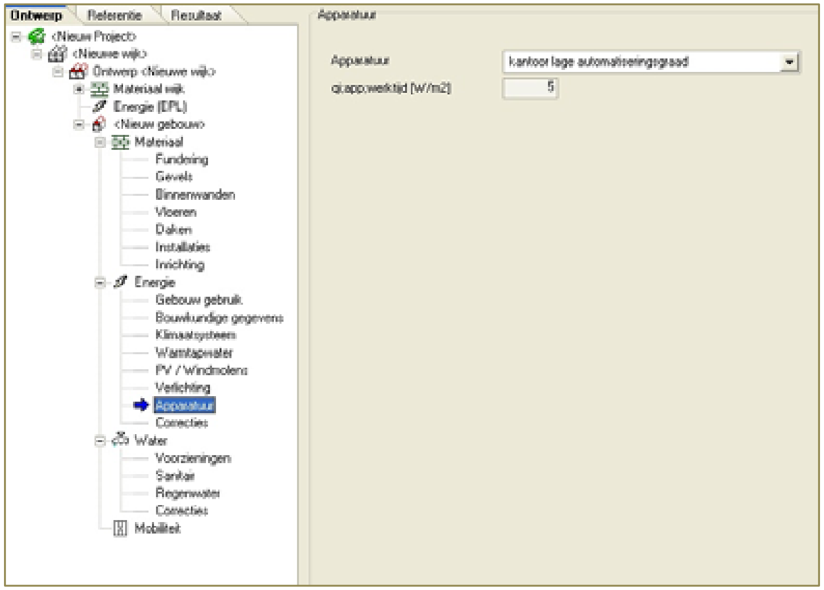
Vloeren
Daken
Installaties
Inrichting
Energie
Gebouw gebruik
Bouwkundige gegevens
Klimaatsysteem
Warmtapwater
PV / Windmolens
Verlichting
Apparatuur
Correcties
Water
Voorzieningen
Sanitair
Regenwater
Correcties
Mobiliteit
Verlichting
Geinstalleerd vermogen (gebouw) 10,0 W/m2
Type regeling veeg + daglichtschakeling
Armatuurafzuiging
Aanwezigheidsdetectie
Oppervlakte daglichtsector 50 % van Ag = 691,8 m2
Aantal branduren per jaar in de dagperiode 2200
Aantal branduren per jaar in de avond / nachtperiode 200



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Energie (EPL)
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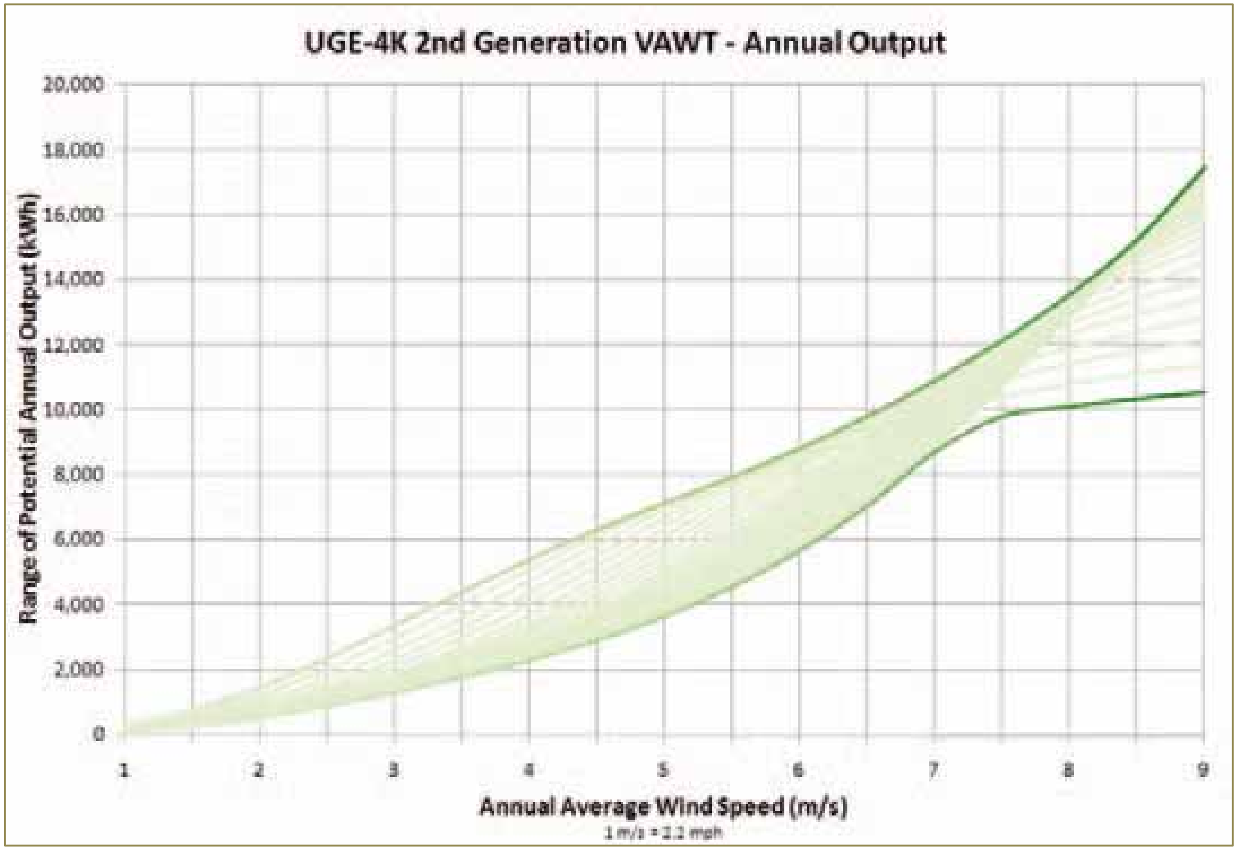
Fundering
Gevels
Binnenwanden
Vloeren
Daken
Installaties
Inrichting
Energie
Gebouw gebruik
Bouwkundige gegevens
Klimaatsysteem
Warmtapwater
PV / Windmolens
Verlichting
Apparatuur
Correcties
Water
Voorzieningen
Sanitair
Regenwater
Correcties
Mobiliteit
Apparatuur
Apparatuur kantoor lage automatiseringsgraad
qi;app;werktijd [W/m2] 5

Appendix 4 Technical data wind turbine



Specifications

Performance:

Rated Power – 4 kW

Rated Wind Speed - 12 m/s

Operating Range - 3 - 25 m/s

Maximum Wind Speed - 50 m/s

Noise Level at 3 Meter Distance:

@ <7 m/s - < 27 DB

@ 7 - 10 m/s - < 32 DB

@ 10 - 13 m/s - < 37 DB

Physical Parameters:

Mill Size - 4.2m x 2.75m (165” x 108”)

Tower Height (Standard) - 5.5m (18’)

Gross Weight w/o Tower - 200kg (440lbs)

Gross Weight w/ Tower - 500kg (1120lbs)

Gross Weight w. Roof mount - 350kg (770 lbs)