L. Hammer

Passive Offshore Accommodation

An Energy-Efficient Solution for the Façade Refurbishment of an Offshore Accommodation

TU Delft

Keppel Verolme

Passive Offshore Accommodation

An Energy-Efficient Solution for the Façade Refurbishment of an Offshore Accommodation

By

L. Hammer

in partial fulfilment of the requirements for the degree of

Master of Science
in Building Technology

at the Delft University of Technology

First Mentor:	Prof. dr. ir. U. Knaack	TU Delft
Second Mentor:	Dr. Ir. W. H. van der Spoel,	TU Delft
External Mentor:	Dr. Ir. M. Otheguy	Keppel Verolme

Preface

In the modern world most industries are heavily dependent on products derived from fossil fuels. The offshore industry plays a major role in locating and acquiring these raw fossil fuels, as for example in the recent developments in the arctic, where large quantities of oil reside. Only in the North Sea there are already more than 1500 offshore installations (ARUP, 2014). A lot of these offshore installations house employees in several accommodation blocks that require constant energy supply. Energy is usually supplied by diesel generators that come with considerable environmental pollution and transport-costs for the owner of these rigs.

Recently, onshore buildings have been implementing energy friendly techniques with high success. An example is passive buildings which implement shading techniques, natural ventilation and green energy solutions. Even though offshore accommodation is of high quality, it often lacks energy-saving and conservation aspects. In order to make offshore accommodation more environmental friendly, and to decrease energy costs, the success of passive onshore buildings could be transferred to the offshore industry.

This research is therefore focused on the implementation of sustainable strategies during the refurbishing of offshore accommodation. Refurbishment and repair is the specialty of the Rotterdam based yard of Keppel Verolme. In cooperation with Keppel Verolme and the TU Delft a research will therefore be done with focus on; *Energy-Efficient Refurbishment of Offshore Accommodation Facades.*

The thesis will focus on the façade of the offshore accommodation. In the first few chapters the research framework will be discussed which will be followed by a more in-depth look into the offshore industry, design and regulations. Then several onshore technologies will be discussed and applied on a model created to mimic current offshore accommodation. The results of these simulations will then be used as a starting point for final design, which is the last phase of the graduation research.

L. Hammer
Delft, June 2016

Contents

Abstract

The purpose of this research is to explore the energy balance within an offshore accommodation. The research is done In cooperation with Keppel Verolme BV. and the TU Delft for the department of Building Technology. The offshore accommodation is analysed in terms of structure and energy consumption, as is the typical environmental conditions in which offshore accommodations are operational. A model based on real-life study cases was compiled in the program of DesignBuilder and used to generate complicated simulations. These simulations gave insight into the energy-use aboard offshore accommodations and these insights were used to generate different concepts for reducing the need of fuel with means to generate electricity. The advantages and disadvantages of the concepts were analysed through simulations and were concluded in a final design. This information can be used by the offshore industry or to aid in sustainable future offshore accommodation designs.

Acknowledgements

First and foremost, I would like to thank my family and friends for my research would not have been possible without their support.

I would like express my gratitude to Mariano Otheguy, my mentor from Keppel Verolme for his full support, expert guidance, understanding and encouragement throughout my study and research. Without his motivational input, writing my thesis would have been a much more difficult pursuit. In addition, I would like to thank Jeroen Taen for his help and exceptional skill of relating and working together. The many conversations and support are valued greatly.

I would also like to thank my mentors from the TU Delft, Willem and Ulrich for their professional guidance during the course of my research, which helped me greatly when problems were encountered during the most difficult times of the research.

1 Introduction

1.1 Introduction

The following research will explore into the domain of the offshore industry in relation to sustainable design. In cooperation with the TU Delft and Keppel Verolme the possibility of more energy efficient offshore accommodation units are further researched. The research is partly done with the combined efforts of two students, J. Taen from the Maritime faculty and L. Hammer from faculty of Architecture in Delft.

As part of the group-work, information about current offshore design was collected, like building techniques of offshore accommodations and the regulations applied in this industry. These are discussed in the chapter 2 and 3 respectively. An essential part of these chapters is the development of a model in which we could simulate different sustainable strategies applied.

The research is based on earlier research done at Keppel Verolme as well as in different courses at the TU Delft. These are discussed in the first chapter of the thesis, the introduction. Also the proposed design direction for further research is considered in a later part of this chapter.

Then a more individual approach is applied when searching for different sustainable strategies applicable in this industry. Sustainable strategies such as extra insulation, shading and energy generation are base for further research and design. These strategies are then developed in different concepts, which then were assessed during a testing phase. This testing phase is explained more thoroughly in chapter 6. Basically the parameters of each concept are applied to the simulation model, in order to get an idea of how much savings each concept can deliver.

The testing phase will result in a concept which will be developed further in the 7th chapter. This chapter includes the costs of the system, the pay-back time and multiple drawings.

1.2 Research Framework

Background

The shipyard *Keppel Verolme* is specialized in offshore platform and ship conversion, repair, upgrade and new build and is exploring the possibilities to develop a more energy efficient accommodation. The interest in this topic is fueled by energy savings and savings on costs, but also in a broader view such as reducing the use of polluting energy sources, from the diesel generators aboard drilling rigs.
The research project is part of an ongoing effort at Keppel Verolme towards improving the performance of offshore units. The research will be carried out with a multidisciplinary team in collaboration with *Keppel Verolme*, the department of *Building Technology at the Architecture Faculty* at the TU Delft, and as the *Faculty of Marine Engineering at the TU Delft.*
The goal of this research is to provide an innovative solution which could be implemented in to be refurbished or new drilling rigs, in order to lower the energy and environmental costs of accommodations over time.

Problem Statement

Previous research showed that the accommodation units on board of drilling rigs currently use diesel generators to get their demand of energy. The current design of these accommodation blocks can be improved to reduce energy and environmental costs, caused by the generators (Otheguy, 2014).
While sustainable technologies are widely used in onshore buildings, there is a lack in offshore accommodations. The financial aspect is the primary design factor in current designing processes, and this results in designs where the sustainable innovation is a secondary factor. Because sustainable innovation is where the *onshore* industry has made a lot of advancements, especially in the last decades, these innovations could be used in offshore designs. Estimated is that in 2015, around 48 % of newly built architecture can be considered 'green'. From 2005 to 2012, the number of new green building designs has increased by 39% in the US (Peters, 2016).

Implementing onshore designs in the offshore industry is difficult due to several limitations in this industry:

- There is significantly less information about the influences of new sustainable strategies in the offshore industry.
- The extreme environment on open sea, together with the salty water, hard wind and fire-danger, cause difficulties when designing innovative solutions.
- New sustainable solutions could bring higher costs and would make it harder to convince investors. This directly relates to the ratio of operational expenditures to capital expenditures (Otheguy, 2014).
- The reliability of the onshore strategies is harder to guarantee offshore because it is less frequently implemented. *(P. Morgan, personal communication, January 6, 2016).*
- There is a high cooling load in the summer, or in tropic climates. This requires extra solar blocking or reflection solutions.

Objective

The objective derived form the problem statements is designing a specific solution for the in-efficient offshore accommodations, where lowering the energy costs and avoiding environmental pollution are the main driving factors.

The following sub-objectives were formulated in order to reach the main objective;

- The assessment of current energy-saving strategies to find its potential for use in the offshore industry.
- Providing simulations with DesignBuilder in order to help with the design process and choices, as well as ruling out other strategies.
- Assessment of current state of the art offshore accommodation, in order to find problems and solutions.
- Keeping track of the CAPEX & OPEX in order to use it as an important factor for several design choices.
- Focus as much as possible on reliability of the product during the design process

Completing the objectives and sub-objectives will result in the following final products;

- A general research into the different important strategies and concepts considering the Energy Sufficient Offshore Accommodation. This research will contain simulations, boundary & constraints for design as literature research.
- An Energy Sufficient Offshore Accommodation draft design by research for refurbishing of a drilling rig, based on the research, simulations and literature.

In order to reach the objectives and finish the final product, a hypothesis was formed about the direction of solutions.

First there should be a sufficient research into the different strategies and simulate these strategies into a possible design of a drilling rig. This is a literature research in combination with a technical research and programs like DesignBuilder. The hypothesis is that the design of the offshore accommodation is made more sufficient when change the solar heat gain, and avoid thermal transition through the walls.

1.2.1 Boundary conditions

The boundary conditions for this research are derived from several literature sources provided by Keppel Verolme and the TU Delft, as well as derived from online sources like the Institutes which formulate the offshore regulations (i.e. DNV, NORSOK).
Many of the starting points are based on the design of the Multi-Purpose-Unit (MPU) block. The MPU-Block is an offshore accommodation unit for 50 persons, currently standing at the Keppel Verolme site in Rotterdam.

Starting-points:

The starting points of the research and design are provided by the TU Delft as well as Keppel Verolme.

- The MPU block available at Keppel Verolme will be used for research into more sustainable strategies. Because the MPU block is relatively new, with a building year of 2009, it's construction drawings and design conditions give us a clear insight in the current offshore industry design. This makes the MPU block a good starting design.
- At Keppel two papers were written, one by M. Otheguy and one by T. Sneep. Otheguy's paper explores the possibilities into more sustainable offshore accommodations, and will be used as a starting point for the proposed design (Otheguy, 2014).
- The research-paper written by T. Sneep will be used as a starting point for the Benchmark Case Chapter. This paper explores the energy use aboard the GlobalTech 1, The GlobalTech 1 is an offshore platform which includes accommodation currently in operation in the North Sea. Sneep proposes several sustainable solutions.
- The products of the Extreme-course at the TU Delft, this course focused on the design of a sustainable floating hotel. The final products provide a lot of possible strategies.

Constraints:

The project has been limited by several constraints regarding time limitations and costs or availability of materials. In case of this research project the following constraints were applied;

- Only focus on the offshore accommodation unit. The water, electricity and air is provided from outside of this accommodation unit. This means no research will be done into the installations and details which relate to these issues.
- The focus of the research topic will primarily be the refurbishing of the façade of an offshore accommodation unit.
- Regarding to the teamwork within this research project, the part focused on in this report will be the minimizing of energy losses within an accommodation unit, whereas the report of the other graduate will be more focused on installations within the accommodation.
- The current set up of the research translates primarily into research of the envelope and internal divisions within the accommodation unit.

Assumptions:

In some instances, there was not enough material or time to substantiate certain factors. The following assumptions were therefore made;

- DesignBuilder gives a sufficient insight into the energy loss and use of an accommodation unit.
- It is assumed *that the MPU-block* and *the GlobalTech 1* is representative for the offshore accommodation units in general.
- In order to calculate the savings, it is assumed that the energy costs are 20 euro-cents/kWh, this Information is supplied by Keppel Verolme BV.

1.2.2 Research Question

The main research question to be addressed in this research project is:

What design is *technically* and *financially* feasible for refurbishing the façade of an existing accommodation based on *onshore strategies, in order to make the accommodation more energy-efficient*?

Next to the main question, the following sub-questions should be asked;

1. What does the current offshore industry look like?
2. What are the current rules and regulations used within the offshore industry?
3. How is a conventional offshore accommodation built and what are its effect on its energy-use?
4. What sustainable concept should be focused on?
5. How to determine a concept on this information?
6. How to implement a final design?

1.2.3 Approach & Methodology

The literature study will contain the next parts:

1. Introduction and Research Framework
2. Relevant topics of offshore Industry
3. Relevant topics of Energy Efficient Solutions and Analysis
4. Boundary conditions and first schematic concept development

The research methodology for designing and constructing low energy buildings is derived from a ten-step processes laid out in the technical report of the National Renewable Energy Laboratory (NREL) (P. Torcellini, 2006, p. 27). This methodology is the result of a technical analysis of the design process of 6 zero-energy projects.
The methodology looks like this:

1 First phase is the '**Predesign**'. At the start of this phase the team will set specific and measurable energy performance goals, which may include percent energy-saving, percent energy cost saving, and emission reduction, and the more locally used kWh per square meter. Also an understanding of the building environment, local weather patterns, and building functional requirements are important. Next to these functional requirements we will also do a study into the Standardization and Rules of designing an offshore accommodation. During this period, we will also brainstorm energy-saving solutions, with help of previous projects of the Extreme-course, and available literature, which are provided by the internet, the TU Delft and Keppel Verolme. We will also look more in detail to previous generated simulations of energy use aboard the GlobalTech 1.

2 The second step is the start of creating a benchmark building model to quantify benchmark energy use and costs. For this we will design a simulation model based on the GlobalTech 1 and the MPU-block. When a working model is established. It will be able to provide us with the information of its energy use.

3 Based on this benchmark model study a parametric analysis will be made to determine possible sensitivities to specific load components. Sequentially eliminate loads such as conductive losses, lighting loads, solar gains, and plug loads from the benchmark building, these will be the boundaries and constraints for possible concepts.

4 At this step several concepts will be developed. These preliminary design solutions will then be assessed on their potential in costs, savings, workload and other topics discussed in the literature.

5 The fifth step is the beginning of the **'Schematic Design'.** Basically this will be based upon the developing of several concepts of the step before. The energy impact and cost effectiveness of each concept/variant are determined by comparing several simulations where the variant is applied on the Benchmark or the new study case. After this the best solution(s) will be chosen to develop further.

6 At this step several construction drawings will be prepared. These drawings will show the essence of the chosen variant.

7 At the seventh step the **'Design Development'** begins**.** In this stage the previous simulations will be combined with an identified HVAC system. This HVAC system should complement the building architecture and exploit the specific climatic characteristics of the site for maximum efficiency. This is when we will update the simulations, and analyze the new results.

8 This step is the '**Construction Documents and Bid**'. Once we analyzed the new results from the third phase, the plans and specifications will be finalized. It should be ensured that the building plans are properly detailed and that the specifications are accurate. There should also be a final design simulation which incorporates all cost effective features. These drawings and simulations will then be presented at the fourth graduation presentation. This will be around the last graduation presentation, the P4. The last two steps are not included in the graduation, but are mentioned because of their relevance to the total process.

9 The ninth step is '**Construction**'. In a period after the graduation the designed solution could be implemented during the refurbishing of an offshore drilling rig. During this implementation, the simulation should be ran again before changes are made in the design during construction. This is because these design changes should not negatively affect the energy performance.

10 The final step is '**Post Occupancy Evaluation**'. Here we should measure and evaluate actual energy performance to verify if design goals are met.

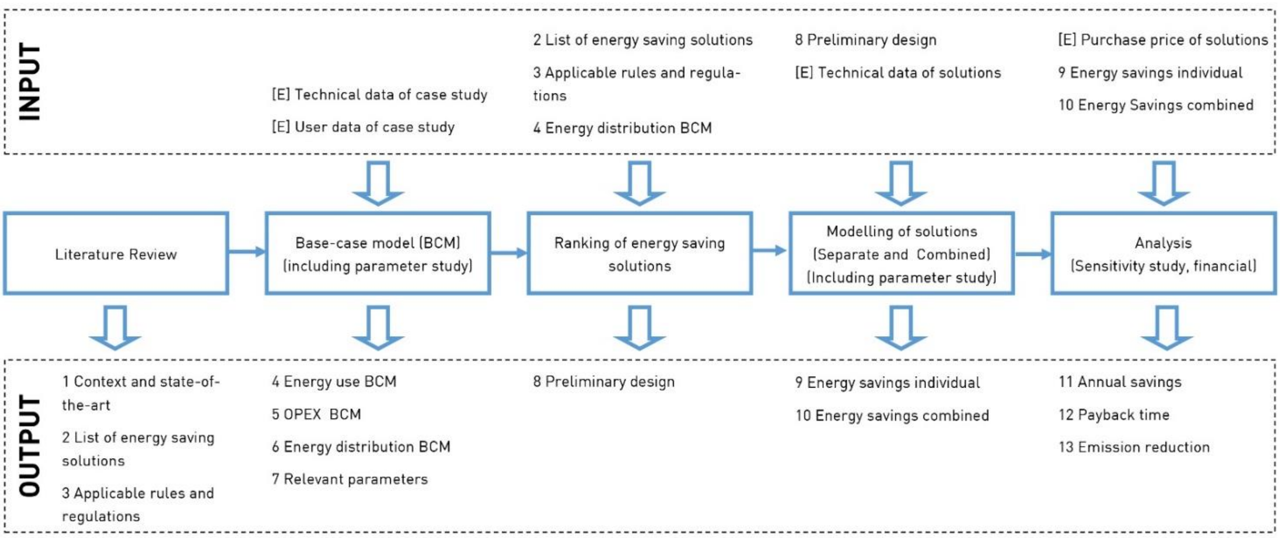


Figure 1: Information Flow (Source; Taen)

Figure 1 depicts the information flow in order to get the wanted results. Basically the research is set up in 5 points. The literature review, the Benchmark (base-case) model, ranking of energy-saving solutions, modeling of these solutions and analysis. Each of these require certain information and provide certain information. The information which follows an (E) depicts information which should be retrieved from external sources.

These steps will be done within a *research team* which includes: Lars Hammer (Building Technology Graduate) and Jeroen Taen (Ship Design Graduate).
Outside of this team we will be supported from the Architecture Faculty by Ulrich Knaack (Façade Department), Willem van der Spoel (Climate Department) and from the Maritime Faculty; Robert Hekkenberg (Ship Design, Productions & Operations) and finally as external mentor, provided by the company Keppel Verolme, Mariano Otheguy, who is the initiator of this project and will supervise the project while on site.

1.3 Previous Studies

1.3.1 Designing with Flows: Energy-Efficient Offshore Accommodation

Introduction

In the Technology Review of Keppel Verolme, the article: 'Designing with Flows; Energy-Efficient Offshore Accommodation' by M. Otheguy, the possibilities for a future energy sufficient offshore accommodation are explored (Otheguy, 2014). With special interest in onshore energy saving techniques, the question is raised how these techniques could be applied to the offshore industry.
The paper first discusses several onshore energy-positive buildings, and the potential of the used strategies in the offshore Industry. Several strategies are implemented on a case study offshore accommodation. This accommodation is the Transformer substation in the North Sea, an accommodation for maintenance employees of a wind park located in the German sector of the North Sea. This substation houses 32 persons, and the used energy consumptions estimation are based on design specifications and meteorological data. The specific strategies discussed and their consequences will be explained below.

HVAC

HVAC is the largest energy consumer in accommodations on board ships and offshore platforms, as seen in Figure 4. Of this energy consumed around 40% of it corresponds to the consumption in supply fans, exhaust, local re-heaters and controls. When the other 60% is used in main heating, cooling and humidification. Reducing these costs is the focus area of this research.

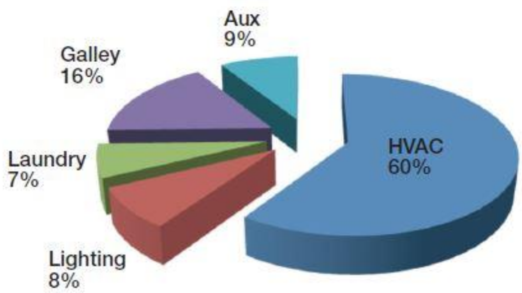


Figure 2: Energy Use Aboard Transformer Substation (Source; Otheguy)

Insulation

Currently the offshore accommodation uses 105 mm standard mineral wool as insulation, but according to Otheguy, when doubled it will result in approximately 36% savings due to lower thermal losses through walls and decks while costing 55% more than the benchmark insulation. It is important to notice that this will have a payback time of 5.2 years.

Windows

In the case study, windows only represent 1 – 2% of the accommodation envelope insulated area. Currently the windows consist 550 x 750 glass area with corner radius of 75 mm, outside glass of 15 mm, air gap of 8 mm, inside glass 6 mm. When replaced with a three times more thermal resistance commercial energy saving window for ships and platforms which incorporate an extra insulating inert gas filling between glasses and a dedicated coating on the outside glass facing the gap the estimated savings could be up to 4% of the total energy used for heating and cooling. With a costs of 56% and a payback time of 4.3 years.

Enthalpy Wheel

The use of an enthalpy wheel is also discussed, these air to air heat exchangers are currently installed in many different industries, and has great potential when implemented in the case-study. According to M. Otheguy the enthalpy wheel is a cost-effective energy-saving measure recovering under given assumptions an additional 20% of the heat and 10% of the humidity at a cost of less than 20% of that of the air handling unit. The resulting payback time is less than 5 months.

Heat Pumps

Another heat recovery strategy discussed is the heat pump. Where under winter water temperatures of the North Sea the heat pump has a coefficient of performance of 3. Which translates to the savings of 66% of the energy needed for heating and cooling.

LED

It is assumed that the lights of cabins are on for 10% of the time, which results, when replaced with LED lights, in a saving of 50 % of the energy, but with the costs of 3.2 times more. However, with the costs of replacement every 50000 hours, the implementation of LED lamps is approximately 10 years.

Hot Water for Showers

Hot water heat recovery in showers is assumed to have an efficiency of 30%, this leads to a payback time of 7 years.

Solar Power

The energy available with solar power is related to the local conditions of the implemented PV-Panels, but when assumed that a solar power plants covers 50% of the case study, it could at 17% of the remaining electricity needs after implementing all the energy saving measures above. It would have a payback time of 9.5 years.

Conclusion

When these strategies are implemented at a transformer substation in the North Sea, under the conditions mentioned in the paper, this could result for energy savings of 40 to 50% with an extra of 9% of total costs. The total payback time of the implemented measures would be 5.9 years and could save up to 875000 euro after 25 years of service life.

1.3.2 Extreme Projects

Introduction

In November 2014 a project was started at the TU Delft in order to involve students in the research of sustainable offshore accommodation. This involvement was modelled like a course where students had to come up with an innovative design of an accommodation block. They were given a standard fundament to build on. Literature was provided by Keppel Verolme and the TU Delft.
In this chapter several strategies will be discussed which are used by the students, which could give some insight in the research in reducing energy-loss in offshore accommodation. The driver behind this project is to explore how to achieve such a higher energy-effectiveness by means of architectural design and system integration (TU Delft, 2014).

Natural Ventilation

One of the techniques used a lot in the Extreme Projects, was the use of natural ventilation. Basically, natural ventilation is employed to leverage freely available resources like wind and outdoor air to satisfy cooling loads and provide occupant comfort. For onshore buildings the natural ventilation is a much used strategy because the advantages are energy efficiency, improved indoor environmental quality, potential for lower costs, reduced maintenance and price costs, compatibility with daylighting and increased range of thermal comfort (Price Industries, 2011).

Floor Heating

Another technique was the use of floor heating. In onshore buildings it is often used in combination with a heat pump, where the under floor heating is optimized the efficiency of the heat pump, and is able to provide a constant, controlled heat. Reducing running costs and carbon footprint. What is interesting, especially in regards reducing the total energy use in offshore accommodation, is that floor heating is basically low temperature heating and therefor good to be combined with a heat pump installation. There is also a freedom of design, which is often a problem in offshore accommodation. In offshore accommodation certain furniture should be welded onto the floor, and the underfloor heating could be designed around these welded elements (Advantages of Underfloor Heating, 2015).

Wall – Floor systems

Insulation is important when reducing the energy loss, there are some Extreme projects which implemented a new system however. One implemented special IDES floors, which are of low weight and with integrated systems. And built out of cassettes originally employed for explosion walls (IDES Floor, 2015). Other systems applied are wall systems with mainly attention to build cold bridge free elements.

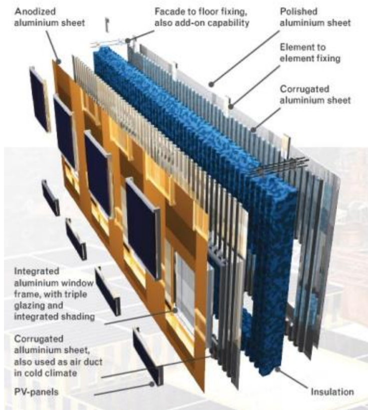


Figure 3: Wall-system (Source; R. van Houten, TU Delft, 2014)

Windows

An interesting use of windows was by the design of Ivo Sombroek, the windows in his design were designed in an angled position. This design prevented the accommodation to heat up because of infiltrating sunlight. According to previous research by Keppel Verolme, the heat gain through windows was a major problem when trying to lower the energy use (Sneep, 2014).

Conclusion

The strategies implemented at the Extreme course, are themselves not researched in detail. However, the above mentioned strategies could very well be promising in regards to offshore energy saving. Further research will have to be done in order to test the feasibility of these strategies.

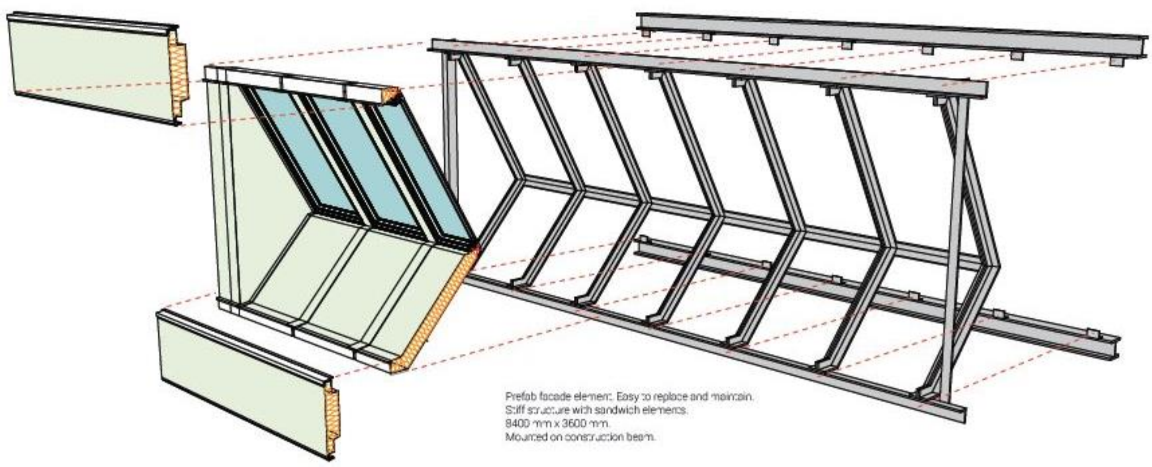


Figure 4: Angled Walls *(Source; I. Sombroek* TU Delft, 2014)

1.3.3 Research & Simulations by Keppel Verolme

Introduction

In 2014, Thom Sneep, an intern at Keppel Verolme studied into the energy use of an offshore accommodation. This research is used as a starting point for the current research, and collaborated with the research of M. Otheguy.
This research is divided in two parts; *Research of energy-efficient offshore accommodations in warm areas* and *Research of energy-efficient offshore accommodations in cold areas.*

Research of Energy-Efficient Offshore Accommodation in Cold Areas

In this research a closer look was taken to offshore drilling rigs in the North Sea, the performance was based on the GlobalTech 1 platform, a rig in the North Sea. The weather data was taken from the GORM station and Helgoland, an island in the German part of the North Sea. Different parameters were applied to the model, to see its influence.

After analyzing the simulations made with this data and parameters, a few conclusions could be made. When heating up the indoor with 2 degrees, 37% more energy is spent to heating. A decrease of 2 degrees, saves up to 12%.
Doubling the insulation will decrease the amount of heating much more than the amount of cooling. Window improvement has a very low impact.

Research of Energy-Efficient Offshore Accommodation in Warm Areas

In this research a closer look was taken to offshore drilling rigs in two tropical areas, Gulf of Mexico and an area near Gabon & Ghana. The available air temperature data was the reason for this decision. However, the other data was not easily available, especially in the area near Gabon. Here T. Sneep had to extrapolate different graphs in order to get the right data to work with. The data is implemented in the DesignBuilder program, with the same construction data as the *Cold Area* research and analyzed.
After analyzing these simulations, it was concluded that increasing the insulation had more impact on the consumption for heating than the cooling. Improving the windows has low overall energy reduction. It has more impact on heating than cooling. Increasing the amount of windows would result in way higher energy consumption. (Sneep, 2014)

Conclusion

The research gives a good impression of the energy use in an offshore accommodation. However, since the data used could differ a bit in regards to this research, it is important to double check the weather data.
According to the simulation of the GlobalTech 1, the things that make the most difference is change in the cooling and heating load. Where the change in insulation has a positive influence on the heating, but not on the cooling.

1.4 Proposed Design Direction

Introduction

When researching the previous studies in the team, several topics came up in order to develop further. During a small selection cycle we dismissed a few strategies of which was thought that they were not possible with current time or funds. After this selection cycle a small concept diagram was made to categorize different strategies.

Focus Area

In the figure below you can see the focus of this research, which is the energy-output of the offshore accommodation. The efficient energy-output can be divided in two main topics; reducing energy demand and reducing energy losses.

Energy demand is based on the use of electricity, heat and water. The electricity demand could be lowered by implementing LED and energy efficient appliances. Heat is influenced by the use of floor heating, smaller and linked spaces. The strategy which could lower the water use is low flow showers and toilets.

Energy losses is based on the loss of energy through the façade, this can be influence by insulation and the openings in the façade, e.g. windows and doors. The insulation can be improved by adding on the inside as well as on the outside and the energy loss through windows could be reduced by using better insulated windows, making smaller cold bridges and change the size or location.

As shown the diagram, the whole energy aspect of the accommodation will not be researched here, however they will influence the results of this research. This is why the other topics will be focus of research of the other graduate student, *J. Taen*. And will be added in a later stage into this research.

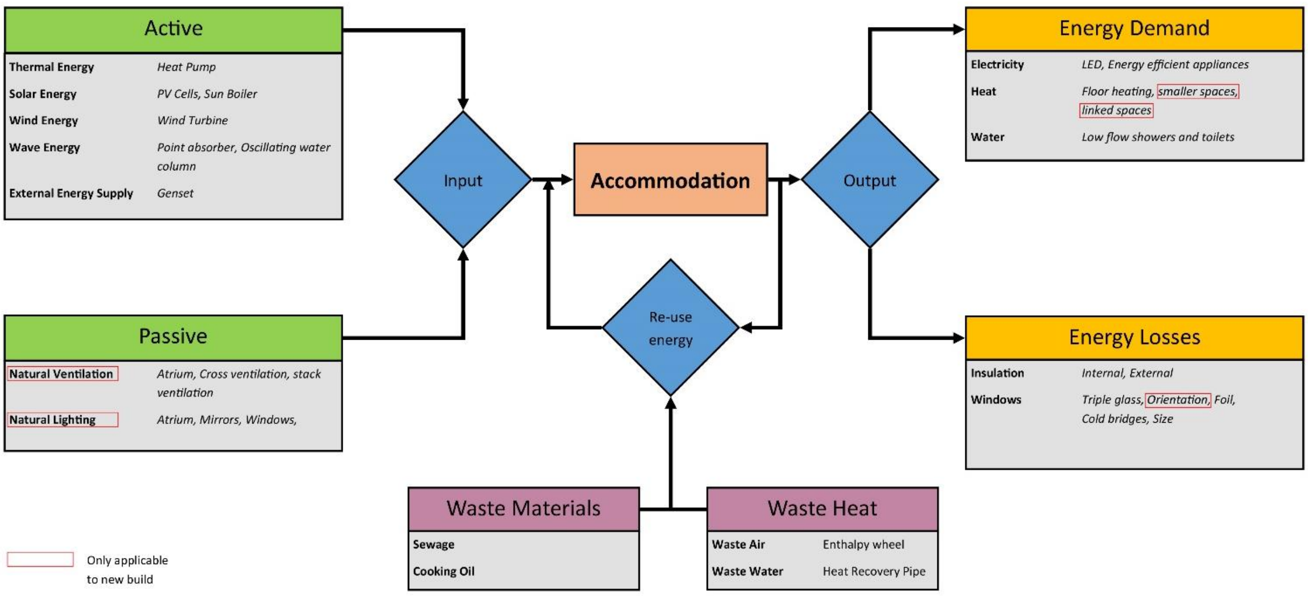


Figure 5: Division of topics (Source; author)

Sub-Focus Areas

The sub-focus is determined because of the Offshore context. Within the offshore industry, certain design aspects have priority over other ones. Since the offshore accommodation will be built onto a drilling rig, there is a higher chance for fire accidents. Through the implementation of the ALARP technique, As Low As Reasonably Practicable, which basically means that you should assume accidents will happen and being as well prepared as possible, trying to prevent accidents, and when they do happen, reducing their consequences both to the installation and to the people (Vella,

2015). This is why fire safety is one of the core aspects of offshore design. Other than compartment-design and escape routes, fire safety can be related to blast resistant design as well as using fire proof materials.
Next to fire safety, this research will focus on material use, energy use, indoor comfort (acoustics, humidity, temperature) and costs. Costs is specifically important because of the commercial motivation behind this research.

These topics will be applied to building elements which relate to sustainable strategies, the insulation and façade openings. These are the windows, doors, external walls, internal walls and insulation, as is derived from the NORAC catalog for building elements of offshore accommodation (NORAC AC, 2015),

Conclusion

The proposed design direction will focus on reducing the energy demand as well as the energy losses, which can be achieved by applying several sustainable strategies. The design will focus on influences of fire safety, material use, energy use, indoor comfort and costs on windows, doors, external walls, internal walls and insulation.

2 Offshore Industry & Regulations

2.1 Offshore Oil and Gas Industry

The offshore industry is a broad industry based on drilling and exploiting gas and oil, but the focus has shifted more towards wind energy and aquaculture. The oil and gas exploiting industry will be explained further in this chapter, first by explaining some common definitions from the industry, and later by going a bit deeper into the Accommodation part.

Fire Safety

Gasses can escape during the drilling and leakage during processing can cause dangerous explosions and fire. Since this is a serious threat aboard an offshore drilling rig, as can be seen from the experiences of the Deepwater Horizon (Figure 6), basically all external elements should be fire proofed and blast resistant. Fire Safety can be guaranteed through passive, active and/or protective measures.

Protective measures are put into place in order to prevent a fire. Informing the employees of escape routes and dangerous situations and telling them how to prevent or put out fire are forms of protective measures.

Active Measures are focused on the application of smoke detectors, separation of different escape-routes, application of specific fire worker elevators as well as implementing additional ducts for firefighting water.

Passive Measures are the implementation of fire-compartments, which are based on specific square meters per compartment. Also floors, walls and facades should be fireproof for a specific amount of time. For onshore buildings this time for walls, floors and facades is 60 minutes, however, for the construction this is 120 minutes. The weak points in the fire compartments are the windows, doors and duct shafts. These should therefore be very consistently detailed. Another passive measure is the implementation of at least two separate flight routes (Fire Protection Measures, 2015).

Figure 6: Fire Aboard the Deepwater Horizon, April, 2010 (Source; author)

OPEX/CAPEX

A big part of this research is with attention towards the economics of the provided sustainable solution. This means attention to the OPEX and CAPEX.
OPEX is short for **Op**erating **Ex**penditures, which are the periodic costs of a product or system. Which could be the maintaining costs, energy costs or rent. The OPEX is the direct opposite of CAPEX. (Maguire, 2008)
CAPEX is short for **Ca**pital **Ex**penditures, and is basically the cost to develop or provide parts of the product or system. These are non-periodic, so have just to be paid once. (Capital Expenditure, 2015)In regards to the research situation. The CAPEX is the investment the client makes into a sustainable strategy, where the OPEX will be the amount of energy costs. When these energy costs are low enough, the client will accept to a higher CAPEX.

Compliant Tower(CT) (370 to 910 Meter Depth)

A compliant tower which is used at depths ranging from 370 to 910 meters is also a founded on a piled foundation, however it is a narrow, flexible base which provides support for an conventional deck for drilling and production. Because of this flexible base it can withstand large lateral forces by sustaining significant lateral deflections. (McLendon, 2016)

Semi-submersible platform (60 to 3000 Meter Depth)

This floating structure is possible because of its large hulls (columns and pontoons) with sufficient buoyancy. But has the weight which keeps the structure upright. This has an advantage; they can be moved and the depth can be varied by filling up the buoyancy tanks. They are fixed at their place with the use of chains or ropes, but can also use its dynamic positioning. (McLendon, 2016)

Jack-Up drilling rigs (up to 120 Meter Depth)

These platforms can be jacked up above the sea using legs that can be lowered. These Mobile offshore drilling units are therefore limited in their operational depth, but have an advantage in their flexibility, as they can move from place to place. (McLendon, 2016)

Floating Production Systems (FPSO)

Next to Semi-submersible, there is another kind of floating drilling structure, the FPSO. These consists of large mono-hull structures, generally ship shaped, equipped with processing facilities. However, they are not used to actually drill for oil or gas. (McLendon, 2016)

Tension leg

A tension leg platform has a bit the same principle as the semi-submersible platforms. However, this platform is fixed to the ocean floor with taut, vertical tendons connected to the sea floor. (McLendon, 2016)

Spar platform (up to 1000 meter)

A spar platform derives his name from the spar of a ship (the mast). A spar platform is a single, wide diameter cylinder which support the service area of a drilling rig. Typically, this cylinder has a diameter of 130 feet, and these types of drilling rigs can be applied to depths up to 1000 m, with recent advancement in the technology which makes depths of 3000 m. possible. (McLendon, 2016)

Bulkhead (Wall)

A bulkhead is the external wall of a ship or container, but also in case of offshore accommodation the vertical external wall is often referred to as the bulkhead. The main purpose of these bulkhead is increasing the structural rigidity, the division of functional areas, create watertight compartments. Some of the bulkheads (like in offshore accommodation) are fire resistant rated. (Wikipedia, 2016)

Subcategories Offshore Accommodation

For this research it is important to devide the offshore accommodation in the following four subcategories. The fixed offshore accommodation, the mobile offshore accommodation, the refurbished offshore accommodation and the new-build offshore accommodation. The devision between these four kinds is needed because of the location and way of building. This will have a great impact onto what sustainable solutions could be applied.

The fixed accommodation or rig (Figure 7), is often built onshore, after which it will be transported to a specific location near an offshore oil-well or windpark. Built onto a permanent foundation construction which consists of tubular steel jackets, supported by piles. These are driven into the seabed and are therefore unable to be transported after installation. The maximum feasible depts for fixed oil rigs is 520 meter below the surface, and are technically applied all over the globe. Repairement and maintainance sets the fixed accommodation most apart from mobile. Since its location is permanent it will stay there for an approximately 20 to 30 years. Repairment and maintainance should be performed on site (McLendon, 2016). Because the location of the platforms is permanent, the configurations of the façade could be perfectly adjusted to the local climate.

Figure 7: Fixed offshore installation (Source; Oilworker)

Mobile accommodation platforms are built onshore and are often called ‘flotels’. Flotels are semi-submersible offshore units, which only function is accommodating offshore working people. The name is derived from Floating Hotels (Wikipedia, 2016). Flotels will be used for specific periods and projects. When not used they will be stationed within a harbor where maintainance and repairment takes place. After that they can be operational world wide. In comparison to the fixed platform, the architecture aboard a mobile platform should be able to deal with all kinds of different climates, from tropic to colder climates due to its global operation scope.
Another aspect in regards mobile rigs is the load balance, the load must be evenly devided over the rig in order for the rig to be balanced. This is also the reason why often aboard mobile rigs, the accommodations almost never are built in to the height, but more 1 to 2 decks, spread all over the rig. As can be seen in figure 7, this is not the case at fixed rigs

At Keppel Verolme the offshore accommodations are often refurbished. These are already older platforms, which are repaired or upgraded for the next 20 - 30 years. The technology and architecture aboard is then stripped and upgraded to current state of the art, this is often the most cheap solution for clients. When applying new technologies onto older architecture, it should at least be financially feasible for the following period. Most often the refurbished platforms are mobile platforms, however when fixed installations need to be worked on, additional semi-submersibles provide extra manpower on location. These activities may include internal and external refurbishment.

Newly build offshore accommodations are more up to date and applied in the same rate to mobile and fixed platforms. When considering new strategies, the new build has a higher range of options.

2.2 Offshore Design Regulations

In order to redevelop a refurbished and or new build sustainable offshore accommodation, it is important to know the different rules and standards used in the offshore industry. The general regulations, regulations for windows and regulations for insulation will be used to get better insight into the construction of offshore accommodations, the info will be implementation in a later period to develop a good working and realistic model of the offshore accommodation for simulations.
These rules and standards differ a lot from the onshore building sector, but also from country and organization. In offshore oil and gas units, their compliance is governed by five continental shelf regulators (Norway, Denmark, Germany, Netherlands and UK), with each different rules and regulations.

UK and Norwegian oil and gas sectors are the main producers of oil and gas in the North Sea. But both countries use different regulations where the UK uses a more safe-case regime and the Norwegian authorities use a more prescriptive route. It is generally accepted that the regulations of the North Sea fleet have the highest standards for quality, safety, loss prevention and risk management. This has to do with the over 40 years of experience, a highly skilled and trained workforce, a culture of continued development and a cooperation between many organizations who strive to aim higher than the minimum operating standards (Hines, 2012).

The NORSOK standards are regulations of the Norwegian authorities, and because of their prescriptiveness as well as in regards to their high standards, the decision was made to research these regulations and keep these as a base line for the designing phase in this research.

While all regulations and standards are important to consider, in this report we will only focus on essential standards and regulations in the context of façade – design.

The NORSOK standardization studied in this chapter is called the *NORSOK Standard C-002 – Architectural Components and Equipment*. The focus will be on *Materials, Acoustics, Fire Safety, Energy-Use and Indoor Climate.* All in regards to the most essential building elements in this context. Which are the windows and glazed surfaces, insulation, internal and external walls and floors.

The indoor climate regulations were harder to find, however the *ABS guide for Crew Habitability on Mobile Offshore Drilling Units,* has the regulations for modular offshore drilling units, it is assumed that these are usable for offshore accommodation units. ABS stands for the American Bureau for Shipping and is a classification society and their thermal regulations are derived from the ASHRAE report for *thermal environmental conditions for human occupancy*. Their mission is to promote the security of life, property and natural environment. And is the second largest class society. This is why their regulations for Indoor Comfort will be used for our research (ABS, 2012, p. 30).

Regulations for Indoor Climate

Thermal comfort is defined as a condition of mind which expresses satisfaction with the thermal environment. The ABS guide states therefore that the sensation of thermal comfort is largely subjective and varies from person to person. This makes it hard to specify a single thermal environment which is satisfactory to everybody. The regulations should conform within acceptable limits, in which the biggest group of people is satisfied. Temperature aboard an offshore accommodation block should range between 20 to 25 degrees Celsius during the winter and 22 to 27 degrees Celsius during the summer.

The HVAC system should be capable of providing and maintaining between the 30 and 70 percent of relative humidity. The enclosed space vertical gradient cannot differ more than 3 degrees Celsius between 100 mm from the floor to 100 mm from the ceiling. In cabin areas, the difference between the inside bulkhead surface temperature adjacent to personnel cabins and the average air temperature within the space shall be less than 10 degrees Celsius. The air velocity is not allowed to exceed 30 meters-per-minute or 0.5 meter per second. And the Air Exchange Rate should be at least 6 complete changes-per-hour. This is a lot higher than in onshore buildings (ABS, 2012).

2.2.1 Regulation on Windows and Glazed Surfaces

Material Standards

Materials for the windows and glazed surfaces within the offshore accommodation unit have to be as light as possible. In the regulations three materials are discussed for the window frame; carbon steel, stainless steel and aluminum. Aluminum can only be used when it is of seawater resistant type. The stainless steel can have a maximum carbon content of 0.05%. The carbon steel should be in accordance with NS-EN 10025, S355 J2G3 or equivalent (NORSOK, 2006, p. 32).

Acoustics

Since windows are the weak points in the façade, they could cause acoustic problems, this is why the total window (glass and frame) should reduce the sound with 48 dB in general and 53 dB in cabins and HTCC. In order to achieve this sound reduction, it is allowed to apply a two glass packs, separated by air (NORSOK, 2006, p. 32).

Fire safety & Blast Resistance

The main regulation considering fire safety in windows is that the complete window units should have the same fire-rating as the wall in which they are installed. Windows should not be installed in H-rated fire divisions.
The same goes for the blast resistance, the window units shall have the same blast pressure resistance as the adjoining wall. Each unit shall be fully intact after being exposed to the specified blast pressure, maintaining full fire rating and functional integrity (NORSOK, 2006, p. 32).

Thermal Energy

The thermal properties of the window should not exceed the U-value of 1,5 W/m^2 °C (NORSOK, 2006, p. 32).

Daylight

The use of windows to provide daylight wherever possible is highly advised. But windows shall at least provide daylight in dining rooms, main recreation rooms, work places that are used more than 6h a day and the cabins. The minimum glazed area for these windows is 0.6 m^2 in cabins and 0.9 m^2 in offices or other work places. In recreation areas larger windows shall be provided if possible (NORSOK, 2006, p. 7).
In order to stop light from entering the cabins, offices and other areas, windows shall be fitted with blackout blinds/curtains, these should be completely impenetrable to light. It is important that they are robust, reliable and of a suitable weight in order to withstand continuous daily use (NORSOK, 2006, p. 32).

Installation & design

In offshore living units, all window frames should be continuously welded to the outside surfaces of the external wall, and only in few cases bolted windows are allowed. The windows should be in line with the insulation of the external windows, and should have an adjustment capability in depth to accommodate various external wall thicknesses. Detailing between internal frame and cut-outs in internal linings shall allow for mechanical closing of any gaps between these items, to stop passage of smoke and air borne noise.
The windows installed in the vertical walls should be detailed that all maintenance, repair and replacement of glass can be carried out from inside the accommodation. This happens often with the use of internal bolts. These should be hide behind an easily demountable profile system which surrounds the whole unit.

The complete window unit shall be totally gas- and spray-tight. Where window units are applied horizontally or at an angle, a complete drainage system shall be provided as an integral part of the unit. On floating units, like a semi-submersible drilling unit, windows shall maintain the integrity of the bulkhead in an accidental heeling condition. (NORSOK, 2006, p. 32)

2.2.2 Regulations on Insulation

Material Standards

The regulations on materials in insulation are a bit less detailed as for the glazed surfaces. However, the regulations are mainly focused on the application of dry-fix insulation. But if its proven impossible to use dry fix insulation, a spray-on type alternative may be considered. In any case the material should be water repellent with good non-cracking and adhesive properties. The combination of fire, thermal and acoustic insulation is allowed where appropriate. But it is absolutely not acceptable to use glass wool anywhere in the building (NORSOK, 2006, p. 34).

Acoustics

The acoustic insulation should be flame retardant and impervious to moisture. The wall panels are not allowed to be perforated below 1500 mm above finished floor level. It is allowed to apply sound absorbing cassettes which are mounted onto the external walls (bulkheads), but also onto the walls, ceilings and underside of decks in areas where additional absorption of sound is required. These cassettes shall have good sound absorption properties in the 63 Hz to 4 000 Hz frequency range (NORSOK, 2006, p. 36).

Fire safety & Blast Resistance

The application of fire insulation. B-0 class draught stoppers shall be installed above suspended ceilings. The distance between draught stoppers shall not exceed 14 m. Where there is a cavity between the external wall and internal lining, the draught stopper shall continue down the cavity to provide a continuous seal. Insulated structures and elements designed to resist a specified fire and design blast pressure, shall be fully intact after being exposed to the specified blast pressure, maintaining full fire rating and integrity (NORSOK, 2006, p. 36).

Thermal Energy

The thermal insulation should be placed on the internal (warm) side of the structure. For the offshore accommodation and other manned areas, the complete construction, including thermal insulation shall provide a U-value of 0,5 W/m^2 °C, or better.

Humidity

The vapor barrier installed with the insulation should be in a strong, non-combustible and suitable material (e.g. 0,048 mm reinforced aluminum foil), shall be used where there is a temperature differential. The vapor barrier shall be fixed on the internal (warm) side of the insulation. All joints and penetrations shall be properly sealed with tape of the same material as the barrier. Overlap at joints shall be at least 50 mm. The vapor barrier should be impervious to moisture, completely sealed including all edges, and free from any punctures (NORSOK, 2006, p. 35).

Installation & design

The external wall (bulkhead) and the decks can be insulated and should be provided with fixing pins and washers to retain the insulating material. These pins and washers shall be spaced at a maximum center-to-center distance of 300 mm in both directions, perpendicular to each other. The pins shall be welded to the structural material, e.g. steel surface (NORSOK, 2006, p. 35). In areas where access may be required for periodic maintenance, the insulation pins shall have capped dome washers to avoid injuries to personnel. Gluing of pins may be acceptable in certain cases for fixing of acoustic and thermal insulation.

When installing fire rated dry fix insulation, additional galvanized wire mesh secured by the pins and washers, must be used to retain the insulation. On insulated structures that are designed to resist a blast overpressure, the fixing pins shall be long enough to be bent over the washer and the wire mesh, and allow the mesh to flex in both directions in the event of a blast (NORSOK, 2006, pp. 34,35).

3 Study Case: Offshore Accommodation

3.1 Accommodation Explained

In this chapter the current offshore accommodation design will be discussed. Several catalogs, data from actual new-build accommodation block projects carried out at Keppel Verolme, will be used as sources (Figure 8), in order to provide a benchmark case for Offshore Accommodation. They provide information about the current state of the art offshore accommodation buildings. It will give insight into the layout and construction, but also about its energy use. And provide questions like; which are the possibilities for changing this energy use? The energy use itself will be modelled in DesignBuilder, where a simplified model of the benchmark case described accommodation will be simulated. It is assumed that this model represents the greater half of the current offshore accommodation market.

Layout & Dimension

Offshore accommodations are basically developed for the oil, gas and the renewable energy industry. The accommodations are designed to house the employees for several days, weeks, or months aboard an offshore drilling rig. These situations make it necessary for accommodation to perform a lot of other tasks compared to onshore accommodations. These accommodations often include the workspace modules including offices, laboratories, test cabins and coffee shops/tea shacks. Ancillary modules such as recreation rooms, gymnasiums, locker rooms, galley/mess rooms, laundry rooms and medical suites can be part of the larger accommodation complexes. (Offshore Accommodation and Workspace Modules, 2015).

For the Benchmark Case the layout represented in the table below is used. It is important to note that each accommodation block represents several sleeping dorms, with a total of 19 accommodation rooms.

	BenchMark Layout
Ground Floor	Changing Room, 1 Corridor, Galley, HVAC, Laundry Area, Mess Room, Staircase, Storage Room
1st floor	5 Accommodation Blocks, 1 Corridor, 1 Staircase
2nd Floor	3 Accommodation Blocks, 1 Corridor, Gym, Hospital, Office Area, Staircase, TV-room for smokers, TV-room for non Smokers

Each accommodation is build specifically for its use, that is why there is actually not an uniform size of these accommodations. Despite this, we looked at the square meters of several to our sources and came up with standard dimensions, like the height of floors, the surface area and façade area. In the table below this data is shown.

	Dimension Sizes
Deck Height	3.5 m
Length	16 m
Width	20 m
	Floor Areas
Total Floor Area	961 m^2
Number of Decks	3
Area per Deck	320 m^2
Accommodations	349 m^2
Hallway	241 m^2
HVAC Room	35 m^2
Mess Area	53 m^2
Galley	39 m^2
Changing Rooms	69 m^2
Lobby	25 m^2
Storage Rooms	7 m^2
Laundry	14 m^2
Office Area	38 m^2
Hospital	22 m^2
Gym	19 m^2
TV Room – Smokers	18 m^2
TV Room – Non smokers	33 m^2

Figure 8: Offshore Accommodation External Wall (source; author)

Occupancy

The occupancy at an offshore accommodation is mainly based on a workforce of employers which work at the location, but it also considers the employees needed for cooking, cleaning and helping out on the platform, also called the 'hotel-crew'. The workforce in our benchmark is considered 37 persons. Of these 37 persons, there are 2 working crews of 15 people and 3 hotel crews.

It is important to consider how the occupancy of the accommodation is related to the workforce. When one hotel-crew is working, the other hotel-crew will be asleep, which also goes for the workforce. This influences the energy-use and demand in the rooms. This is why the occupancy is determined on amount of people per square meter on a specific time. Taen considered the occupancy schedule which can be seen below in table, in a 24 hour schedule as derived from the calculating excel. This schedule is later used in simulations.

				Occupancy Schedule
Time	**Working Crew #1 (15 Persons)**	**Working Crew #2 (15 Persons)**	**Hotel Crew 31 (3 Persons)**	**Hotel Crew #2 (3 Persons)**
12:00:00 AM	Sleep	Eat	Sleep	Work
01:00:00 AM	Sleep	Work	Sleep	Work
02:00:00 AM	Sleep	Work	Sleep	Eat
03:00:00 AM	Sleep	Work	Change	Change
04:00:00 AM	Sleep	Work	Eat	Rest
05:00:00 AM	Eat	Eat	Work	Rest
06:00:00 AM	Eat	Eat	Work	Rest
07:00:00 AM	Change	Rest	Work	Sleep
08:00:00 AM	Work	Rest	Eat	Sleep
09:00:00 AM	Work	Rest	Laundry	Sleep
10:00:00 AM	Work	Sleep	Work	Sleep
11:00:00 AM	Work	Sleep	Work	Sleep
12:00:00 AM	Eat	Sleep	Work	Sleep
01:00:00 PM	Work	Sleep	Work	Sleep
02:00:00 PM	Work	Sleep	Eat	Sleep
03:00:00 PM	Work	Sleep	Change	Change
04:00:00 PM	Work	Sleep	Rest	Eat
05:00:00 PM	Change	Sleep	Rest	Work
06:00:00 PM	Eat	Eat	Rest	Work
07:00:00 PM	Rest	Change	Sleep	Work
08:00:00 PM	Rest	Work	Sleep	Eat
09:00:00 PM	Rest	Work	Sleep	Laundry
10:00:00 PM	Sleep	Work	Sleep	Work
11:00:00 PM	Sleep	Work	Sleep	Work

Energy Generation

Energy is often generated aboard drilling rigs and accommodation with GenSets. These are generators which work mainly on MDO, Marine Diesel Oil. A more heavy variant of the regular diesel oil and often used in smaller ships. These Gensets often produce the energy for the whole accommodation, but also for energy needed outside of the accommodation, like cranes and work equipment. Generating sets are selected on a few criteria, namely the electrical load they are intended to supply, the loads characteristics, but also the expected duty as well as environmental conditions. Most of the larger generator set manufactures offer software that will perform the complicated sizing calculations by simply inputting site conditions and connected electrical load characteristics *(CAT, 2016)*. Data considering the MDO and the GenSet can be found in the table below, it excludes the price of transporting the MDO to the offshore station. The heat generated with the GenSet during generation is currently not used, and thus lost.

The supply costs of the MDO aboard can be derived from the information corresponding to a real platform accessed via Keppel Verolme BV., which is an 306 person offshore accommodation submersible.Refuelling of the ProSafe Regalia typically happens once a month, with the renting costs of an supply vessel assumed to be 35000 Euro a day. This supply vessel also supplies the food and water, however in the renting costs are the vessel fuel costs included, which is related to the load it carries.

	Data MDO & Genset
1 Liter MDO	0,328 Euro
1 m^3 Liter MDO	880 kg/m^3
1 Liter MDO	39.6 MJ = 11 kWh (100% efficiency)
Alternator Efficiency (Genset)	90%
Medium Speed Four Stroke Motor (GenSet)	35,75%
Total Efficiency (GenSet()	32.75%
Costs 1 KwH	9.10 Eurocent
MDO	74.9 KG of CO_2 / GJ
Cost of Supplier	35000 a day
Total Assumed Costs per kWh	20 Eurocent

HVAC

The heating system used within the conventional offshore accommodation is an air handling unit, which includes an hot air heating system and combined with a humidifyer. Local heating is possible in the rooms. The HVAC is powered by electricity and heats up air which is send to the specific room, to keep the room on temperature, this system is also known as an electrical resistance heating. The hot air is supplied through a vent in the ceiling of the specific room, at where there is also a local reheater system, in order to extra heat the air locally. The local reheater is located at ceiling level, where the air enters the room. Air extracts are located in the corridors. Vents in the rooms allow the ventilation air to pass from the rooms to the corridor.

Lighting

A specific lighting plan in the accommodation is used according to the design data of the GlobalTech 1, derived from Keppel Verolme. In this template all available lighting can be devided into two groups. One group where the lights are always on, and a group where people who are present in the room can put the lights on or off. The latter is only for the sleeping dorms, where the lights which are always on are placed in the; gym, hospital, office area, both tv rooms, changing room, galley, HVAC room, Laundry area, Lobby & Storage area, Mess room and all corridors and staircases.

Openings

Openings in the external façade consist of 4 – 5 % of windows per orientation, this is a small percentage compared to onshore buildings. All windows are laid in a stainless steel frame, bolted or welded onto the external façade. The windows in this particular Benchmark case are 55 cm by 75 cm.

Construction Layout

The internal elements commonly used in offshore accommodation, are prefabricated insulation panels with varying thermal insulation. However, since standardization is important in prefabricated elements aboard, all are 600 mm wide and 3000 mm high. Weight varying from the use of metal or aluminum. The systems are built in a modular profile system, and can be clicked into each other. The modular profile system will be welded or bolted onto steel floor. (NORAC AC, 2015, p. 5)

The external wall is built up as an 8 mm steel outer layer, with 10 centimeter of mineral wool insulation. This steel layer is protective against blast and sound, and makes it easy to create an air-tight design.

In figure 9 to the right the build-up of an external wall can be seen aboard a ship. The steel outer layer is covered with a layer of insulation and a construction to hold the internal wall partitions.

In figure 10 is the GlobalTech 1 shown, an offshore installation used as study case for this research.

Figure 9: Picture of Offshore External Wall system (Source Author)

Figure 10: GlobalTech 1 (Source; author)

3.2 Energy Use On Board Of Offshore Accommodations

The energy-use on board of offshore accommodation is the result of a combination between the climate data and the building data mentioned before.

Climate

An offshore drilling rig is built to be available world wide. This means it will perform in several different climates, which in turn has a lot of influence on the cooling and heating loads of the offshore Accommodation.

The Benchmark case will therefor be situated in two specific locations, an 'colder location' which is in the North Sea and an 'hotter location', located in the Gulf of Mexico. Most of the information is retrieved from weather data collected on offshore drilling rigs and buoys. The rigs are Station 42001 in the Gulf of Mexico, and Station 01400 in the North Sea.

SunPath

The sunpath and solar radiation of each location (Figure 11 & 12) determines the heat gain on the facades and also through the windows. This heats up the accommodation when not necessary, and should be avoided in hotter climates, in colder climates it could however reduce the heating costs of the HVAC system by passively heating the room with solar radiation. To have an insight into the solar radiation, a sunpath was determined on the coordinations of the stations.

	Coordinates Stations
North Sea	56.540 N 3.220 E
Gulf of Mexico	25.897 N 89.668 W

	North Sea Solar Data
Highest Elevation Point (12:00 PM – 21 June)	57°
Lowest Elevation Point (12:00 PM – 21 December)	10.5°
Average	34°

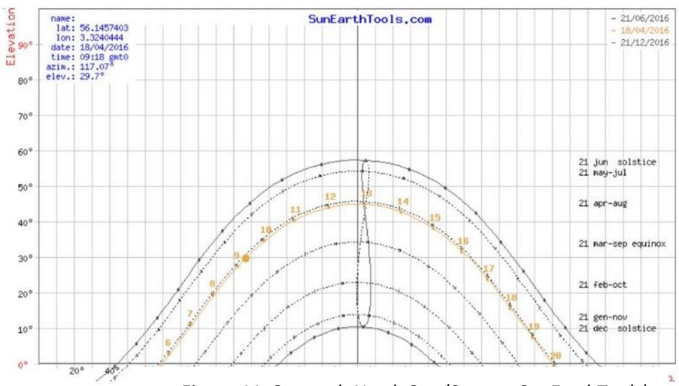


Figure 11: Sun path North Sea (Source; SunEarthTools)

	Gulf of Mexico Solar Data
Highest Elevation Point (12:00 PM – 21 June)	88°
Lowest Elevation Point (12:00 PM – 21 December)	41°
Average	65°

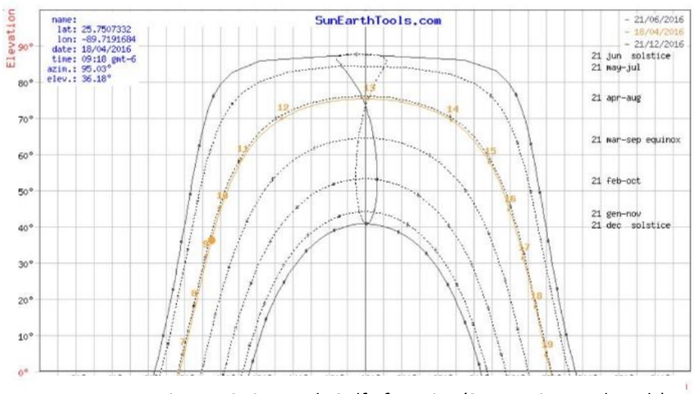


Figure 12: Sun Path Gulf of Mexico (Source; SunEarthTools)

The solar radiation intensity was determined by retrieving data from the closest inland city. This was necessary since data aboard of drilling rigs was unfortunately not available. The data used for radiation in the North Sea was from Aberdeen (Figure 13), and the radiation information of in the Gulf of Mexico was taken from New Orleans (USA).

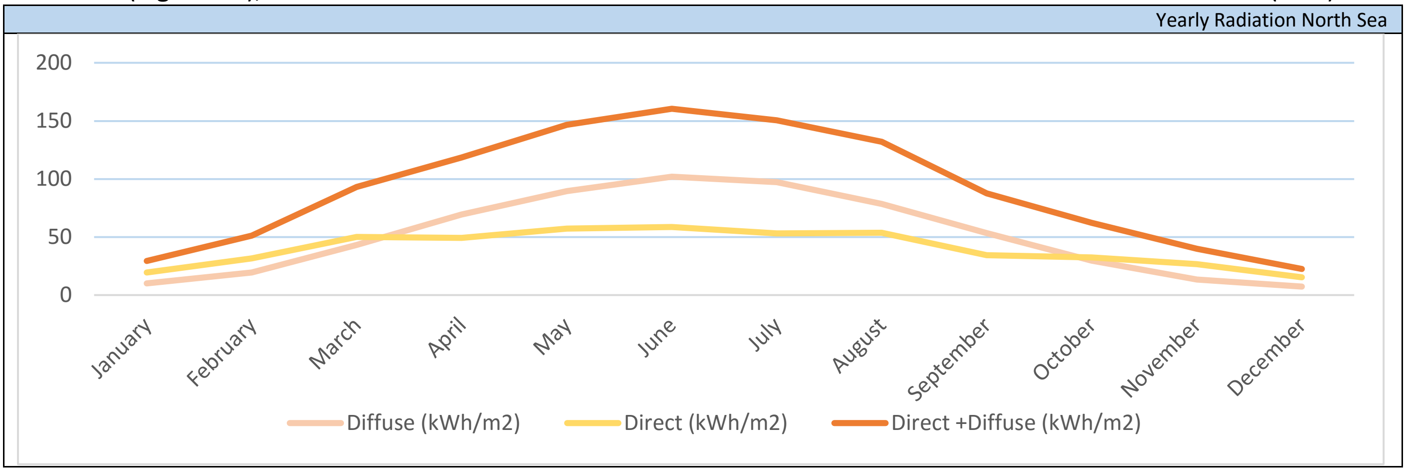


Figure 13: Solar Radiation in the North Sea(Source; author)

Other data, like temperature, humidity and cloud coverage was available from the stations. This hourly data makes it possible to see the energy-use per hour or per day. An overview of this data can be viewed in the tables below.

This data is collected in a so-called EPW-file. A weather data file which works together with EnergyPlus calculations. The following part will discuss the energy use aboard the offshore accommodation.

	Yearly Data Used From North Sea
Average Outside Dry-Bulb Temperature (°C)	8.45
Average Outside Dew-Point Temperature (°C)	5.15
Average Relative Humidity (%)	79.9
Average Wind Speed (m/s)	6.85
Average Wind Direction (°)	198.2
Solar Altitude (°)	11° (winter) 58° (summer)
Solar Azimuth (°)	135° - 225° (winter) 42° – 318° (summer)
Average Atmospheric Pressure (Pa)*10^3	101241
Yearly Direct Normal Solar (kWh)	481
Yearly Diffuse Hoizontal Solar (kWh)	612

	Yearly Data Used From Gulf Of Mexico
Average Outside Dry-Bulb Temperature (°C)	24.98
Average Outside Dew-Point Temperature (°C)	18.06
Average Relative Humidity (%)	65.37
Average Wind Speed (m/s)	3.35
Average Wind Direction (°)	143.78
Solar Altitude (°)	41° (winter) 88° (summer)
Solar Azimuth (°)	115° - 245° (winter) 62° – 298° (summer)
Average Atmospheric Pressure (Pa)*10^3	101668
Yearly Direct Normal Solar (kWh)	1444
YearlyDiffuse Hoizontal Solar (kWh)	676

Total Energy Use

The total energy use is calculated using model calculations with the program DesignBuilder version 4.6.0.015. DesignBuilder uses EnergyPlus as a calculation engine. EnergyPlus is a calculation method widely used by engineers, architects and researchers to study the energy consumption of whole buildings. (EERE, 2016).

Designbuilder lets you model HVAC, daylighting, airflow, cost, energy & carbon. And makes it possible to optimize any of these to meet our design goals and maximize the benefits. (DesignBuilder, 2015) When going through the simulations and its effect of changing parameters, an impression can be made and used for coming up with specific design goals. DesignBuilder works by different parameters, which will be applied on a basic layout of the building.

Yearly Energy Use in the North Sea

Bases on the simulations, the following conclusions can be made; The total energy-use within a 37-man offshore accommodation within the North Sea is about *998 MWh (Figure 14 & 15)*. With most energy going to the Interior Equipment (350 MWh), with following the Heating system (343 MWh). Since the outside temperature in the North Sea is on average well below the aimed indoor temperature, heating energy is high and cooling is almost non-existent with just 0.65% of the total use.

The annual energy use (kWh) aboard offshore accommodation is summarized in the tables below;

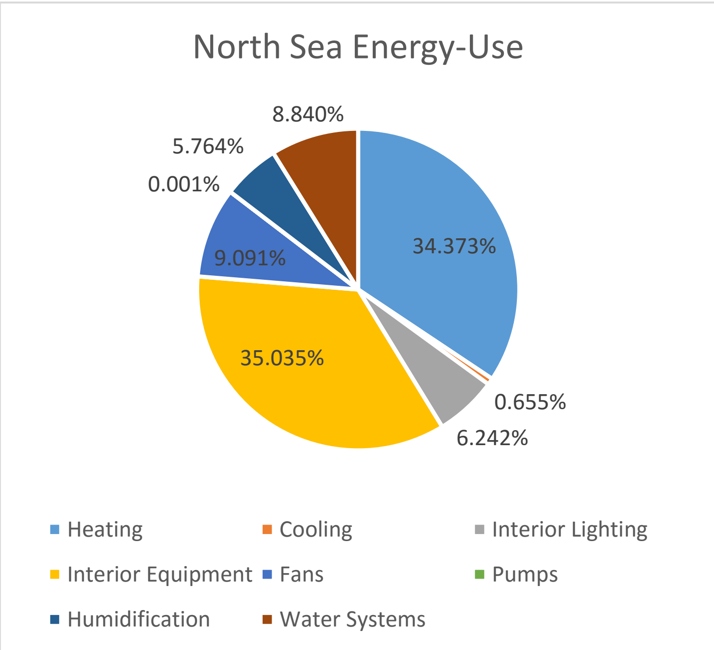


Figure 14: North Sea Energy Use (Source; author)

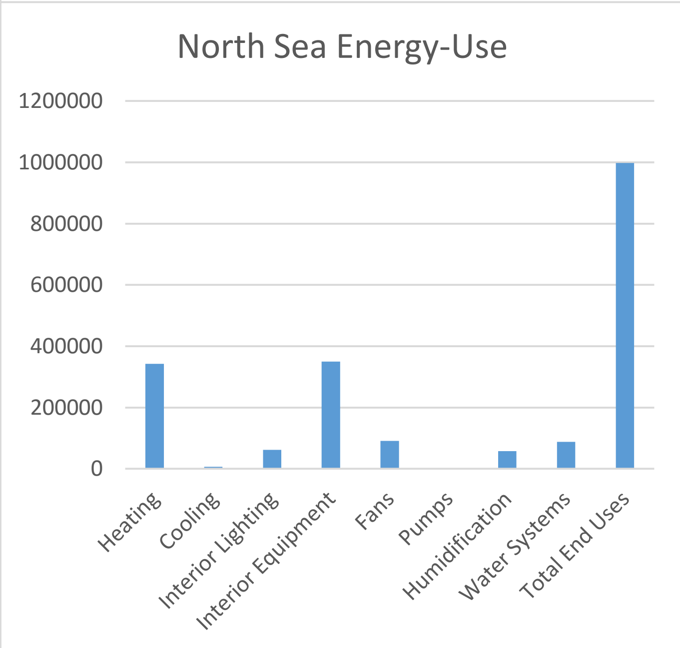


Figure 15: North Sea Energy Use (Source; author)

The energy use aboard differs per season, so DesignBuilder can calculate next to annual use, also the whole summer/winter and the energy-use for a typical summer week, as well for a typical winter week. Because some summers can have outliers in their temperature, for example when a heat wave is present, DesignBuilder also considers a Design Summer/Winter week. This is the week in which the highest temperature is measured in summer or lowest temperature is measured in winter.

Yearly Energy Use in the Gulf of Mexico

In contrast with the North Sea Energy Use, the Gulf of Mexico, with a total use of *822 MWh (Figure 16 & 17)* over a year, the second-most energy use is with an almost 28.15% of the total the cooling system of the HVAC. The interior equipment uses the same amount of energy as in the North Sea, which is therefor a lot more percentage of the total. Shown below;

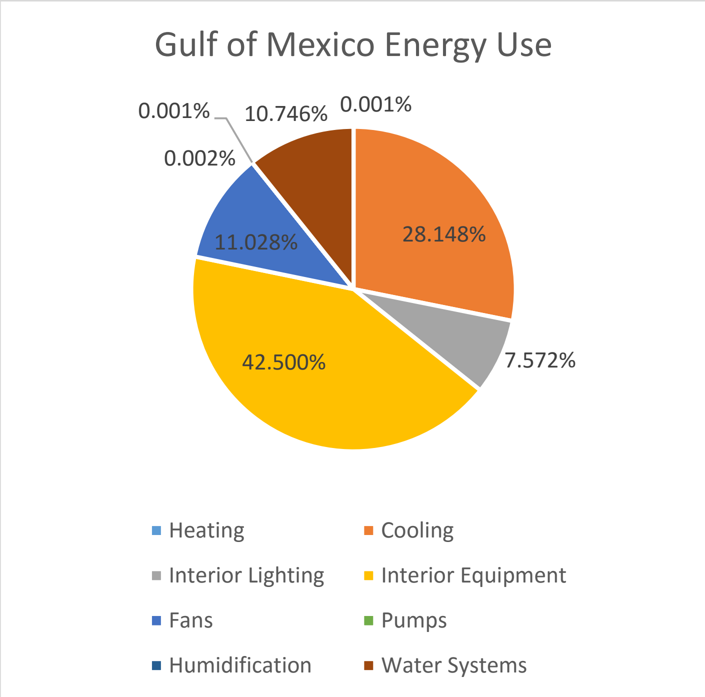


Figure 16: Gulf of Mexico Energy Use (Source; author)

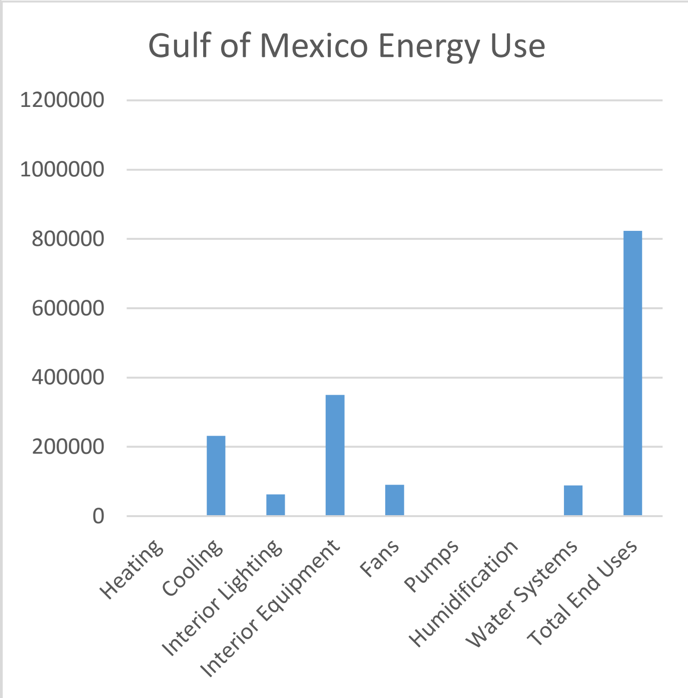


Figure 17: Gulf of Mexico Energy Use (Source; author)

Heat Loss/Gain Through External Walls at North Sea

In EnergyPlus, the heat loss and gain through walls is determined as Opaque Surface Heat Addition/Removal for every zone. DesignBuilder calculates this heat loss/gain by adding and subtracting all the other heat gains and removals. The resulted amount is then assumed to have been gained or lost through the external walls.
The heat loss through the external façade in the North Sea can be seen in the graph below in figure 18; There is an amount of 25.3 MWh lost through the façade over the whole year. With just a really small yearly addition, this addition occurs during the hot summer days.

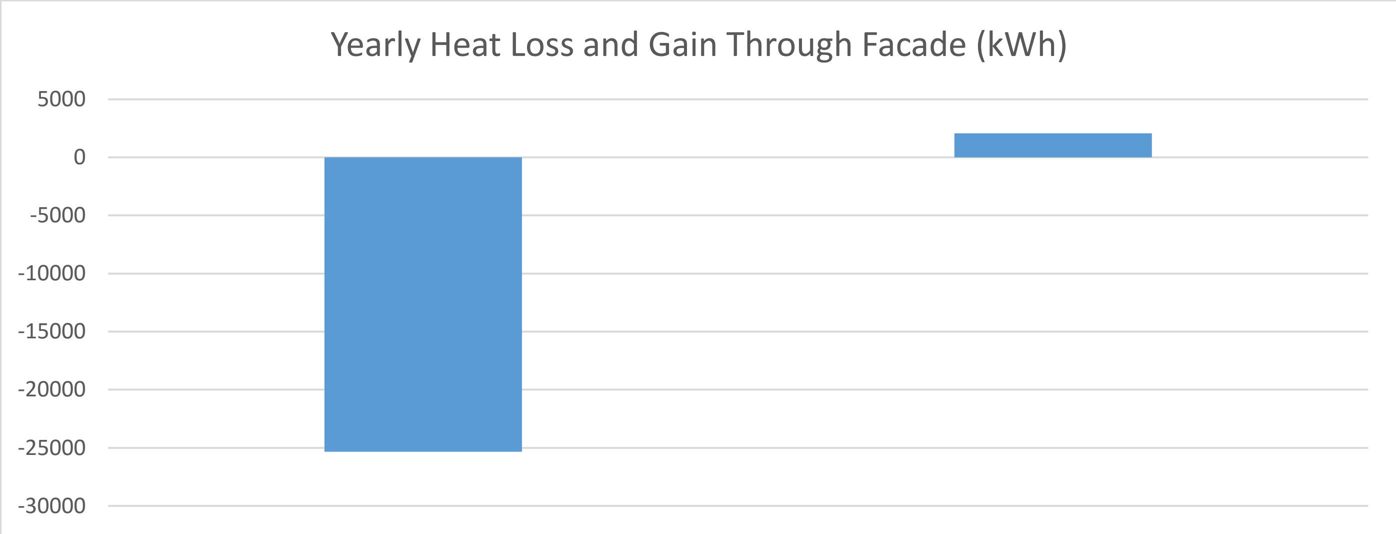


Figure 18: Yearly Heat Loss Through Walls (Source; author)

Heat Loss/Gain Through External Walls at the Gulf of Mexico

The heat loss through the external façade in the Gulf of Mexico is less than in the North Sea, this has everything to do with the temperature difference and solar radiation in this climate. There is therefore a higher addition because of the heating of the external walls. However, the loss is still significant with 18.3 MWh (Figure 19).

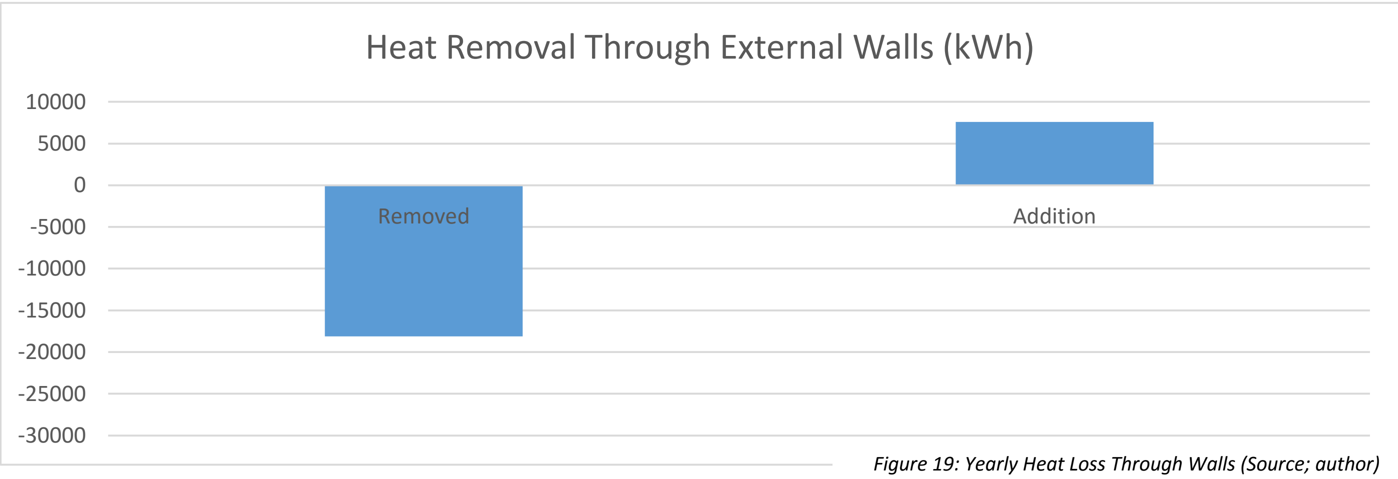


Figure 19: Yearly Heat Loss Through Walls (Source; author)

The energy-use aboard the offshore accommodation is resulted from many different factors, where the layout of the building, the built-up of building elements but also the equipment used and the amount of people present greatly influence the total energy use. The focus of this research is to reduce the energy loss, which means the heat removal through the external walls, but also added unwanted energy through the wall. It is important to reduce the heat loss through walls in areas where the heating is the highest (North Sea). And to reduce the addition in areas where the cooling is the highest (North Sea). According to Finite Element calculations carried out at Keppel Verolme, the cold bridges add an additional 10% heat loss through the steel offshore accommodation walls at the Gulf of Mexico and the North Sea. This will be added onto the Heating/Cooling energy costs in a later stage.

4 Energy-Efficient Strategies

4.1 Energy Efficient Strategies

The focus of this chapter will be on *different sustainable solutions in onshore buildings regarding the façade*. First a few important definitions regarding sustainability in buildings will be explained, after which that a deeper look will be taken into the concept of the PassivHaus. Then several strategies used in the PassivHaus concept will be explained; the implementation of PV – panels, the use of different shading devices and applying superinsulation.

In recent years, the architecture industry focused more and more on the sustainable aspects of building, also referred to as 'green building' or 'green architecture'. Green architecture is the theory behind buildings which are designed according to environmentally friendly principles. These principles are minimizing the number of resources consumed in the construction, operation and use as well as reducing the negative effect on the environment through emission, waste and pollution. (Ragheb, 2015) Considering the focus of the research lies within the reducing the emissions of an offshore accommodation, applying Green Architecture concepts in this industry could prove successful.

There are quite some concepts which try to improve the share of green architecture in the housing industry, for example the many home energy ratings, low energy-building techniques and different building standards. One of the low energy housing standards is the PassivHaus, a standard which has been applied to 25000 houses up to August 2010. In order to see what techniques are currently used within green architecture, we will take a more detailed look into the concept of PassivHaus.

PassivHaus

PassivHaus refers to a rigorous, voluntary standard for energy efficiency in a building, reducing its ecological footprint. (Zeller, 2010) This standard originated in May 1988 and resulted in ultra-low energy buildings. That require little energy for space heating and cooling. (Grondahl & Gates, 2010). Passive houses should fulfill the following requirements (Cepheus, 2015):

- It should be designed for a peak heating and cooling demand of not more than 15 kWh/m^2 per year in heating and cooling energy OR be designed with a peak heat load of 10 W/m^2.
- Total primary energy (source energy for electricity, etc.) consumption. (primary energy for heating, hot water and electricity) must not be more than 120 kWh/m^2 per year.
- The building must not leak more air than 0.6 times the house volume per hour at 50 Pa.
- To achieve these lower heat energy consumption, there are often several specifically implemented techniques and technologies used in the building design. These can be categorized in passive solar design, superinsulation, advanced window technology, airtightness, ventilation, space heating, lighting and electrical appliances.

The following definitions are often applied within the framework of green architecture, in relation to the reducing of output

R-value

When working with energy losses and gains through facades, one of the important things to consider are the R-value and the U-value. The R-value, is also called the thermal resistance or the insulating capability in m^2 * K/W. This indicates the resistance to heat flow. A material with a high R-value is more effective at insulating than a material with a low R-value (Department of Energy , 2015). Below some R-values are given for a specific material.

U-value

The U-value is internationally used, and represents the opposite of thermal resistance. The U-value shows how big the heat transfer is through a construction with a temperature difference of 1 degree Celsius. The thermal transfer density over a construction with a temperature difference can be calculated with:

$$Q = U * \Delta T \ [W/m^2]$$

This means that the lower the U-value is, the less heat it transfers, the better it insulates. According to Jellema, the U-value of single glass (4 mm) is around 5,7 w/m^{2}K. And the U-value of an isolated cavity wall is 0,6 w/m^{2}K. (Zeegers, 2006) The U-value of glass often includes the window frame, and represents an average U-value. However, center-of-glass U-value represents the U-value of only glass, often shown as U_g-value. Currently there is sustainable glass with the U-value of 0.4. The U-value can be derived from the R-Value by:

$$U = 1 / R$$

Material	R-Value per inch (m² * K/W)
Vacuum Insulated Panel	5.28-8.8
Silica Aero Gel	1.76
Brick	0.030

Advanced Window Technology

Windows with U-values of 0.85 to 0.70 W/m^{2}k are not exceptional in use in passive houses. These are often triple-pane insulated glazing with a good solar heat gain coefficient, low emissivity coatings and gas filled inter-pane voids. The frames are often thermally broken.

Ventilation

When possible, a natural ventilation is designed to lower the energy costs for ventilating the building. This can be done with either stack or crossed ventilation. When the design doesn't allow natural ventilation, a heat recovery ventilation system is applied. These often have a recovery rate of 80%.
Space heating in passive houses is often done by using their intrinsic heat. This is produced by internal sources, like lighting, electric devices and body heat.
Passive and active daylighting is implemented to reduce energy consumption, when these strategies are not possible, mechanical lighting is applied. However, this mechanical lighting will be as energy efficient as possible.

Peak Heating load

The peak heating load represents the amount of heat lost to the outdoor environment at design outdoor and indoor conditions, which must be made up by the HVAC system to maintain occupant comfort. The total estimated heat loss is a combination of sensible heat loss through conduction, infiltration, and ventilation loads. (Burdick, 2011, p. 7)

Peak Cooling Load

Peak cooling loads represent the amount of heat gained by the house from the outdoor environment at design conditions, which must be removed by the HVAC system to maintain occupant comfort. Cooling loads are made up of the sensible and latent heat gains. The mechanisms of heat gain are conduction infiltration, ventilation, and radiation. (Burdick, 2011, p. 8)

Acoustic Insulation

Acoustic insulations is also called soundproofing and are any means of reducing the sound pressure with respect to a specified sound receptor. There are several basic approaches to reducing sound: increasing the distance between the source and receiver, using noise barrier to reflect or absorb the energy of the sound waves, using damping structures such as sound baffles, or using active anti-noise sound generators (Wikipedia, 2016).

Thermal Comfort

When designing sustainable architecture, there are certain standards related to the energy which have to be kept in mind (Figure 20). One of these is the standard of thermal comfort. The more constant the indoor temperature is, the better het thermal comfort. Thermal comfort is the condition of the mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation though the ASHRAE standards (ASHRAE, 2013). The thermal comfort is the main reason for the use of an HVAC system. Which goal is to maintain the Ashrae standards for thermal comfort for the occupants of buildings. Changes in the buildings HVAC design can be of great positive influence on its sustainability, as long as the Ashrae standards have been respected.

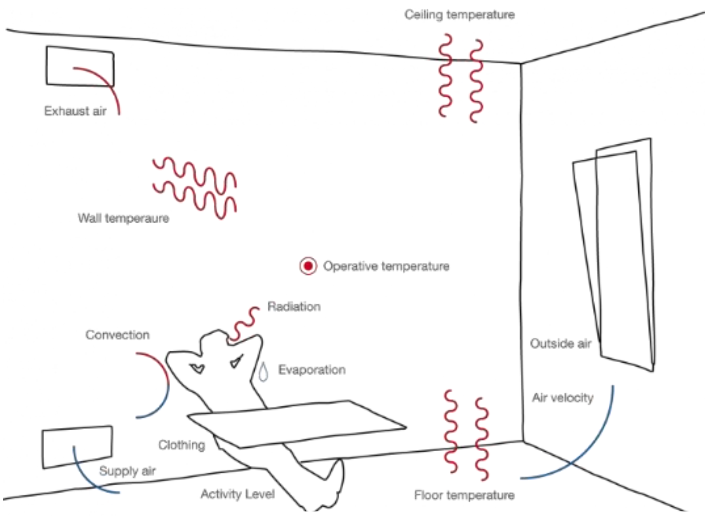


Figure 20: Thermal Comfort (Source; Hausladen, 2010)

Thermal Bridge

A thermal bridge (Figure 21) is an area of an object which has a significantly higher heat transfer than the surrounding materials. This causes a thermal leakage overall in the structure. Thermal bridges occur in three ways; namely holes in the insulated layer, parts with higher thermal conductivity than its surroundings and penetrations in the thermal envelope (Gorse, 2012). It is of high importance that unwanted thermal bridges are avoided as much as possible. Unwanted thermal energy could be gained through the bridges, but more often a thermal bridge is a heat sink for the indoor thermal energy. Needing higher energy costs to compensate for the lost energy through the walls. The picture to the right shows an thermal bridge at the crossing of an balcony and wall.

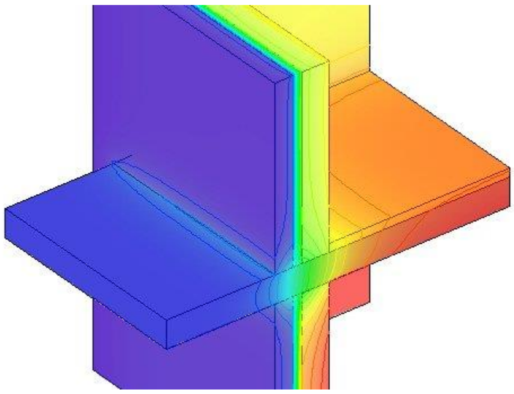


Figure 21: Coldbridges (Source; Lundberg,2015)

Airtight Design

For years, energy-efficiency specialist have advised to design airtight with a good ventilation system. This is in great contrast with older buildings, which are leaking air in every corner of the house. However, because of this high leakage, the indoor comfort is not easily controlled and thus costs a lot more energy than in air tight designs. Next to these advantages, airtight design has a high influence on many factors of indoor comfort. When designing the envelope of a building air tight, it keeps the humidity outside of the envelope, reduces the sound pollution from outside and avoids the leaking of heat or penetration of cold/warm air from outside (Figure 22).

Figure 22: Sustainable Solutions (Source; HammerAndHand)

4.2 Thermal Insulation

Airtightness is often used with two other applications in order to reduce the energy-use. These are the extreme thermal insulation and the reduction of thermal bridges, as can be seen in figure 23. Thermal Insulation is the reduction of heat transfer between objects with the use of specific methods, processes, object shapes and materials.
The use of 'super' insulation is often used within the PassivHaus concept. In terms of using a wide range of materials with really high R-Values (low U – Values). These materials often are in the range of 0.10 to 0.15 W/m^2. When applying the superinsulation, extra attention is given to eliminating thermal bridges.

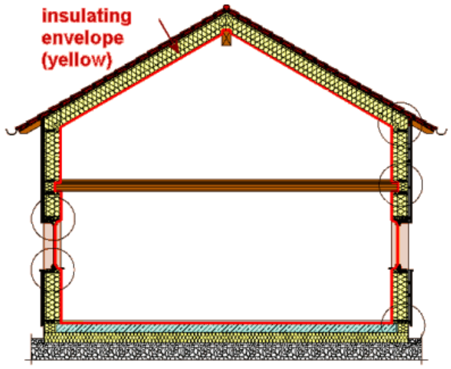


Fig 23: Superinsulation (Feist, 2016)

Superinsulation is a strategy applied to passive houses, there is no standard set of requirements, however, it often includes very high levels of insulation (typically with R-values of 40 and U-values of 0.15 W/(m^{2}K). It is increasingly desirable to refurbish superinsulation to an existing house or building, by adding layers of continuous rigid exterior insulation (Ueno, 2010).
Since airtightness and reducing heat loss and gain by applying high levels of insulation are the main aspects of superinsulation. For best insulation results the insulation has been detailed to ensure continuity where walls meet roofs, foundations and other walls. This improves airtightness around doors and windows in the façade but also a lower amount of windows would improve the effectiveness of the superinsulation. This makes it an interesting approach for offshore accommodation, where the window to wall ratio does not exceed 4 percent (Otheguy, 2014).

It is often said that superinsulation does not pay back, but Feist shows otherwise. On his website dedicated to passive housing, he uses with a simple trick that in an average house with an external wall surface of 100 m^2, could save as much as *482 Euros* when the insulation is raised from U = 1.25 W/m^{2}K to 0.125 W/m^{2}K.

This amount could even raise since it is probable that the energy price will be even higher in the future, the insulation lasts 40 years on average and the implementation of superinsulation is often subsidized by the government. (Feist, 2016)

The material choice for insulation is very broad, but when considering material for superinsulation there are a few factors affecting the consideration of materials used for insulation. These are thermal conductivity, moisture sensitiveness, compressive strength, ease of installation, durability, ease of replacement, cost effectiveness, toxicity, flammability & environmental impact (Wikipedia, 2016).
In the table below some materials are given with their corresponding U-value and thickness.

Material	Heat Conductivity (W/m*K)	Thickness (m) Needed to meet U = 0.13 W/m^{2}K.
Concrete B50	2.100	15.80
Solid Brick	0.800	6.02
Hollow Brick	0.400	3.01
Wood	0.130	0.98
Porous Bricks	0.110	0.83
Straw	0.055	0.410
Typical Insulation Material	0.040	0.300
Highly Insulating Material	0.025	0.188
Nano-porous 'super-insulation'	0.015	0.113
Vacuum Insulation (silica)	0.008	0.060
Vacuum Insulation (High Vacuum)	0.002	0.015

4.3 Solar Power

A solar panel converts energy from light, directly into electricity. This makes it a safe and easy way to harvest energy on offshore accommodation.
The solar cell does this through a physical and chemical process. In this process photons of sunlight hit the solar panel and are absorbed by semiconducting materials. After the absorption, electrons and protons are excited from their atom, and these travel towards an electrode in the solar cell. This flow of electrons through the material is captured. When enough of solar panels are available, this can be converted into a usable DC current. (Boer, 2016)

Building Integrated PV-Cells or Lay-on PV-Cells

Building Integrated PV (BIPV) is an PV-cell which is integrated in the building elements (Figure 24). This is in contrast with the lay-on or additive PV-cell. These Lay-on or additive PV cells, are stand alone and are most famously used for their rooftop implementations. However, the BIPV system is a lot less common, it generated just 1% of the total energy solar energy generation in Germany in 2004. The reason BIPV is used is mainly because it can enhance and satisfy a building image. The aim for integrating PV-cells in offshore accommodation is to have an easily installable system, which must withstand the forces it will encounter at the ocean. This is why it seems necessary for these cells to be at least partially integrated into a façade element, with the possibility of replacing the cell only.

Fig 24: Building Integrated PV-Cells (Source: Wikipedia)

Monocrystalline Silicon

Like the name of monocrystalline, a PV-cell made from monocrystalline silicon is manufactured from a single crystal ingot of high purity. The ingot is a cylinder of silicon and have a specific diameter of 4 to 5 inches, and thus will the cells derived from the ingot will not exceed this size. However, the original shape of the ingot cylinder will often not be found back in the PV-cell, since the edges will be cut away for more efficient packaging (Figure 25).

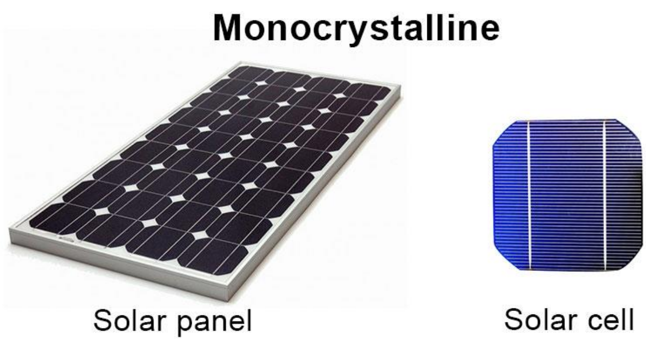


Figure 25: Monocrystalline panel (Source: Bouweninsu)

Polycrystalline Silicon

Polycrystalline Silicon cells are slightly less expensive then monocrystalline silicon. This is because the producing of the silicon material is melted into a cuboid form, after which is solidifies. When solidifying, large crystals are formed. The silicon ingot is basically a concentrated version of these large crystals. Which is then sliced into thin layers just like monocrystalline silicon. However, because of the more crystals, the polycrystalline silicon panels are a bit less efficient. Since it is possible to make a bit larger cells (8 inch) a possibility is that the overall module efficiency of a polycrystalline silicon could be more efficient than a monocrystalline module (Figure 26).

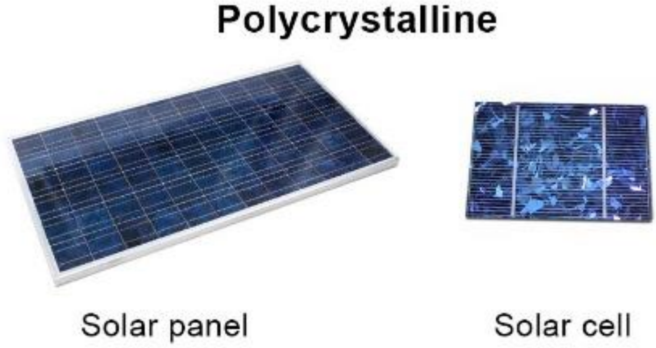


Figure 26: Polycrystalline panel (Source: Bouweninsu)

Thin Film Technologies

Another possible solar cell product are based on thin film technologies, in this case an extremely thin silicon layer is placed onto a piece of glass, or on the backside of the module. An advantage when making these PV-panels, is that not much material overall is used, and the temperature needed to manufacture these panels are just between 200 and 600 degrees. Especially compared to the crystalline silicon cells which are produced at a temperature of 1500 degrees this is an enormous saving on energy (Figure 27).

Figure 27: Thin Film Application in OpTic Building (source; OpTic)

High Performance PV Cells

Considering the cost benefits, the efficiency of a solar panel is the most valuable measure of its performance to cost ratio, it is known that the energy reaching the surface is about 1 kW/m^2. This way the efficiency can be easily determined. The last years there have been more and more implementations (Figure 28) which caused the research into solar panels to rise, this directly translated to higher and higher possible efficiency of solar panels.
However, the commercial efficiency lags behind research development. Solar panels for commercial use now reach the efficiency of 21.5 percent. (SunPower, 2016)

Fig 28: Solar Panels on Façade (Inhabitat, 2016)

Thermal Collectors

A solar thermal collector is a form of active solar heating. This is done with water or another heat transfer fluid which is circulated through a duct and heated from direct solar light in the solar collector panel. This kind of active solar heating could capture the amount of energy per square meter ranging from 300 to 800 $kWh/m^2/yr$. The water from the solar collector is used directly for tap water or space conditioning when needed.

There are a few different kinds of solar thermal collectors, but they can be divided into two main groups: Air-based active-solar heating and Liquid based solar heating.
Air based systems use the air as the working medium in transferring and absorbing the solar energy. These work together with a heat recovery ventilator or heat pump. Advantages of these systems, with offshore design in mind, that these cannot freeze, or that small leaks cause significant problems.

The liquid based system work with water or other solar head absorbing fluids. These liquids are flowing through the high pressure piping network controlled by a circulating pump. Once the liquid has passed through the collector and it has been heated, it runs into a storage tank or a heat exchanger for immediate use (Lopez, Solar Thermal Collector in Facades, 2011).

4.4 Shading on Façade

When focusing on shading in a façade, it is important to consider that the building windows should be shaded from the sun as many hours as possible. However, a balance should be achieved, in order to avoid that necessary daylight is not compromised. Shading is most important at facades with a lot of glass, like high-rise buildings and office buildings.
The shading often differs in every direction of the façade, the north façade is basically never in sun and therefore doesn't need to be shaded, when the south façade receives the most solar hours. The east and west facades receive also solar heat, but under a different (lower) angle than the south façade. The south facing façade can receive solar shading by using multiple horizontal shading elements, also called the brise-soleil (Figure 29).

A fixed brise-soleil does not perform as well on the east and west façade. Since sunlight will just pass under the horizontal shading (Colt International Ltd., 2016). In this case a movable solar shading should be more effective.

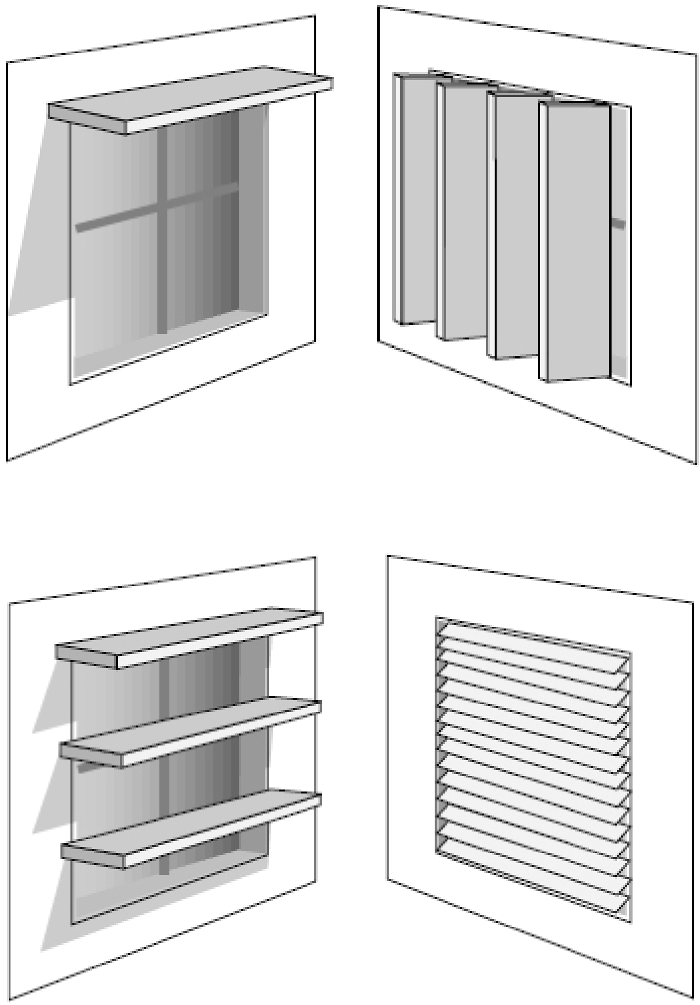


Fig 29: Different Kind of Solar Shading (Source; Lopez, Solar Thermal Collector in Facades, 2011)

In the above chapter several sustainable strategies are discussed, which will be the starting point for the following concept designs. The passive house concept is very interesting for the offshore accommodation and aspects of this concept will be tried to be implemented in the design. One of these aspects is the use of superinsulation. Which appears to be a promising technique. This could probably be combined with several other techniques in order to lower the energy use aboard. The cool roof could be implemented on top of the accommodation in order to reduce the heat gain in summers, and could maybe even be applied to the façade.

5 Concept Development

5.1 Application of PV-Panels

PV cells have been implemented in the marine industry with for example the newly built ship, the Texelstroom (Figure 30), a ship between the touristic Dutch island 'Texel' and the city of Den Helder. The ship has 700 square meters of solar panels and produces enough for 40 – 50 % of the hotel-load. The hotel load is all energy used aboard without the propulsion energy. It can deliver to 150 kWh. (Maritime Battery Forum, n.d.)

Figure 30: Texelstroom (Source; C-job)

Another example is the Aquarius ME (Figure 31), developed in order to reduce the fuel costs aboard a variety of ships and vessels. It is an system of rigid sails, solar panels, energy storage modules and marine computers. The PV-panels are integrated into the sails and can be pointed towards the sun.

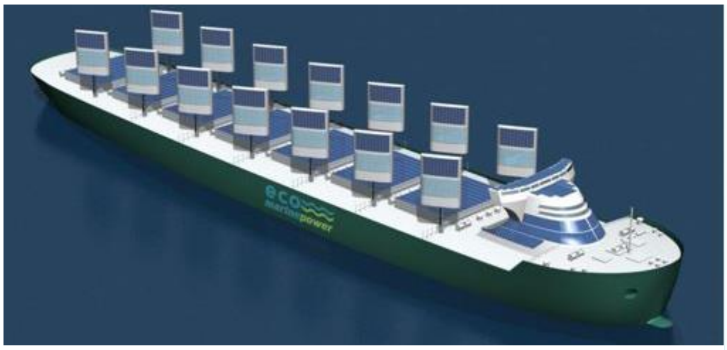


Figure 31: Solar Sails (Source; Ecomarinepower)

There are two separate fixations of the PV cells aboard the offshore accommodation, one is fixed, or always angled at in one direction, while the other one is able to adapt to the solar inclination at that specific time.

Tilt and Orientation

When a solar panel can be angled in direction of the sun, it produces the most energy, however these systems are often more expensive and less reliable, since a tracking system and support should be available. When considering the tilt, the table below provides the optimal PV-panel inclination for the North Sea and the Gulf of Mexico. These were derived from the Solar-Position-Calculator (sun position calculator, n.d.). To the right you can see the sun path in the North Sea (Figure 32).

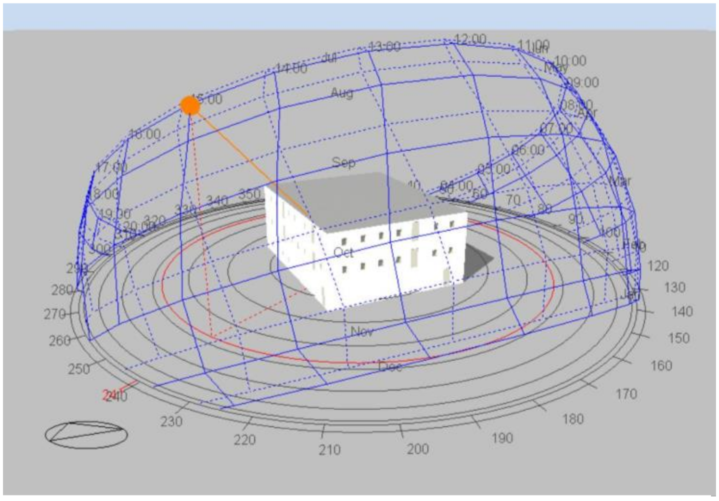


Figure 32: DesignBuilder Solar Orientation (Source; author)

		Solar Angle
	North Sea	**Gulf of Mexico**
Longitude/Latitude	3.3240444 / 56.1457403	-89.7191684 / 25.7507332
December 21st 12:00 pm	**10.5**	**88.34**
Optimal PV Angle	89.5	1.66
March 21st 12:00 pm	**33.59**	**65.24**
Optimal PV Angle	56.59	24.75
June 21st 12:00 pm	**57.39**	**41.53**
Optimal PV Angle	32.41	48.17
September 21st 12:00 pm	**33.66**	**65.19**
Optimal PV Angle	56.34	24.81

In the table above, the optimal angles are broken down for each location. This is an interesting concept which could reduce the amount of energy use aboard offshore accommodation, especially since the accommodation is an stationary object in a sea without any shading elements nearby. It could also provide a source of energy in emergencies, since most of the current energy needs to be delivered by suppliers as diesel oil. Currently the expected lifetime of a solar panel is 20 years, which is planned lifetime after accommodation refurbishment, and should be taken into account when considering if the costs are worth the profit.

Location of PV cells

When applying PV-cells, the orientation is one of the most important factors. When applied on the North Side, it is impossible to generate electricity (when located in northern Hemisphere). But also sun locations from west to south to east differ greatly during a day (Figure 33). The offshore accommodation we work with will be located in a specific direction. However, it should be possible to let it face a specific direction. Currently this could cause problems, because the offshore accommodation unit should support an already located drilling rig. There is only one position able for the accommodation block. In this case it could be advisable to design a system which can be easily dismounted and mounted according to its position.

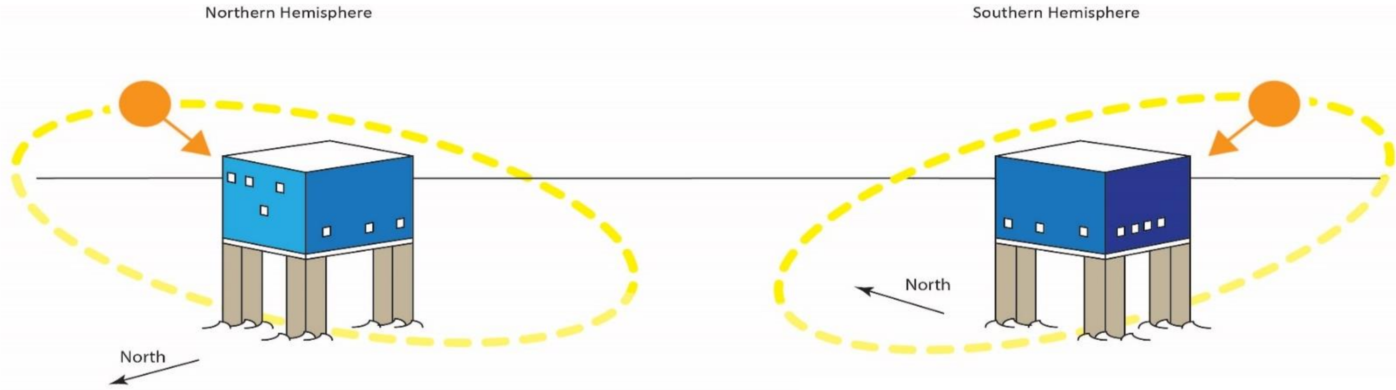


Figure 33: Rotation of offshore installations (Source; author)

Three configurations are interesting for the offshore accommodation, these are the vertical PV-cells, Horizontal PV-Cells and the building integrated PV cells. The horizontal PV-panels are more efficient when placed on the South façade, when the vertical ones are more efficient on the East – West facades of the building.

Optimized PV-panels

When PV-panels are situated as external louvres, if they are horizontal or vertical (Figure 34 & 35), they could serve an additional function as a shading device in tropic climates. This is often used in onshore buildings since it could reduce the cooling loads, as well as providing an extra source of energy. However, in offshore designs, the amount of windows is a lot lower than in onshore architecture, around 4% of the total façade. Louvre systems could be designed to turn automatically, this would complicate the system significantly, since reliability is one of the most important factors aboard the offshore accommodation. And the reliability of a system lowers a lot when using a rotatable system. This is why it is advised to use a fixed system, which is angled towards the sun or perpendicular to the façade.

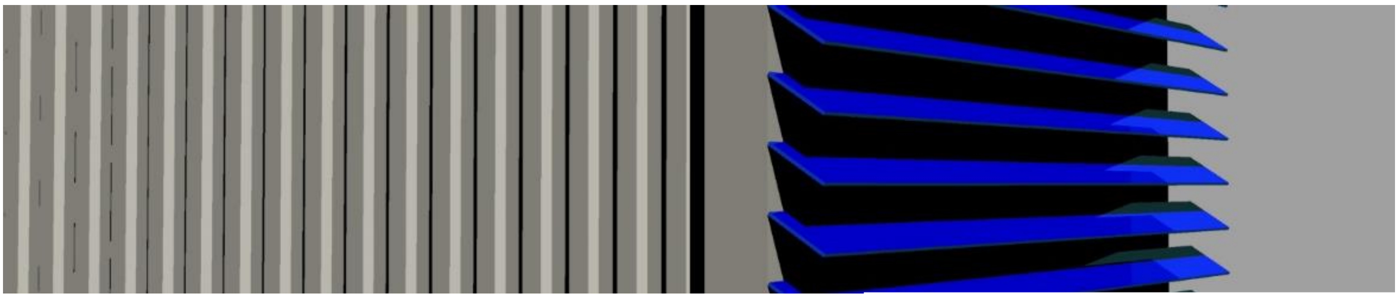


Figure 34: Horizontal Shading (Source; author)

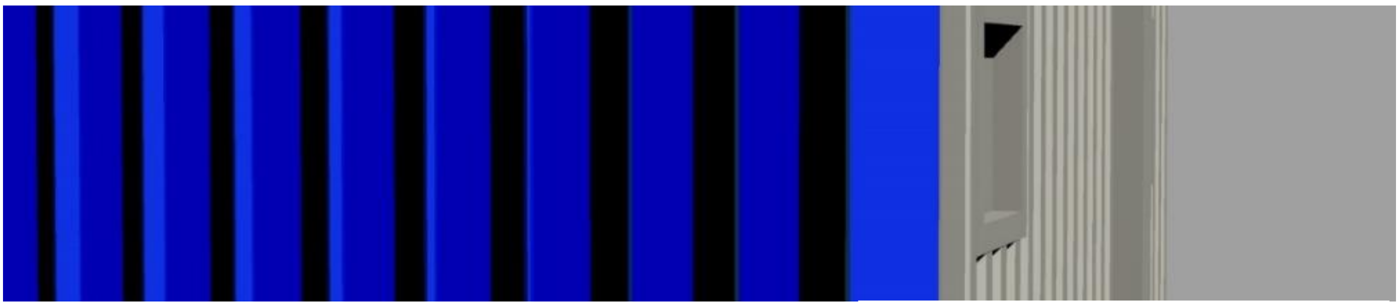


Figure 35: Vertical (Source; author)

Rain Screen Systems

Another implementation of photovoltaic panels in the façade are within a rain screen (Figure 36). A rain screen façade cladding means where the rain and wind barriers are separated by an air-space cavity. The rain screen is attached to vertical rails or fixing brackets, which in turn are attached to outer lying wall, in our case the steel façade. This kind of system is often used for refurbishment of older facades, since applying it is easy and efficient. However often the rain screen is made of aluminum sheets, it can also be used for integrated solar panels. This has a lot of advantages, since major modification of the façade is not necessary.
There are two different kind of rain screen systems, the pressure-equalized rain screen and the drained and back ventilated rain screen. The difference between the two strategies is that the pressure equalized rain screen doesn't allow for a lot of water in between the rain screen cladding and the insulation behind. However, the ventilation behind the rain screen used in with a ventilated rain screen method makes it possible to keep the heat and water out. Therefor this system is further researched.

Another advantage is that cleaning the façade is not necessary, since running down rain water cleans the modules to a degree. However, residue can stay behind based on the local climate, and there for the façade should be cleaned just as much as any other steel façade. In the image below a possible configurations of rain screen implemented PV-panels is modelled. (Simon Roberts, 2003)

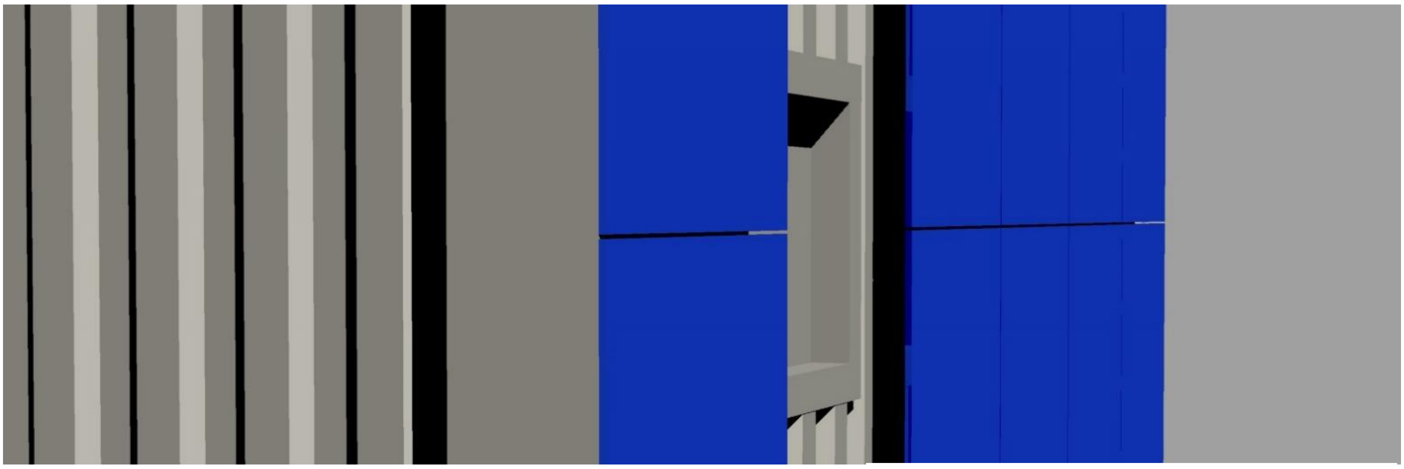


Figure 36: flat plate (Source; author)

5.2 Application of Extra Insulation

Extra insulation could add a lot more to the thermal thickness of the offshore accommodation, as is explained in the previous chapter.
In order to reduce heat-gain and heat loss through the external façade, the possibility of extra insulation should be explored. The fact that the offshore accommodation will be refurbished has a lot of influence on how the insulation will be applied. For example, when applying internal insulation, a lot of work should be done inside the building. Internal elements should be stripped and the current insulation should be taken away. This makes it an expensive operation. Another possibility is adding the insulation on the outside of the façade, where it is easier to apply, but more prone to damage due to external factors (Figure 37). The insulation should thus be protected against any extreme weather, as well as against salt water, fire and blasts.

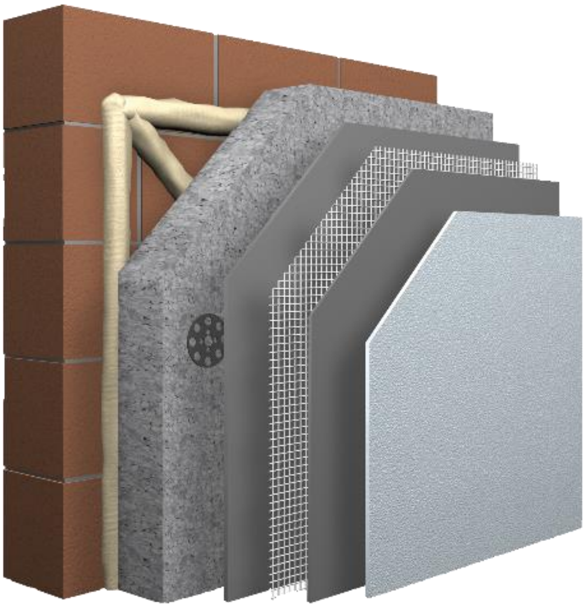


Figure 37: External Insulation (Source; ExternalHomeInsulation.com)

Adding extra insulation

When applying extra insulation, improving the R-value is the main goal. This value influences the thickness and the kind of material, which in turn influences what technique will be applied. The R-value of the whole current offshore accommodation external wall insulation is 2.86. Which will mean that applying an additional layer with an R-value of 2.86 will save as much as 30% of existing heat flow through the façade as was determined at Keppel Verolme.

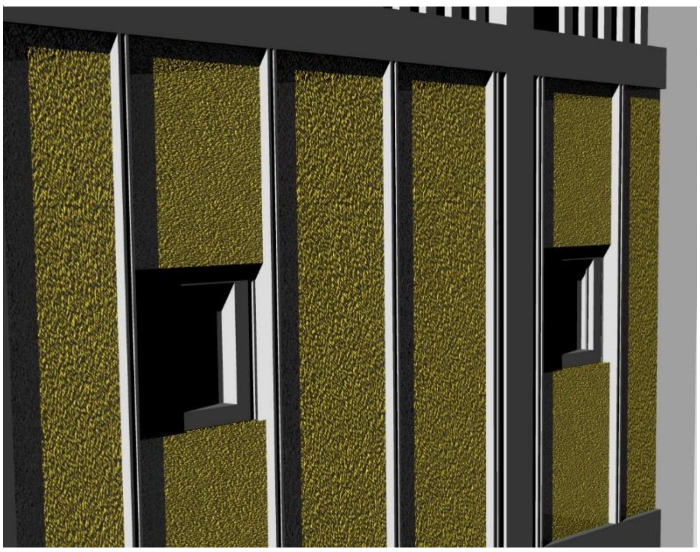


Figure 38: External Façade Cladding (Source; author)

How does it get applied?

Currently added external insulation will be placed onto the existing façade and finished with an additional layer which protect the insulation against water and impact. This additional layers are often made from some concrete solution (Figure 38). One of the most challenging parts of building in offshore, are the extreme weather environments. Wind, waves and water could all damage the existing built up. The salt water is highly damaging and corroding, not only for the insulation, but also for the constructions around the insulation. This could be a problem when applied offshore because of the high humidity, as well as the complexity to repair this part. An onshore solution for this means the water protective layer is applied by adding a watertight flexible sealing over the insulation, and protect this with aluminum rain screen panels (Figure 38). Another possibility is applying rigid panels, which have their protective layers integrated within the panels. These will then be applied onto an construction welded onto the external façade (figure 39).

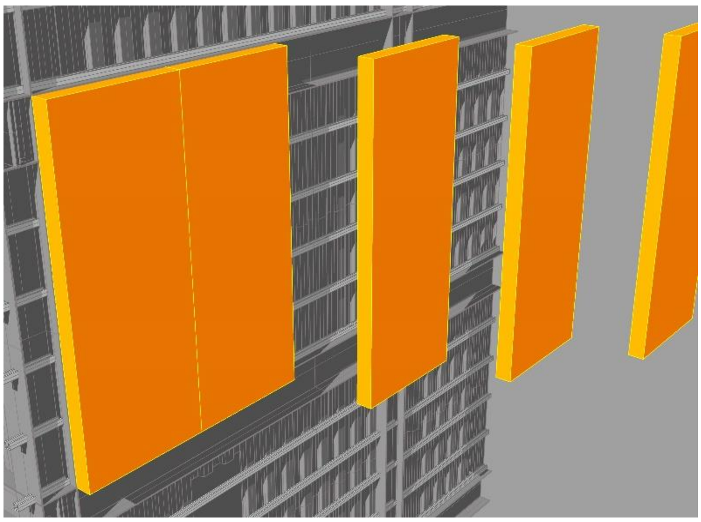


Figure 39: Rigid Insulation Panels (Source; author)

5.3 Application of Local Shading

The solar heat gain is an element which can be used in the advantage and disadvantage of the accommodation block. As mentioned, an offshore accommodation block has way less windows than a comparable onshore building, with only 4% to 5 % of external windows. This low amount of windows causes an already low solar heat gain through the windows, however it is not known what the influence of added solar shading is when applied simultaneously in the North Sea as well as in the Gulf of Mexico.

The effects of the following shading will be researched; The overhang, the overhang combined with side wings and a total façade shading (Figure 40 & 41).

The choice to test the overhang as an shading device instead of lamellae, was made since the lamellae will block natural lighting more. At least with the overhang a certain amount of diffused light will still be able to enter the building while the direct light is unable to.

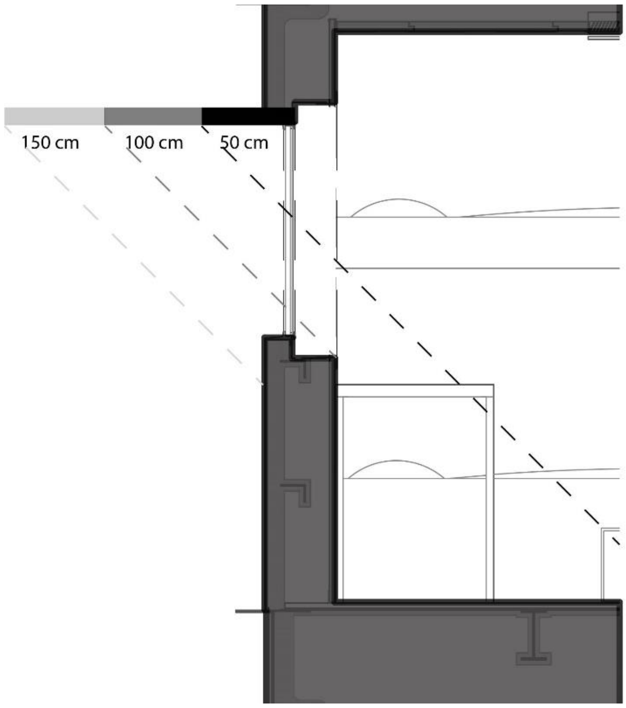


Figure 40: Overhang Concept (Source; author)

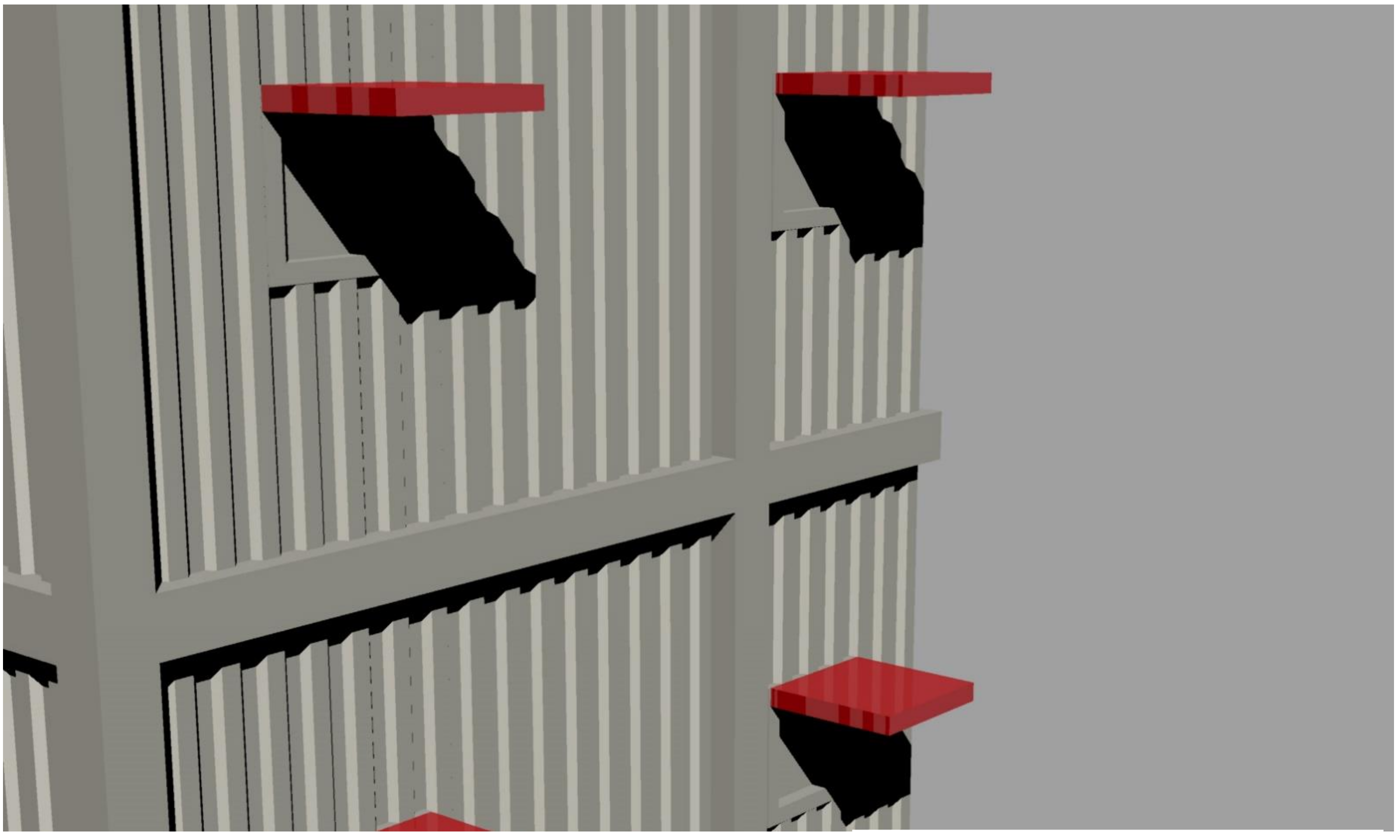


Figure 41: Overhang Concept (Source; author)

The other overhang which will be tested is in combination with sidewings (Figure 42). Offshore accommodations are often mobile and thus one direction of the sun on a façade is not guaranteed. Applying additional side wings could also block direct sunlight from different angles. Direct light reflected from the ocean water towards the windows is very inconsistent and of low strength since water only reflects under really low sun angles, like early morning or late afternoon. But even then the presense of waves reduces the reflected lights, thus the heat gain resulted from these rays are neglectible (Wikipedia - albedo, 2016).

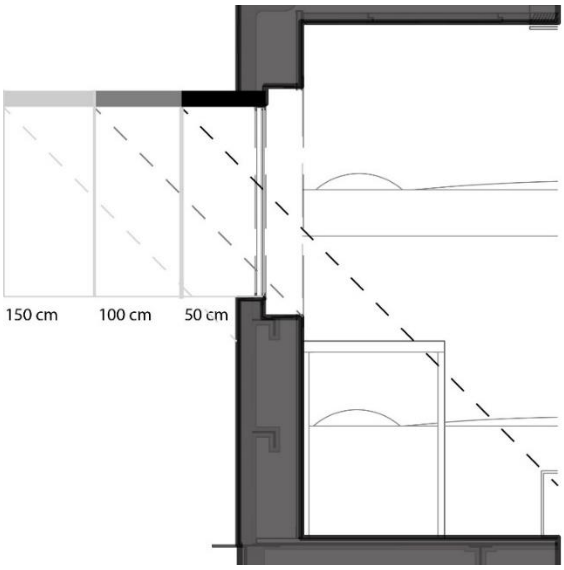


Figure 42: Overhang (Source; author)

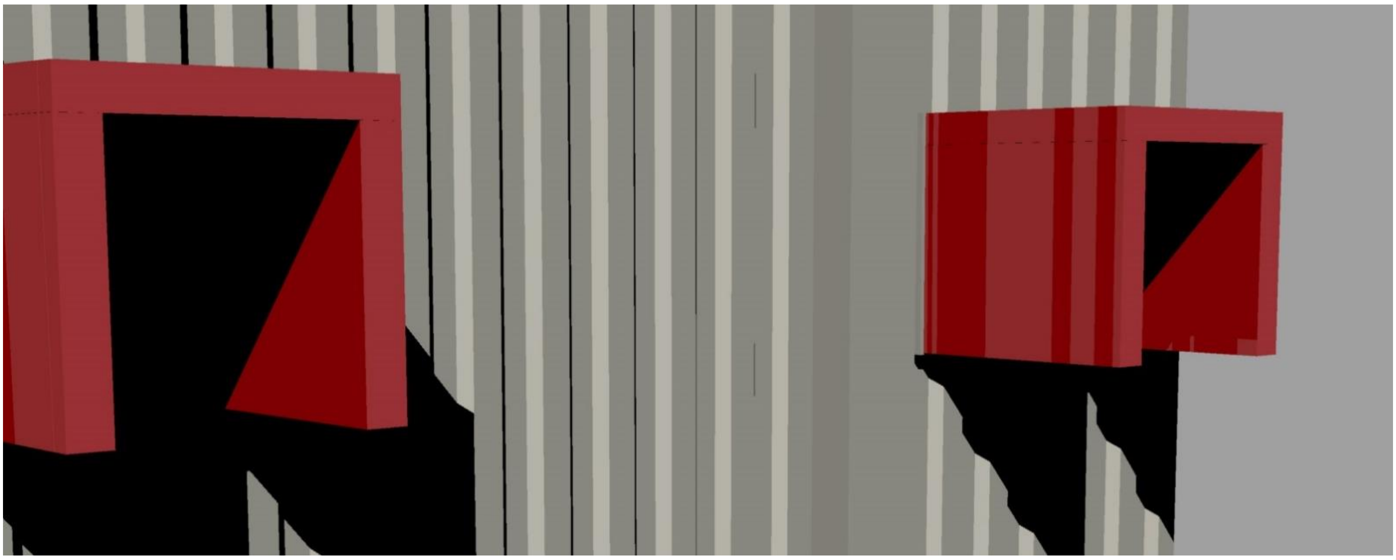


Figure 43: Overhang (Source; author)

The third concept is an total façade shading (Figure 44). The principle of the total façade shading is researching what happens to the total energy use, when the total façade is shaded and thus is also not heated due to solar radiation. This could be done with adding an rain screen onto the conventional façade, with a well naturally ventilated space behind it.

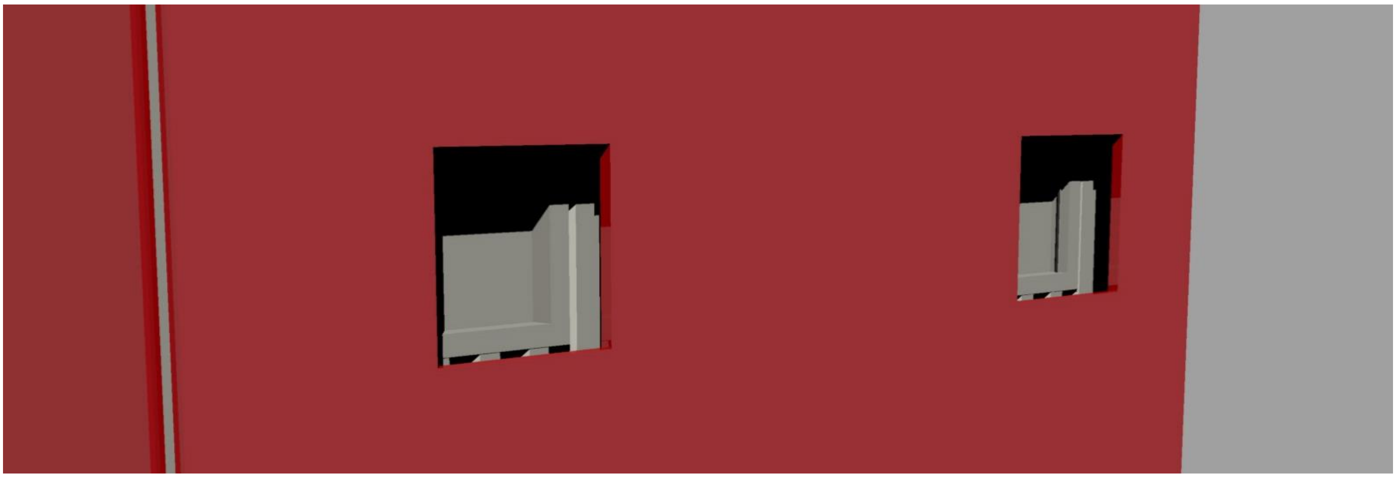


Figure 44: Façade Shading (Source; author)

6 Concept Testing & Results

6.1 Testing PV-panel Application

The assessment of concepts is an essential part of designing a tailored solution for a more energy sufficient offshore accommodation. In order to assess the concepts, different parameters will be applied to the model designed in DesignBuilder. After that the results will be assessed through a decision-matrix. This is a decision making tool, in which the advantages and disadvantages can be put together in order to create a final assessment of the specific concept.

Testing of the PV-panel will be done through a program applied by the European Commission to determine the PV – estimation for a certain orientation and photovoltaic size. The calculator is available on the website of the European union (PVGis, n.d.). It should be noted that this PV Energy Calculator is a mere estimator of possible generated energy. When the possibility of PV-panel use will be further researched, it is advised to contact PV consultants and/or companies.

Specifications

The following specifications are used for both the North Sea and the Gulf of Mexico. The difference between the two locations within these calculations is the direct solar radiation, which are both provided by different databases. The databases provided by the European Union cover the whole of Europe and parts of Africa and Asia. This meant that information about solar radiation in the Gulf of Mexico was non-existent in the used calculator. Therefore, a comparable location was used on the same latitude at the coast of South Morocco (Figure 45).

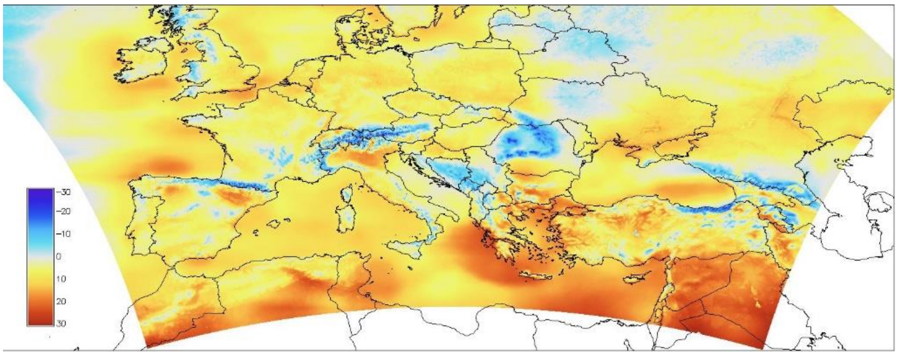


Figure 45: Solar Radiation (Source; switch2solar)

Next to the available database, the generation of the energy is also influence by efficiency of the system, as well as position and orientation of the panel. The estimated system losses are around 14%. However, the estimated losses due to the angular reflection effects differ from each location and orientations, as well as other losses due to temperature and low irradiance. This influences the total system losses, which can be seen in the table below.
The PV-panel which was taken as a benchmark is the Solar Frontier SF170 – S, of which the peak power is determined at 170 Watt (Solar Frontier, n.d.). This Watt Peak is determined after tests in artificial circumstances.

The following data was used to calculate the different kWh generated in the North Sea as well as in the Gulf of Mexico.

	Usable Area	Amount of Panels	Amount of KWp (total)	Free Standing (FS)or building Integrated (BT)	Orientation (degrees)	Slope (degrees)	Available Area used for PV	System Losses North Sea	System Losses Gulf of Mexico
East	156.8 m²	125	21.29298	BT	90	90	100%	25.8 %	28.2 %
South	119.5 m²	95	16.22822	BT	0	90	100%	24.4 %	28.6 %
West	146.6 m²	117	19.91203	BT	-90	90	100%	24.6 %	28.1 %
Roof	320 m²	256	43.45145	BT	0	Optimal (39 degree. North Sea, 25 Gulf of Mexico)	100%	25.1 %	27.3 %

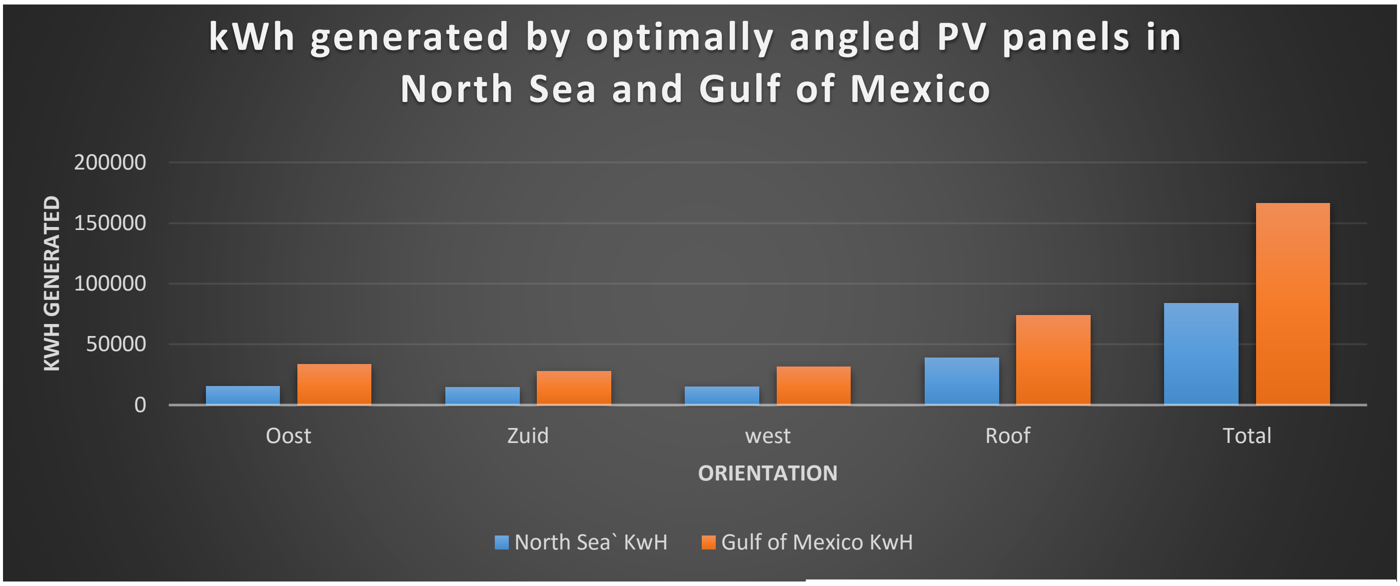


Figure 46: kWh generated by PV-panels (Source; author)

The results of the above data in the North Sea and Gulf of Mexico with optimally angled PV-panels is respectively 84 MWh and 167 MWh (Figure 46).

In the Gulf of Mexico, a total of 118 MWh can be generated through PV panels when these are building integrated, if it covers around 100% of the coverable façade, against 72 MWh in the North Sea under the same circumstances (Figure 47).

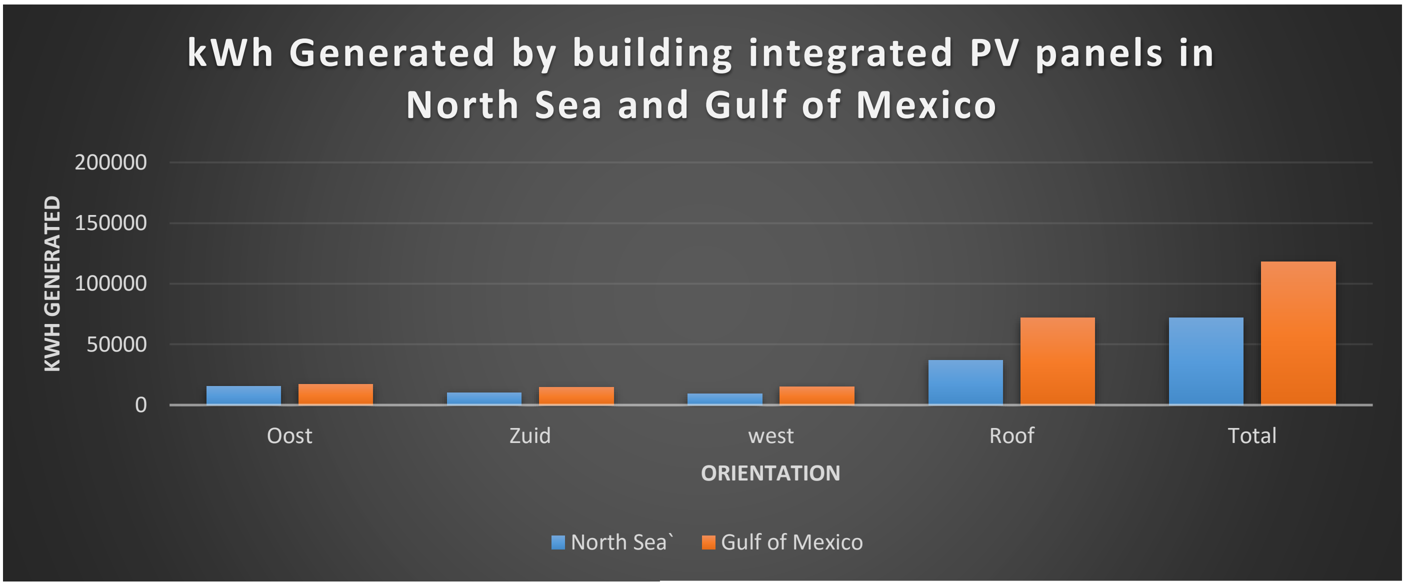


Figure 47: kWh generated by PV-panels (Source; author)

6.2 Testing of Thicker Insulation

By applying thicker insulation to the model in DesignBuilder. The program will be able to simulate the influence of different R-Values of the façade on the Heating and Cooling load.
The R-values tested are the conventional R-values + *X*. Where *X* ranges from 1 to 7. To get a clear image of the effect of each added R-value on the cooling and heating. The simulation is done for the winter and summer months, as well as for the total year. Each Simulation will tell us the total Energy use for that period, as well as the total energy use of the cooling and heating system.

On the right is the buildup of the testing wall (Figure 48), which consists of the original wall, with an additional 'Test Insulation'. This test insulation is then changed in its properties according to the different R-Values. When working with R-Values in DesignBuilder the thickness of the layer does not matter.

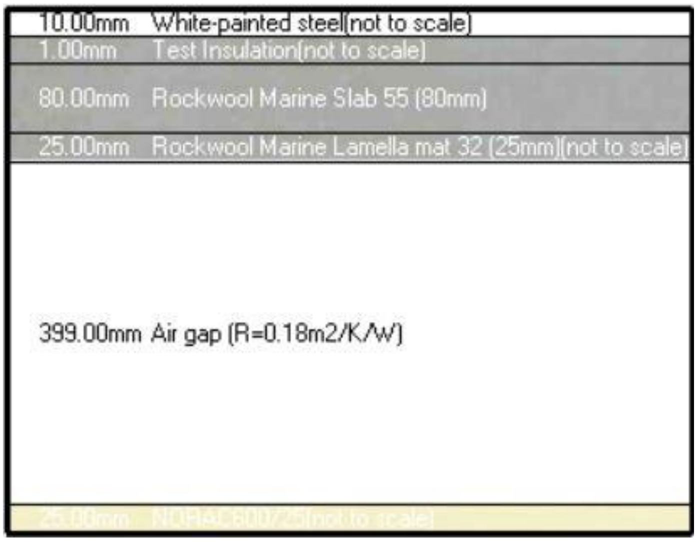


Figure 48: Buildup external wall (Source; author)

Added insulation in the North Sea

When the Insulation value is heightened in steps of 1 R-value, the average annual energy-use lowers with approximately 1 % for each added 1 R-Value. With a total savings of 6.5 % when added R-Value of 7.
In the graph below (Figure 49) are the percentage of savings relative to the total use of cooling (orange), heating (gray) and/or the total accommodation (yellow).

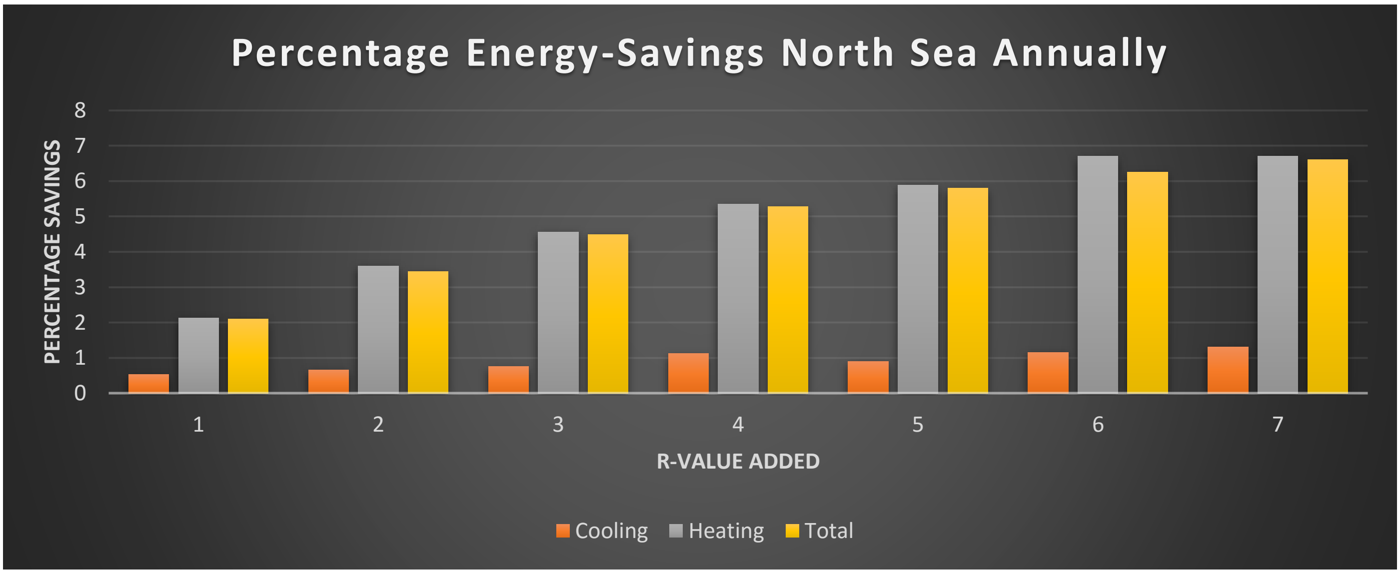


Figure 49: Influence Additional R-value (Source; author)

According to the graph, the cooling savings make a small rise when applying more and more insulation, this can be explained with that climate in the North Sea is colder than the wanted indoor climate, and thus makes the need for cooling insignificantly low. The small rise also consists of only a few kWh per R-Value. The insignificance of the cooling can also be seen in the graph below, where the cooling accounts for 0.6 % of the total energy use.
There is saving on the heating though since the loss of heat through the façade is lowered due to better resistance. Both these aspects have their influence on the total energy use of the building, which savings match the savings of the heating.

The savings in the North Sea are annually for the Heating and Cooling when the R-value of 7 is applied to the external façade is 6.60 % savings. This is a saving of 23.6 MWh on a yearly basis (Figure 50).

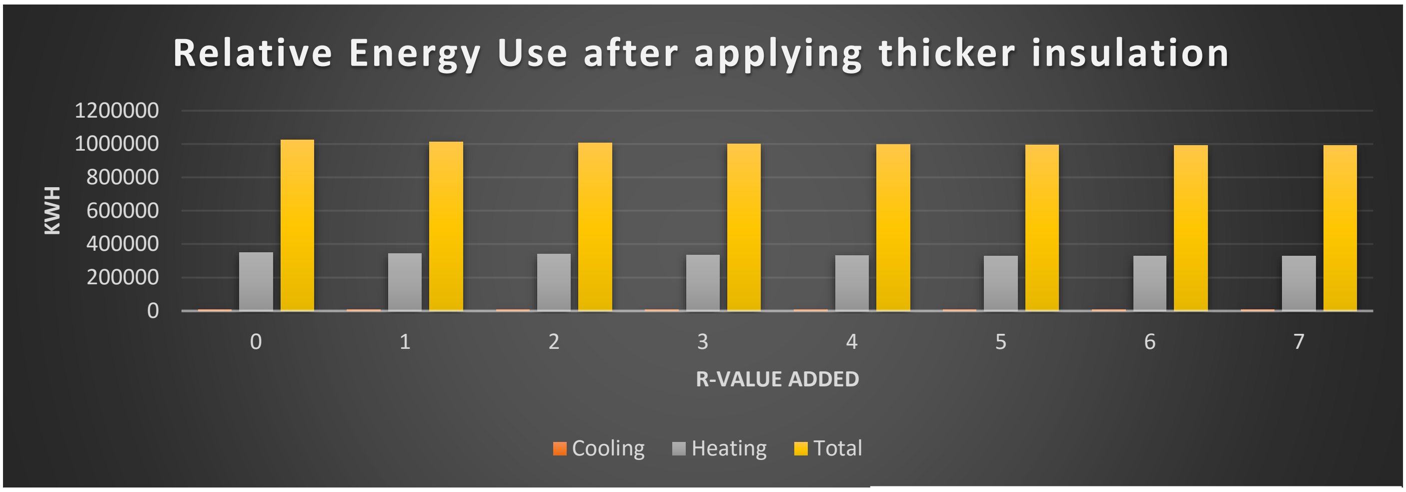


Figure 50: Influence Additional R-value (Source; author)

Added insulation in the Gulf of Mexico

When the same parameters are applied to the Gulf of Mexico, the opposite is happening. There is an overall negative result to the application of thicker insulation. According to the the graph below the annual energy use is actually rising with 0.1 to 0.7 percent (Figure 51). It can also be noted that the heating is not included. This is because the energy use for heating the offshore accommodation is neglectible, with numbers of under the 100 kWh per year. These numbers are also relative to their total.

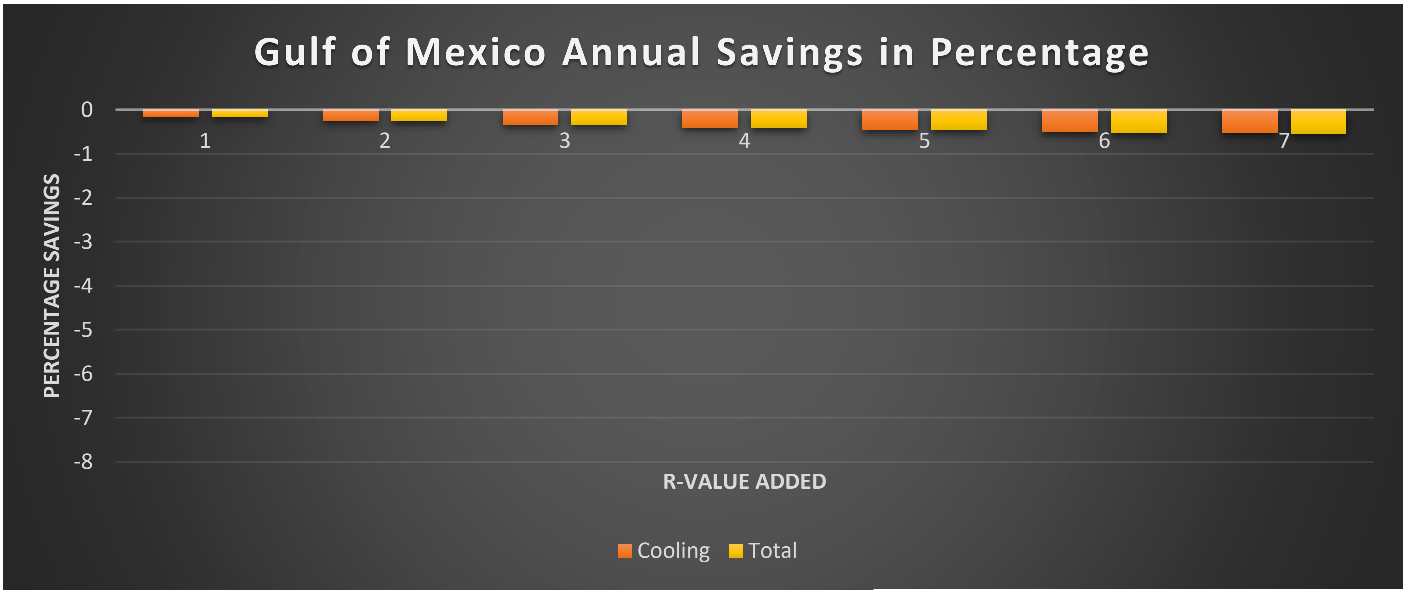


Figure 51: Influence Additional R-value (Source; author)

When looked at the energy savings in kWh (Figure 52), the insignificance of the heating energy use is more clear. Comparable to the North Sea only instead of cooling is the heating in the Gulf of Mexico almost nonexistent.

These results can be explained by the fact that not much of the total energy is lost through the walls in comparison to the loss through mechanical ventilation. The outdoor temperature is still higher than the indoor temperature, and thus needs to be cooled with a specific amount.

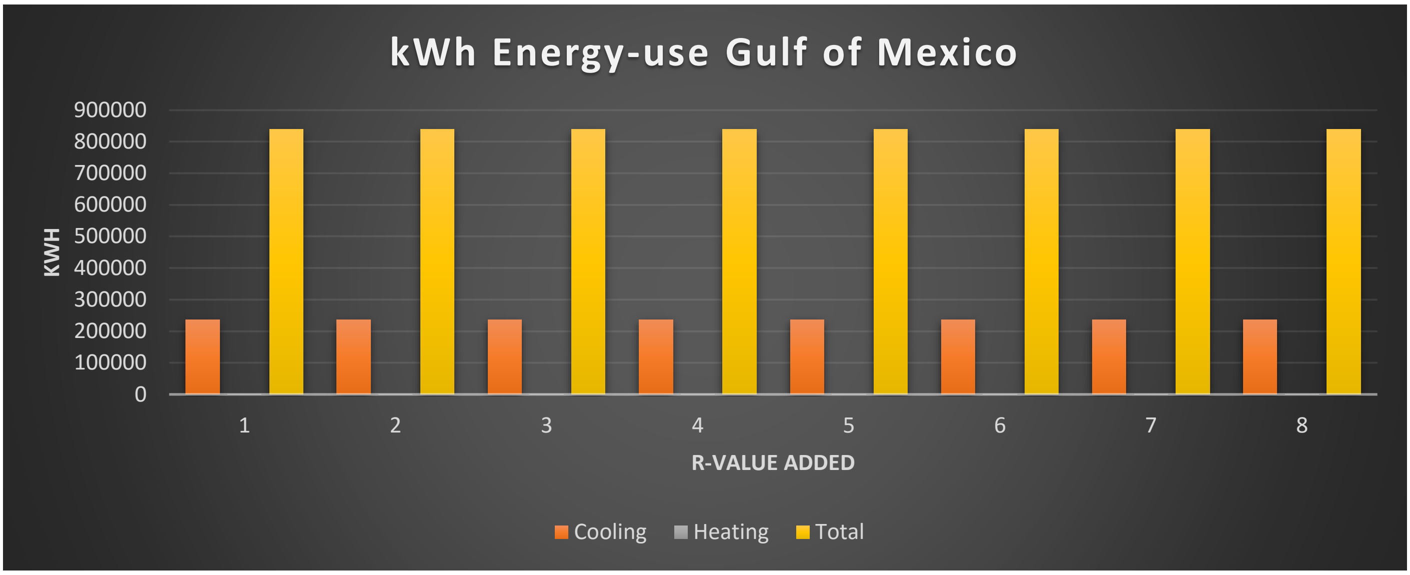


Figure 52: kWh savings through additional R-value (Source; author)

When both locations are compared it shows that the amount of energy saved in the North Sea, far out values the amount of energy lost in the Gulf of Mexico (Figure 53). In the North Sea, approximately 23500 kWh is saved, when the same amount of insulation causes the loss of around 1200 kWh in the Gulf of Mexico. This means that the kWh in the North Sea could be ignored when refurbishing a new offshore accommodation. Since the chance is that it could save energy over its overall life time across the world is a lot higher than losing money.

In this case it would be most beneficial for the project to haven an R-value which is as high as possible. However, when thinking about our concept it was important to assess the current accommodation and what the effect would be when the insulation would be doubled or even tripled. In this case an R-value of around 5 or 6 would therefore be realistic.

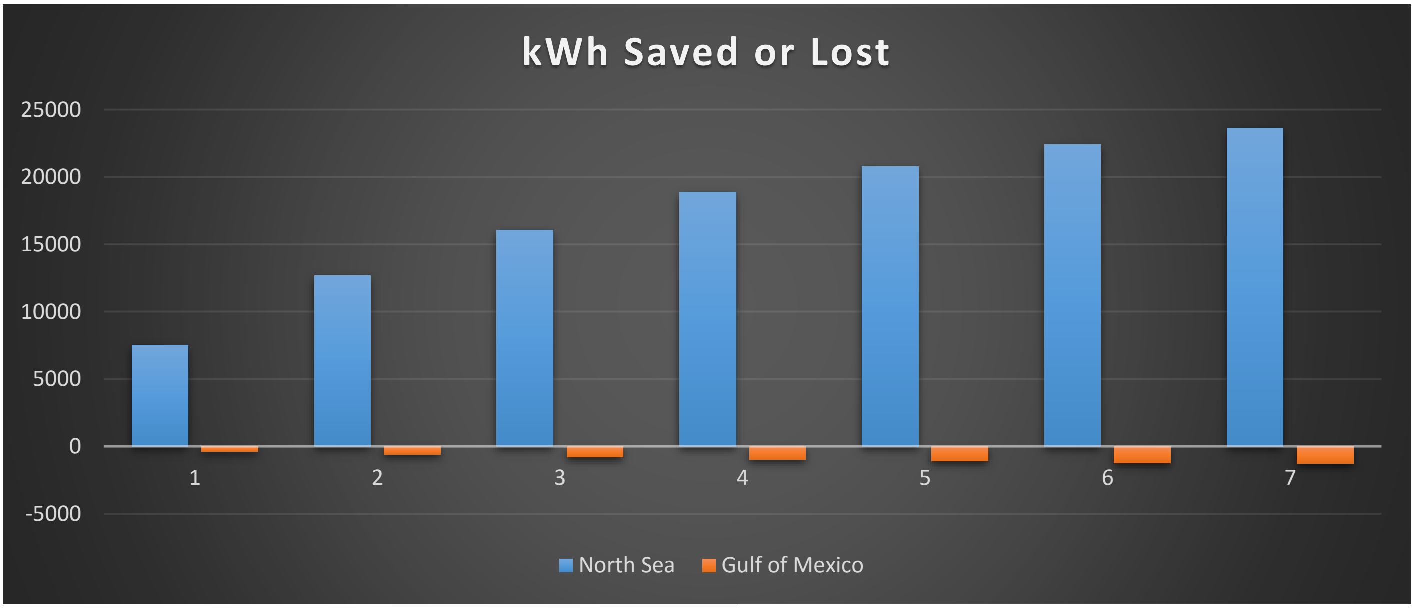


Figure 53: Effect on Energy Use with Extra Insulation (Source; author)

6.3 Testing of Local Shading

Testing of Horizontal Overhang

Several shading overhangs will be tested in the model, and to have a complete view of influence of these overhangs we will apply overhangs in the range of 0.5 meter, 1.0 Meter, 1.5 Meter (Figure 54). The optimum overhang position is based on the position of the sun at these locations. Also it should be considered that the window is laid back a bit into the façade and therefor already is shaded by a few centimeter of overhang of the window sill.

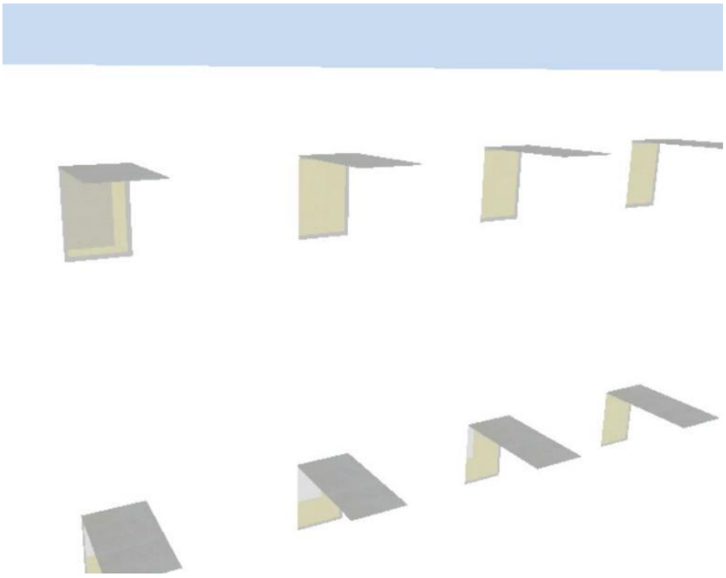


Figure 54: Overhang in DesignBuilder (Source; Author)

It is assumed that applying shading elements to the building will not have an enormous effect on the heating and cooling loads of the building, since only 4 to 5 % of the façade accounts for windows.

The effects will be measured a total year, for the summer and the winter, and when necessary this could be focused down on a specific week or day. The results of different sizes of overhang in the North Sea are simulated in the graph and table below (figure 55).

North Sea & Gulf of Mexico

When testing the overhangs on an offshore accommodation the effects were almost negligible. In the North Sea applying overhangs and side wings would end up for the building to use more energy. This could actually be expected, since the sun in the North Sea also doesn't provide a lot of heat gain, however, what the small amount it does provide will not have to be heated by the buildings HVAC system. In combination with the fact the windows do just account for a really small percentage of the façade makes this negative influence of adding external shading of almost negligible influence. The numbers can be seen below in figure 55.

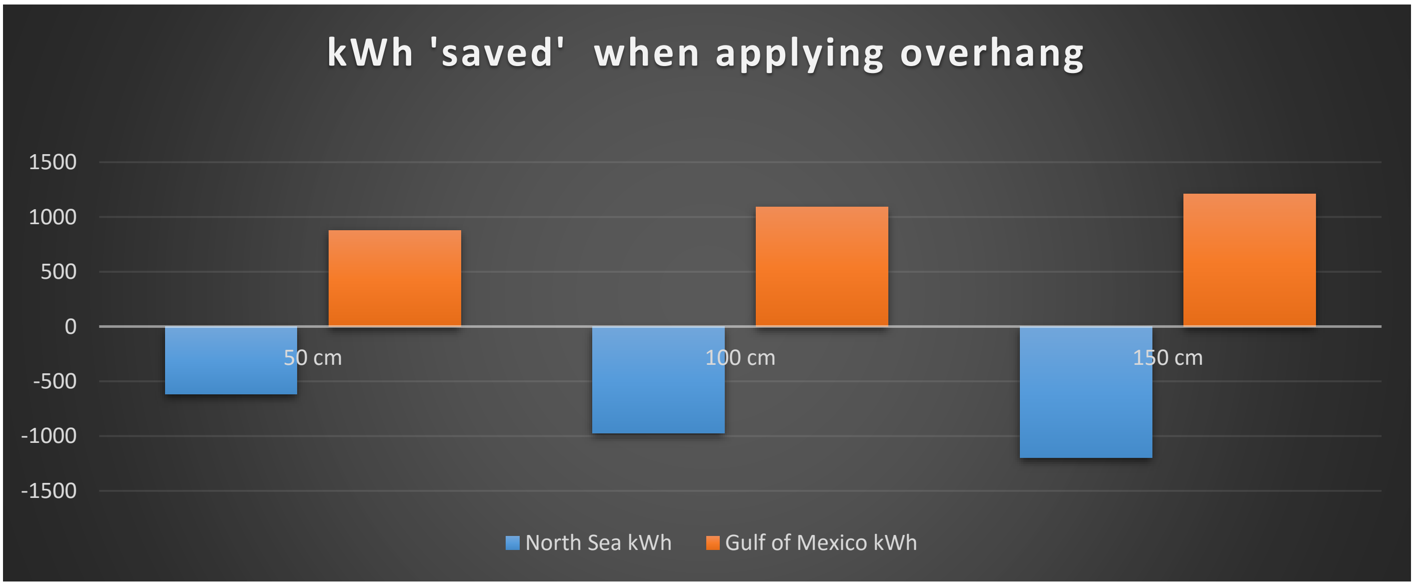


Figure 55: Effect of Overhang (Source; author)

Testing of Overhang and Sideways lamellae at windows

The effect of an overhang in combination with a side lamellae was tested as an extra addition to the shading (Figure 56). This is simulated since when an element is attached to the façade, the shading element is comparable. The model to the right has this configuration with 1 meter overhangs and 1 meter sideways.

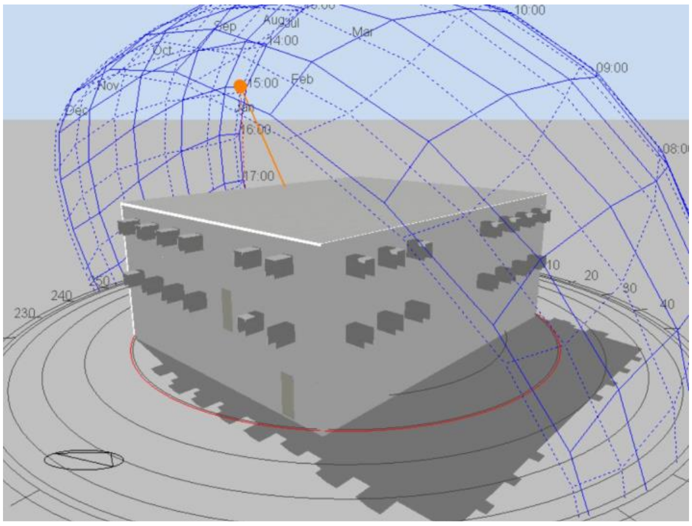


Figure 56: Overhang and Sideways Lamellae in DesignBuilder(Source; author)

It is expected that the numbers will be comparable to the situation when only the overhang is applied, since the amount of windows and the overall difference in shading is almost unneglectable.

The saved kWh is in both locations in the opposite direction from each other, where it is possible to save a bit of energy in the Gulf of Mexico, due to lowered heat gain through the windows, this is an actual benefit in the colder locations like the North Sea.

In this case (Figure 57) the loss in Energy is even more that what can be gained, with a yearly loss of 5257 kWh in the North Sea, against a saving of 2915 kWh at the Gulf of Mexico. This makes the implementation of additional shading not attractive.

In comparison with only the overhang, it shows that the in the Gulf of Mexico only a fraction more is saved.

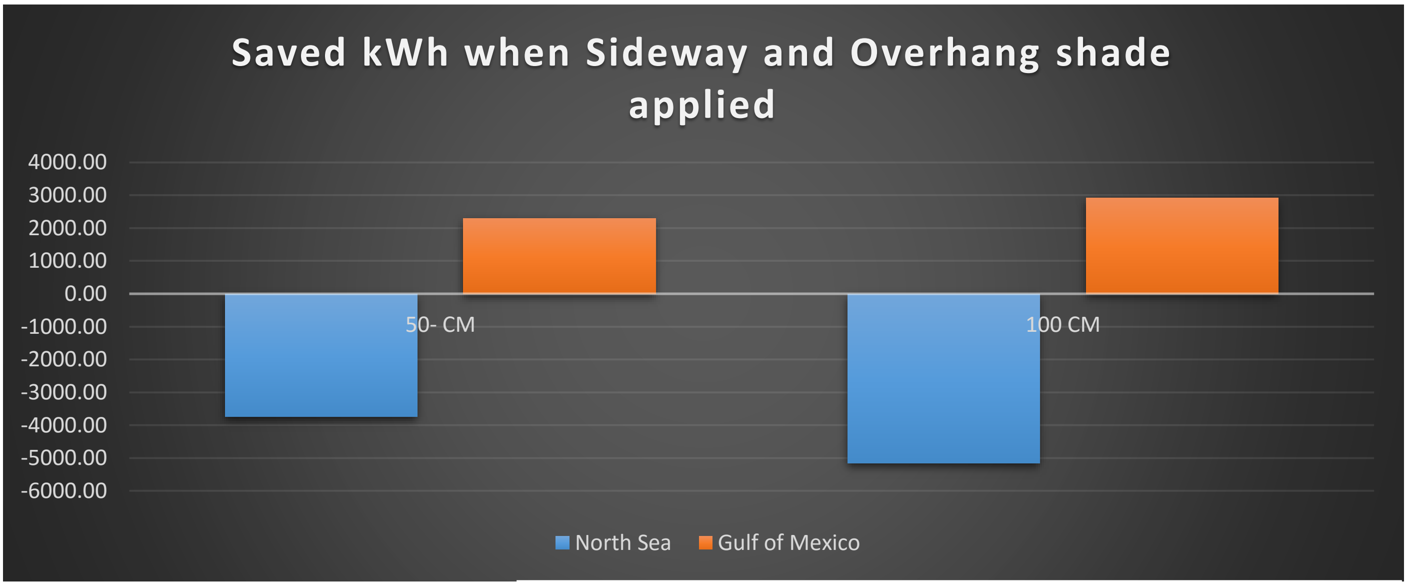


Figure 57: Effect of Overhang and Sideway Lamellae (Source; author)

Testing of Overall Façade Shading

By adding blocks to the façade of the building we can simulate that there would be an adjacent block next to the building (Figure 58). This is combined with three options, where the adjacent block can be modelled as a building, with the same specifications as our model. Or it can be designed pure as a shading device. The latter one is the one used.

The component block was placed onto the roof and each façade and is made of aluminum with a transparency of 0, which means that it wouldn't let any light through all day, every day, the underlying graphs are the results of the application.

The resulting figures are shown in the graph below, where the amount of kWh are saved with a fully covered façade for shading. This is compared to the overhang with side wings interestingly a lot different, where in the Gulf of Mexico the savings are more, and in the North Sea the actual loss is less than with an additional extra façade.

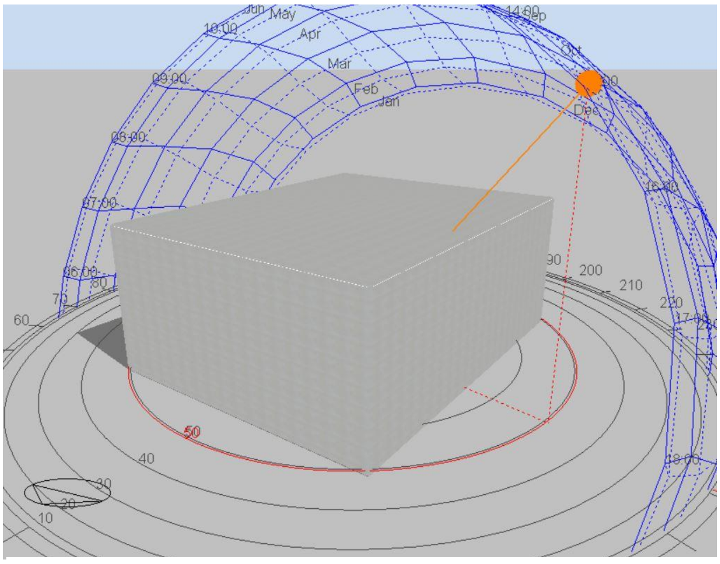


Figure 58: Complete Façade Shading in DesignBuilder (Source; author)

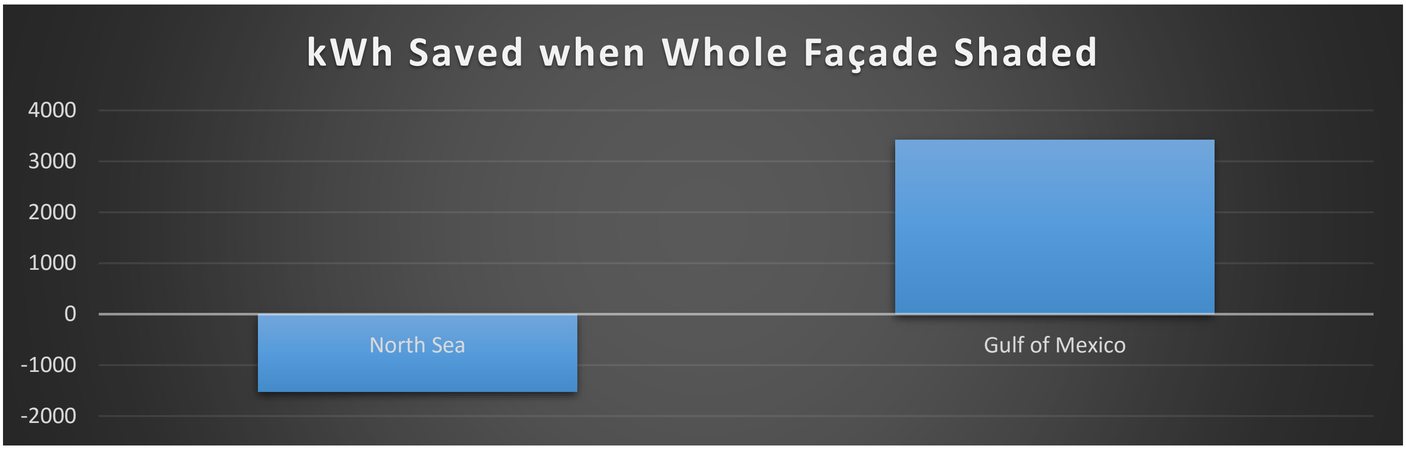


Figure 59: kWh Saved with whole façade shaded (Source; author)

6.4 Test Results & Conclusions

All test results combined in the following table. Shown are the heating and cooling savings of each conceptual parameter. The results of the applied PV panels are added, however, originally the generated electricity is not related to the Heating and Cooling Costs, but to the overall energy use of the building. But in order to see the impact of the PV panels on the heating costs it is assumed that for each generated kWh with the PV-panel, the heating and cooling system can save the costs of one kWh.

In the table below (Figure 60) the savings on the Cooling + Heating system are shown, with green numbers where savings are achieved, and red where there is more energy use.

Savings on Cooling + Heating

			North Sea			Gulf of Mexico		
Concepts			Savings on Total(%)	kWh	Cost	Savings on Total (%)	kWh	Cost
	Insulation							
I-1		R =1	2.1	7527.6	€ 1,881.91	-0.2	-369.2	€ (92.31)
I-2		R =2	3.5	12358.2	€ 3,089.55	-0.3	-596.1	€ (149.02)
I-3		R =3	4.5	16078.0	€ 4,019.49	-0.3	-807.9	€ (201.97)
I-4		R= 4	5.3	18877.9	€ 4,719.48	-0.4	-957.6	€ (239.40)
I-5		R =5	5.8	20770.4	€ 5,192.60	-0.5	-1081.2	€ (270.30)
I-6		R =6	6.3	22403.5	€ 5,600.86	-0.5	-1227.4	€ (306.86)
I-7		R =7	6.6	23644.1	€ 5,911.03	-0.5	-1269.0	€ (317.25)
	Shading							
S-1		1 M Overhang	-0.2	-615.3	€ (153.82)	0.4	891.1	€ 222.77
S-2		1.5 M Overhang	-0.3	-970.8	€ (242.70)	0.5	1108.3	€ 277.08
S-3		2 M Overhang	-0.3	-1199.8	€ (299.96)	0.5	1230.6	€ 307.66
S-4		0.5 M Overhang + Sideway + Lamella	-1.0	-3743.0	€ (935.74)	1.0	2301.6	€ 575.40
S-5		OverAll Façade Shading	-0.5	-1631.9	€ (407.99)	1.4	3416.1	€ 854.03
S-6		1 M Overhang + Sideway + Lamellae	-1.4	-5157.3	€ (1,289.32)	1.2	2915.3	€ 728.82
	PV-Panel							
	1	**Optimal**						
PV-1		100% Coverage	46.6	166678.6	€ 41,669.65	70.7	166678.6	€ 41,669.65
PV-2		50% Coverage	23.3	83339.3	€ 20,834.82	35.3	83339.3	€ 20,834.82
PV-3		10% Coverage	4.7	16667.9	€ 4,166.96	7.1	16667.9	€ 4,166.96
	2	**Building Integrated**						
PV-4		100% Coverage	20.1	71950.8	€ 17,987.70	50.1	118171.0	€ 29,542.76
PV-5		50% Coverage	10.1	36154.4	€ 9,038.59	25.0	58967.6	€ 14,741.90
PV-6		10% Coverage	2	7159.3	€ 1,789.82	5.0	11793.5	€ 2,948.38

Figure 60: Energy Costs Savings with Concepts (Source; author)

Decision Matrix

The concepts will be assessed through a decision matrix. Here we see several important criteria of which it is thought to be important that the concepts should provide, against several different combination of concepts. Only one of the insulating options will be applied, where it is possible to use two options of the shading. Also of the PV-panel one is used.

Concepts

Based on the concept development and the influence on the heating/cooling energy-use the following decision matrix is compiled. There are three different combinations of concepts which are assumed to add significant change to the current energy use. These are an façade with PV and Shading system combined (C-1). PV and external insulation layer added (C-2). And one concept (C-3) where all three are combined.

Criteria

- **Saving in Heating/Cooling costs**

The amount of energy saved while implementing the concepts is of highest priority, this is the main reason for the refurbishment, and could tell us more about the feasibility of the final design.

- **Applicable for Refurbishment**

One interest for Keppel Verolme is the possibility of refurbishing existing platforms for 30+ employees. Hence the question is if the concept applicable for refurbishment. Then it has more potential for this research.

- **Applicable for Fixed Platform & Mobile Platform**

The situation of the platform, if its fixed or not is important when considering the PV panels due to the orientation of its facades, as well as when designing for world-wide use. Is the concept applicable on any of these platforms, and open to change, it has then a clear advantage over other concepts.

- **Applicable for Hot climate & cold climate**

Also the different influence of climates is of high importance, the best solution would be a concept which can be used in both hot and cold climates. However, knowing if the concept is more efficient in a specific climate could be important for later products.

- **Applicable for Availability (e.g. 'Off the Shelf')**

This is an criterion which is of importance to Keppel, is it possible to use systems which are already available onshore? Or should complete new systems be invented. The latter raises the investment price considerably. Therefore, potential for 'off the shelf' products in the concept is important to consider out of commercial point of view.

- **Complexity of Maintenance**

The concept should be able to be fast repaired, as well as well withstand low maintenance. This is because it will be employed at sea and thus easy access to the façade is rare. Less complex systems and more simple systems are there for preferred.

- **Applicable for World Wide Use**

This criterion is specific for possible use in hot and cold climates.

Priority

Each criteria is assessed on its priority and relative weight. The priority number is a number which ranges from 1 to 9 one for each criterion. The highest priority is given to its ability to save costs aboard the offshore accommodation, this one is followed by the availability of material, since availability could influence the initial cost greatly. Thirdly the possibility to apply the concept worldwide for best efficient use has a priority of 7. Since the initial idea was to propose ideas for a refurbished offshore accommodation, these criteria was given a 6. Since in the offshore industry the accommodation blocks will be at sea for a considerable amount of time, the complexity of maintenance has been given the priority of 5. When more or different concepts were offered, this priority should go up. However, the maintenance for each current combination of concepts does not differ a lot and thus has given a quite low priority.
The same goes for the last four criteria; fixed platform, mobile platform, hot climate and cold climate, which are respectively awarded with a priority of 3, 4, 2 and 1.

Relative Weight

The relative weight of each criteria is comparable to the priorities given, however the same relative weight can be applied to several criteria at the same time. I gave the savings in the energy-costs the highest weight, which is 100%, and refurbishment follows it with 60%. The other criteria have been given 40% as weight.

Result

Eventually the result is determined by simply multiplying the given rating with the relative weight and the priority. After this all results are added together to give a final assessment rating.

	9	6	3	4	2	1	8	5	7	Priority (1-5)
Concepts	100%	60%	40%	40%	40%	40%	40%	40%	40%	Relative Wei
Insulation	**Saving Cos**	**Refurbishn**	**Fixed Platf**	**Mobile Pla**	**Hot Climate**	**Cold Clima**	**Availability**	**Maintainance**	**World Wid**	**Result**
C-1 PV	3	3	3	1	3	2	3	1	3	66.2
C-2 PV + SHAD	4	6	5	5	6	4	6	6	5	123.2
C-3 PV + INSULATION	5	5	4	4	4	6	5	5	4	117
C-4 PV + INSULATION + SHAD	6	4	6	6	5	5	4	4	6	128.8
C-5 INSULATION + SHADING	2	2	2	3	2	3	2	2	2	51.2
C-6 SHADING	1	5	1	2	3	1	1	3	1	46.2

Figure 61: Concept Assessment (Source; author)

Shown in figure 61, the highest rated concept is C – 4; Photovoltaic panels, insulation and shading elements. This combination has a rating of 128.8, and will therefore be further developed in the final chapter; Final Design and Implementation.

The following table shows which concepts should be used in which situations (figure 62).

	Fixed Platform		Mobile Platform	
Hot Climate	New-Build	Refurbishment	New-Build	Refurbishment
	Shading PV-panels on all facade	Shading PV-panels on all facade	Shading PV-panels Only on Roof	Shading PV-panels Only on Roof
Cold Climate	New-Build	Refurbishment	New-Build	Refurbishment
	Internal Insulation PV-panels on all facade	External Insulation PV-panels on all facade	Internal Insulation PV-panels Only on Roof	External Insulation PV-panels Only on Roof

Figure 62: Concept vs Context (Source; author)

7 Final Design & Implementation

7.1 Final Design Applied Offshore

The final design is based on the results of the decision matrix. There are several different options to apply on the offshore accommodation as was shown in the chapter before. The final design is the one which enables the most savings thus the following design is built with all available options. It is based on several existing on-shore systems, changed in order to be applied offshore. One of the priorities of the system is that it should be able to be adaptable to the wishes of the client. Therefor the possibility should be available in the design to conform to this adaptability.
In this chapter the design will be explained according to the main elements, with details and drawings and renders as supporting information.

The final design is the result of the research done in past chapters. As has been determined in the 6th chapter, the design will function as an extra added insulation, together with PV-panels and have a passive shading system. These three elements will be thoroughly explained within this chapter.

Since these elements are mainly applied onshore, there are consequences for them to be applied offshore. The offshore industry has different regulations, as the climate and environment is a lot more extreme then onshore. Which solution could be of interest when developing a heat loss reducing strategy in offshore accommodation? What are the factors to consider when applying each of these solutions to an offshore accommodation?

7.2 Insulation

The added insulation consists of aluminum and galvanized steel layered insulation blocks. Which can be attached to the main façade by screwing them onto omega profiles, attached to the conventional steel bulkhead of the offshore accommodation with spot-welding.

The insulating material is called Polyisocyanuraatschuim (PIR), which has a thermal conductivity of λ = 0.020 W/m.K. This meant that if the highest tested R-Value would have been applied, the thickness should be 140 millimeter, as can be seen in the table below (Kingspan, 2016).

R- Value	Thickness of PIR insulation Panel
1	20 mm
2	40 mm
3	60 mm
4	80 mm
5	100 mm
6	120 mm
7	140 mm

The panels are available in different lengths as well as in widths, which makes it an attractive solution for the refurbishment of drilling rigs, where the length and size of each façade can differ greatly. The galvanized steel outer layer makes this the right solution for the current environmental stresses found offshore. According producers of insulating panels alike, the quality is therefore guaranteed for at least 25 years in coastal areas (Kingspan, 2016).

These panels will not only protect against the extreme weather aboard the drilling rigs, but, as has been pointed out in the beginning of the thesis, they will also have to withstand fire. Real life fire study cases have shown that the panels provide a good protection against fires. In a specific case at a burning milk powder factory in New Zealand, these kind of panels were burning for 40 minutes, but did not contribute to the fire spread while the construction behind the panels kept the panels in position as long as the fire burned. In other cases of longer fire exposure, the aluminum outer layer was penetrated but the PIR core did not melt or burn, it charred. This proves as a good additional fire proofing layer onto the conventional offshore accommodation external wall (Kingspan, 2016). In the final design there are however different circumstances, since the panels are applied on an external wall which is currently already fireproof. The newly laid panels would only delay fire reaching the conventional façade from outside, and thus be an extra secure element, but more specific research should be conducted in order to form a clear conclusion about adding this extra layer.

Next to the strong outer layer, another big advantage of the panel is that it can support a second layer, the so called rain screen. This rain screen is necessary in order to apply the PV-panels. This rain-screen system is attached with a bolt and nut system through the insulating panel, onto a supporting railing system.
The connection through the panels and supporting railings system can hold around 28 kilos, so the 20 kg PV-panels in the final design should not be a problem.

The 100 Millimeter insulating panel, will be applied on all facades, including the roof, where a small angle in the underlying construction, makes it possible for the water to flow away. The panels themselves are strong enough to walk on, in case of emergencies.
This final design makes it possible to cover all cold-bridges caused by its steel façade, this reduces an additional 10 % of the heat loss through the walls.

7.3 Solar Design

The PV panels applied to the system are based on PV-panels currently in the market. These panels have been known to be used aboard cruise-ships and it is therefore assumed that they can withstand the local environmental extremes. The panels are mass produced, with a proven efficiency of around 13.4 %. The specific details about the panel can be seen in the table below.

	Datasheet Solar Design source; (Solar Frontier, n.d.)
Weight	20 Kg
Dimensions	1,257 x 977 x 35 mm
Efficiency	13.4 %
Fire Rating	Class C
Snow & Wind Load	2,400 Pa / 1,600 Pa Design load
Cell Type	CIS glass substrate (cadmium free)
Front Cover	Clear tempered glass; 3,2 mm
Back sheet	Weatherproof plastic film (color; black)
Frame	Anodized Aluminum alloy
Edge Sealant	Butyl Rubber
Adhesive	Silicone
Packing information	25 Modules / pallet -> 36 pallets per container

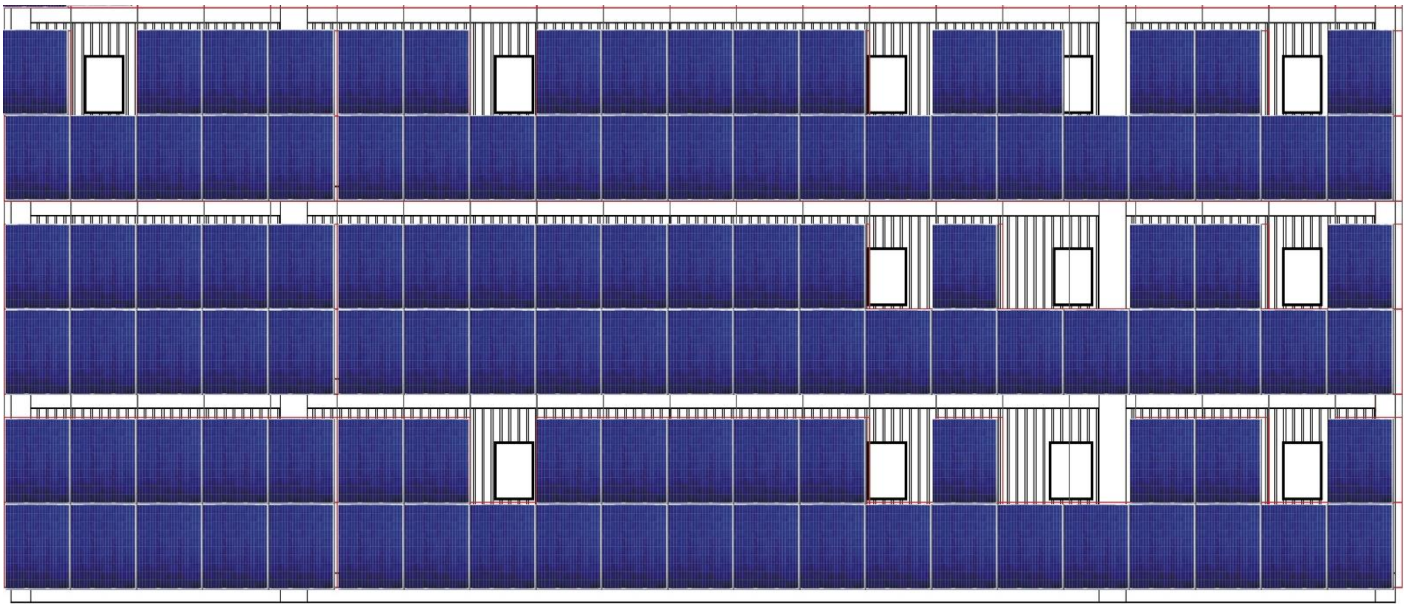


Figure 63: PV-panel configuration (Source; author)

The panels will be attached to the railing system on top of the insulating panels with nut and bolts. This means is done to keep the extra load in weight as low as possible.

The configuration of the PV panels onto the façade are mainly influenced by the location of the windows and doors (Figure 63), as well as the height of the façade themselves. For the benchmark case, the following configuration was chosen.

These configurations make it possible to apply for 385 panels on the East, West and South facades. When we apply the calculations used in the 6th chapter to find out how much power can be generated, the following results can be expected. Possible savings are shown in figure 64.

Orientation	Amount of panels	Watt Peak
Roof	204	34.8
East	112	19.0
West	110	18.7
South	84	14.3

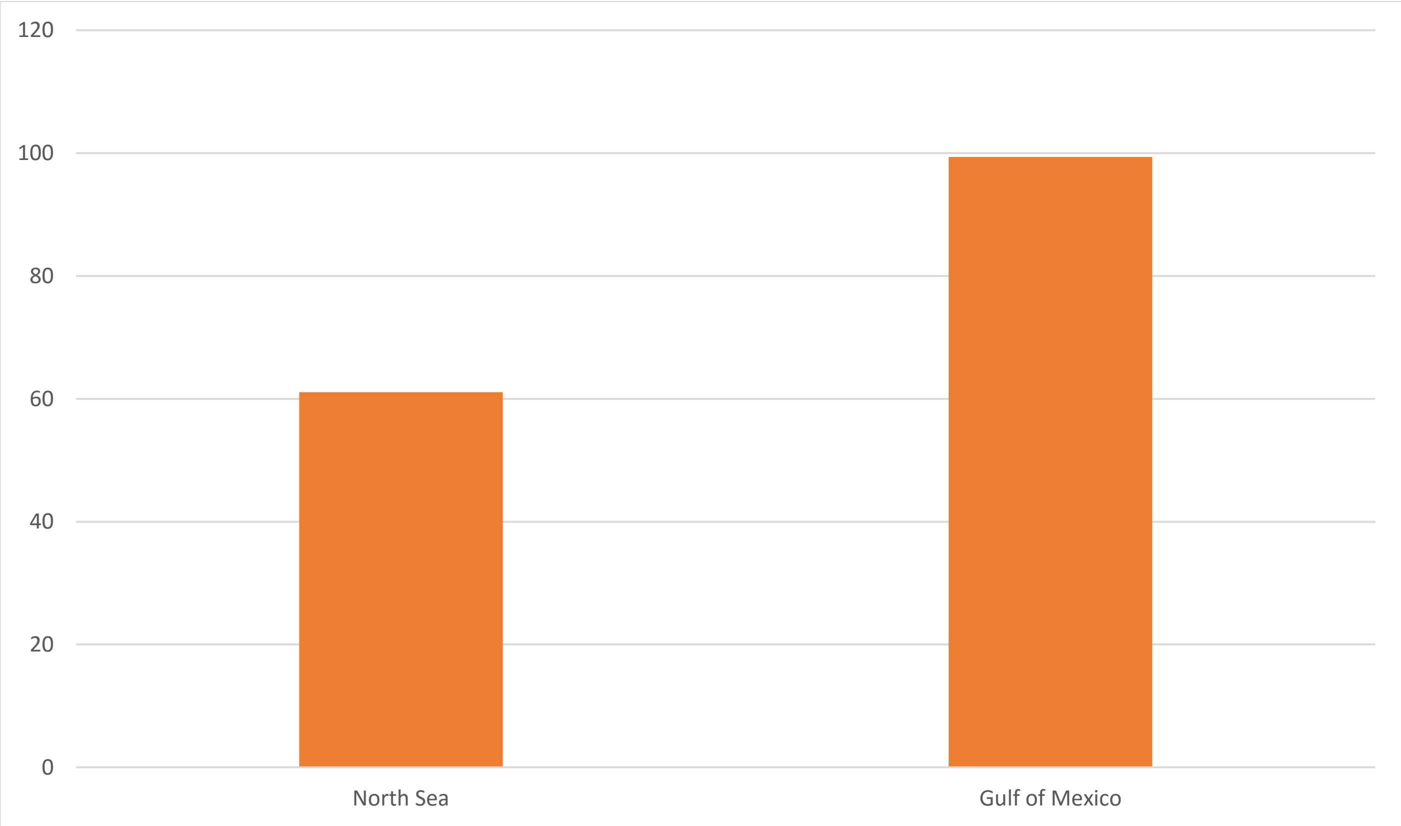


Figure 64: Savings PV-panel (Source; author)

7.4 Shading

However, there was initially not much shading applied, in the final design added shading was more the result as by-effect of the other implementations. Like a thicker external wall and an additional layer onto the external façade caused the sides of the windows to be at least 30 centimeters more outwards. This effectively shades the accommodation windows, resulting in the energy savings discussed in part 7.5.

7.5 Savings of Energy and Costs of Final Design

The savings reached with applying these systems can be broken down in two divisions, savings on the heating/cooling due to the insulation and shading and the added energy due to the application of PV-panels. Both will be discussed in this chapter, together with the total breakdown of costs and final design.

Savings on heating/cooling

The savings on cooling/heating in the North Sea are caused due to the application of the *extra insulation* and the *shading* caused by the addition to the façade (an whole façade shading and overhang at windows due to thicker façade). The savings on the total yearly energy use can be seen in figure 65.

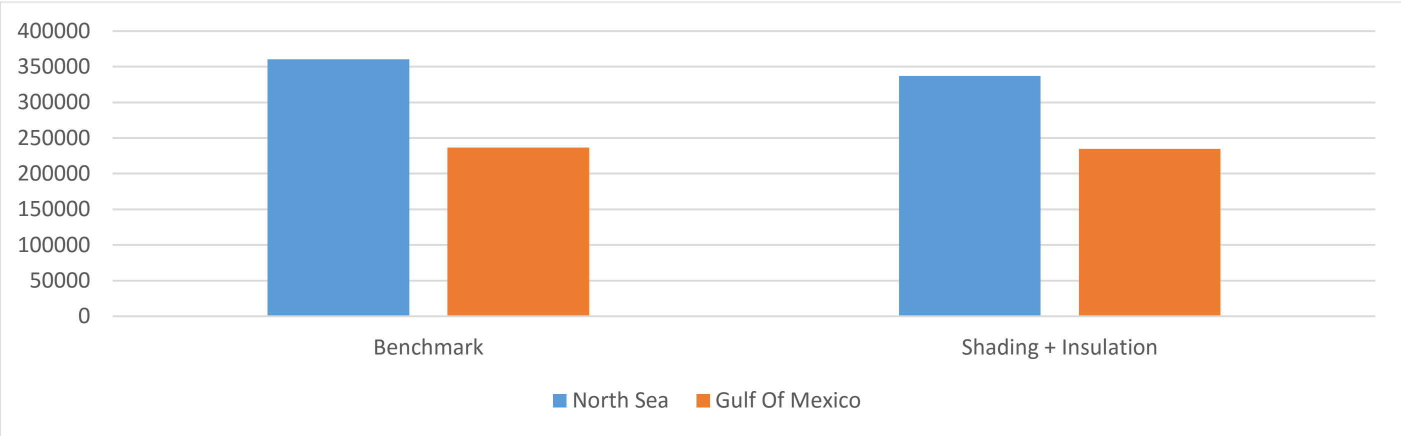


Figure 65: New Savings (Source; author)

In figure 66 and 67 are the savings shown in kWh and the percentage of savings related tot the usual energy use.

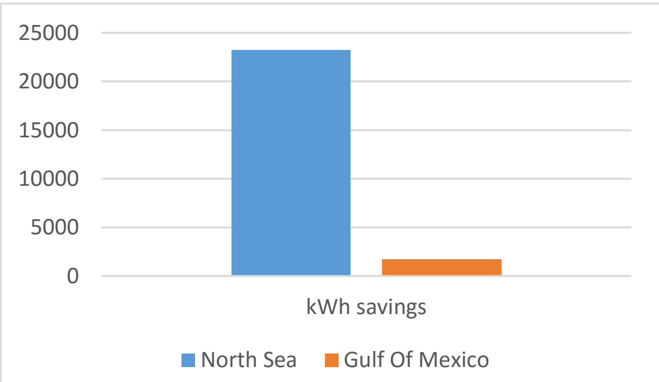


Figure 66: Savings in kWh (Source; author)

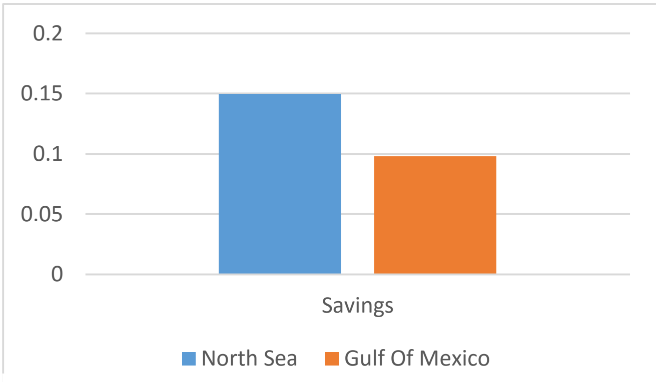


Figure 67: Savings in % (Source; author)

The figures are also broken down in the table below.

Location	*Study Case Yearly Energy Use (kWh)*	*Yearly Energy Use when Shading applied(kWh)*	*Savings percentage of total (%)*	*Savings (kWh)*
North Sea	*396309*	*337044*	*15%*	*23237.27*
Gulf of Mexico	*260320*	*234900*	*9.7%*	*1754.80*

System Costs

The costs of this system are the defined costs per square meter of an external façade as determined in onshore buildings, as well as the costs of insulation as determined at companies specialized at insulation. Adding the external façade includes the structure as well as the aluminum panels. The insulation is based on applying an R-value of 5 on the outside. The costs are access through Keppel Verolme BV, and shown as a percentage of the original costs per square meter.

Strategy	Costs for total façade comparison with original facade
Original Facade	**100%**
Adding the external façade (construction)	**141%**

The total costs per square meter of this system is thus determined at 141% of total investment.

This cost will have multiplied with the square meters of façade which will be covered with this system. The doors as well as the windows are not included in these numbers. Since the PV-panels are not yet taken into consideration, it is reasoned that all facades are covered with aluminum panels. The table below shows the breakdown of square meters.

Façade	Area (m^2)
North	117.1
East	156.6
South	119.5
West	146.6
Roof	320.0
Total	860.4

The affected area of the façade is thus determined at 860.4 m^2.

Payback Time

In figure 68 the payback time can be seen when the building would be operational in the North Sea or in the Gulf of Mexico. In both cases the payback time exceeds our goal extremely, with the payback time in the North Sea at 93 years. This makes sense since the system is relatively expensive considering the savings in heating and cooling. Thus only applying an insulation layer with its shading effects would not be feasible, neither in the North Sea as the Gulf of Mexico.

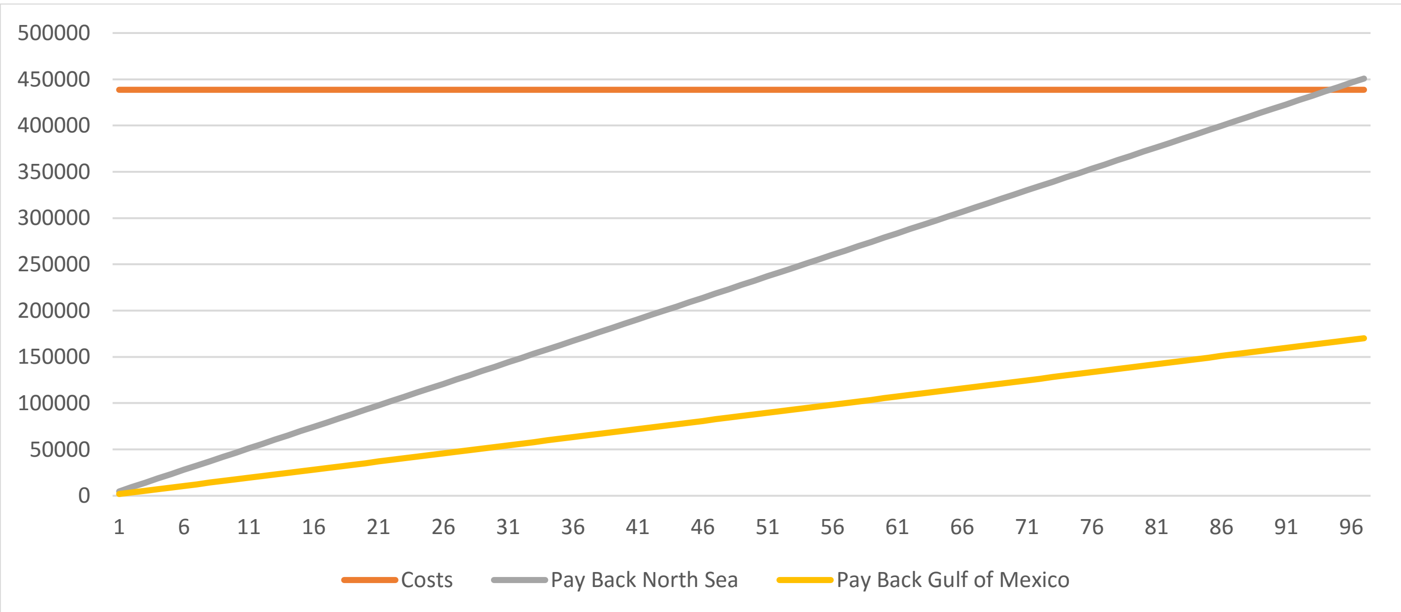


Figure 68: Payback Time (Source; author)

Total Costs

However when PV-panels are applied it is a different story, currently the costs of the installation of PV-cells is determined at .90 cents per Watt Peak, thus 900 euro per kilo-watt-peak. Another way to see these costs are 124.9 euro per m^2. In the figure below the watt peak and costs are shown in percentage of yearly energy costs.

Façade	Area (m^2)	Savings in Energy - Costs
East	156.6	8.3%
South	119.5	6.3%
West	146.6	8.21%
Roof	320.0	15.2%
Total	860.4	38.1%

Adding PV-panels to the façade will thus account for an additional 38% of energy savings. Since PV-panels use the same construction as the aluminum external façade (200€/m^2), except for the aluminum panels itself because the PV-panels substitute the aluminum panels here, the system will cost a bit less at the east, south and the west façade. However, at the corners and in between floors there are no PV panels, so for this there are the construction costs of 200€/$m^{2.}$

It is assumed that the cost of this substituted aluminum panel is 1.77 euro per KG for wrought aluminum and one cubic meter is 2700 kilograms (CES2016). The amount of aluminum panel in one square meter is 1000 * 1000 * 3 = 3000000 cubic millimeters = 0.003 cubic meter, which amounts to the cost of 0.003 * (1.77*2700) = 14.7 euro per panel per square meter. There are also no aluminum panels applied on the roof.

Façade	Area (m^2)	Area PV –panel (m^2)	Area Aluminum Panels (m^2)	Area Construction without Aluminum Panels (m^2)
North	117.1	-	117.1	
East	156.6	137.4	19.1	137.4
South	119.5	103.0	16.5	103.0
West	146.6	135.0	11.0	135.0
Roof	320.0	250.3	-	320.0
Total	860.4	625.7	163.7	695.4

When all these numbers are combined with their respective costs per m^2. The total costs of the façade including PV-panels is calculated in table below;

Façade	Area (m^2)	Relative Costs per m2 (%)	Relative Investment (%)
Original Façade	**860.4**	**100%**	**100%**
PV-panels	625.7	392%	284%
Construction + Aluminum Panels	163.7	141%	26%
Construction without Aluminum Panels	695.4	120%	97%
Total Costs			**409%**

It is shown that the total façade implementation will cost 409% as much as the conventional façade.

Total Savings

When the system is applied onto the offshore accommodation study case the following savings will be made possible in the North Sea and the Gulf of Mexico in MWh.

	Savings North Sea per year(MWh)	**Savings Gulf of Mexico per year (MWh)**
Heating	23.2	-0.1
Cooling	0.08	1.85
PV-Panel	61.1	99.4
Total Yearly Savings (MWh)	120	124

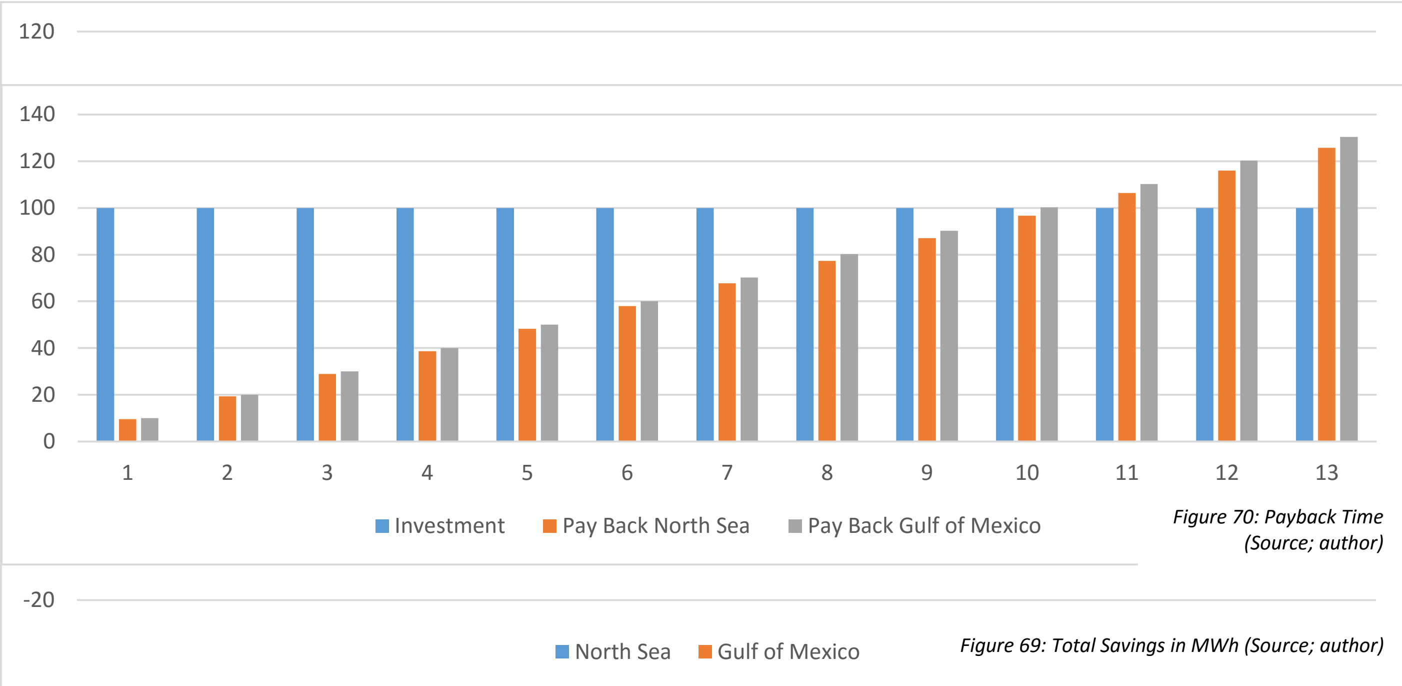


Figure 70: Payback Time (Source; author)

Figure 69: Total Savings in MWh (Source; author)

The savings are will be a yearly return on investments, and in comparison to the initial investment, the following figure 70, determines the Payback time for either Gulf of Mexico and North Sea.

The total Pay Back Time of the final design is thus 11 years for in the North Sea, and 10 years for a rig operational in the Gulf of Mexico. Since the lifetime of the façade is 25 to 30 years, it could earn itself back within its life time, however out of financial and economic reasons this is not advisable.

7.6 Details and Drawings

In this part several drawings are collected which support the design of the façade refurbishment.

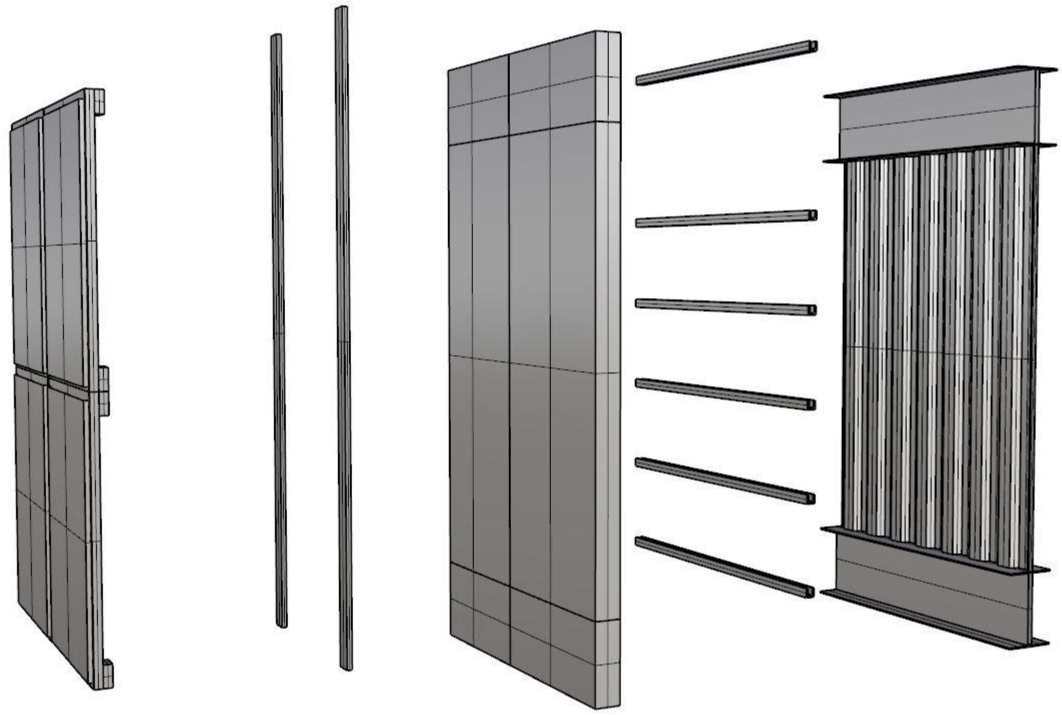


Figure 71: Concept of façade element (Source; author)

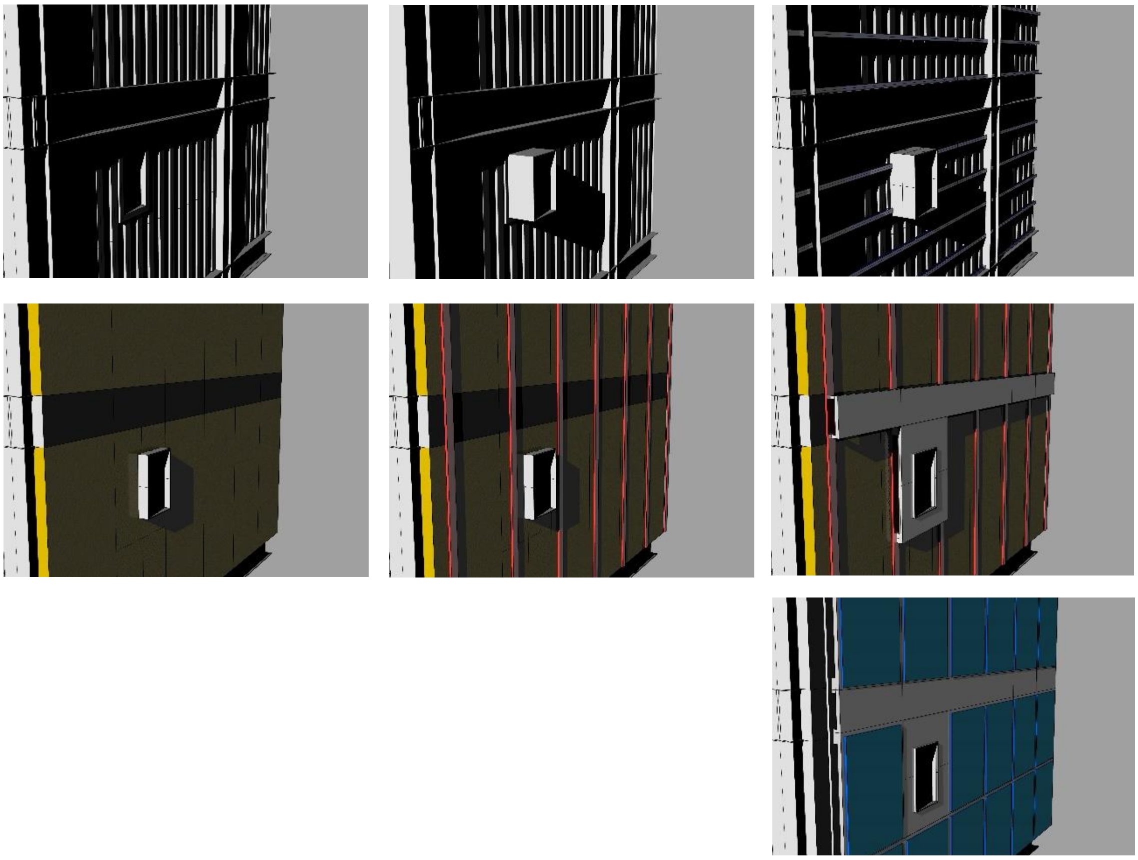
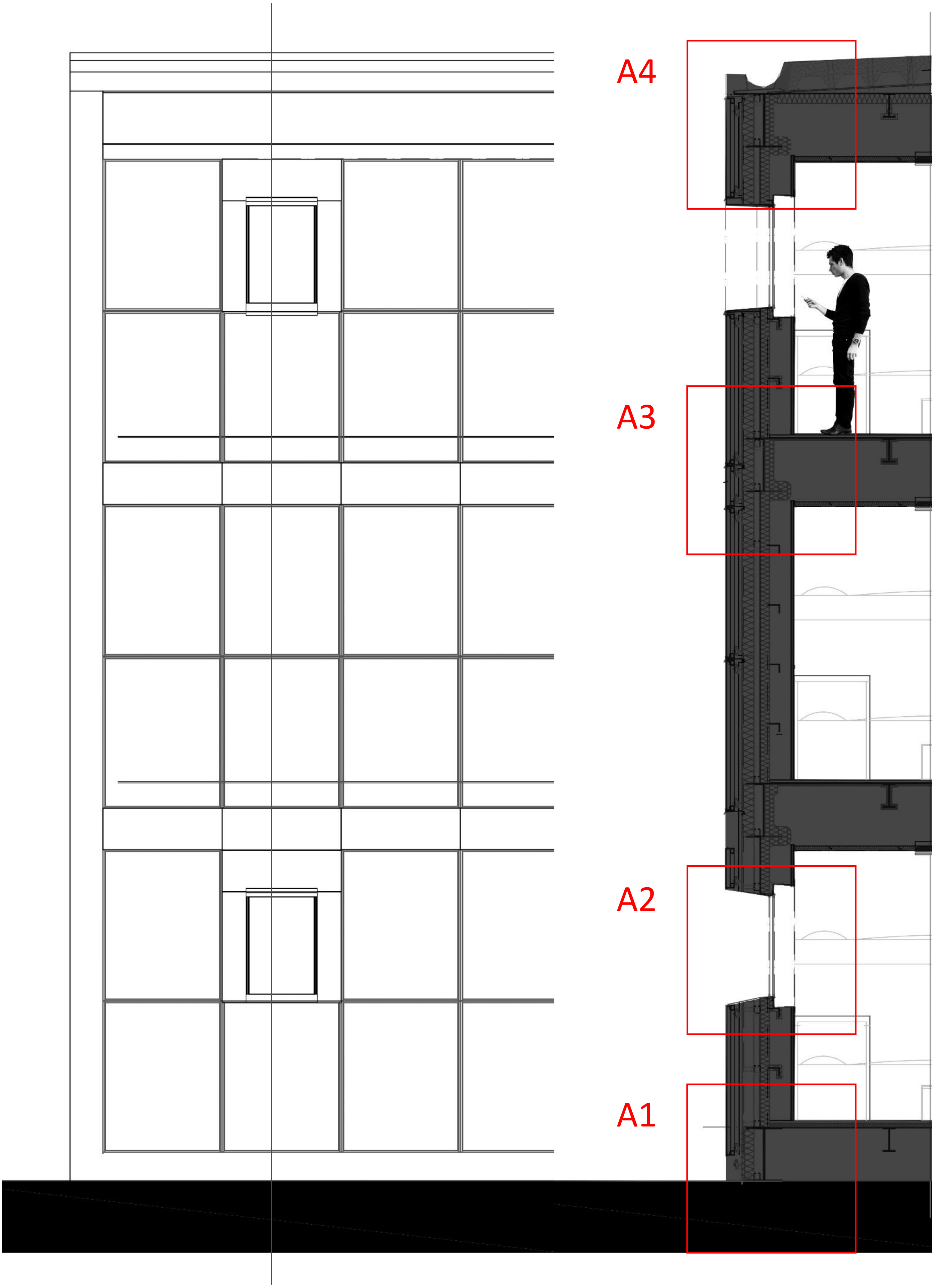
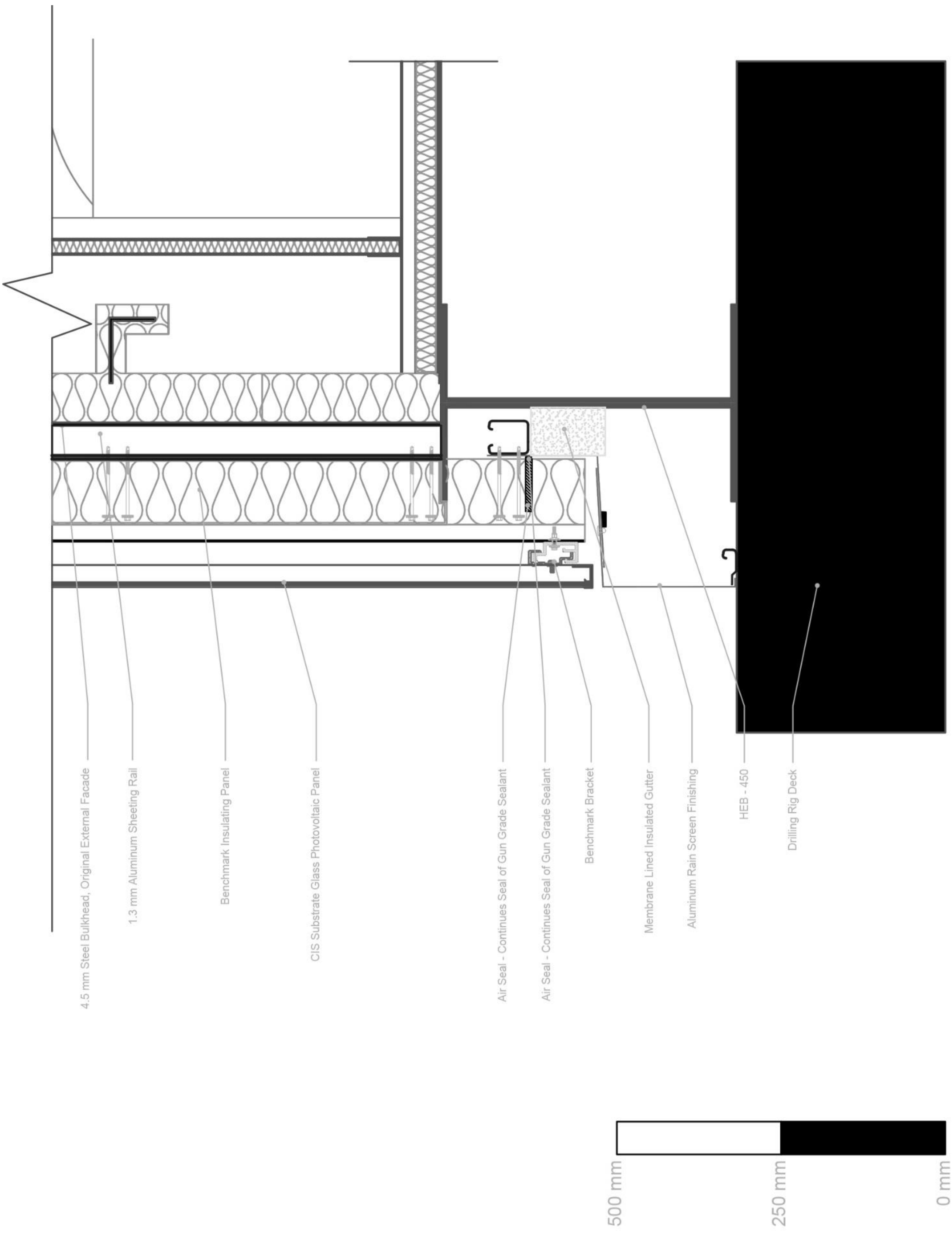


Figure 72: Steps of Assembly (Source; author)

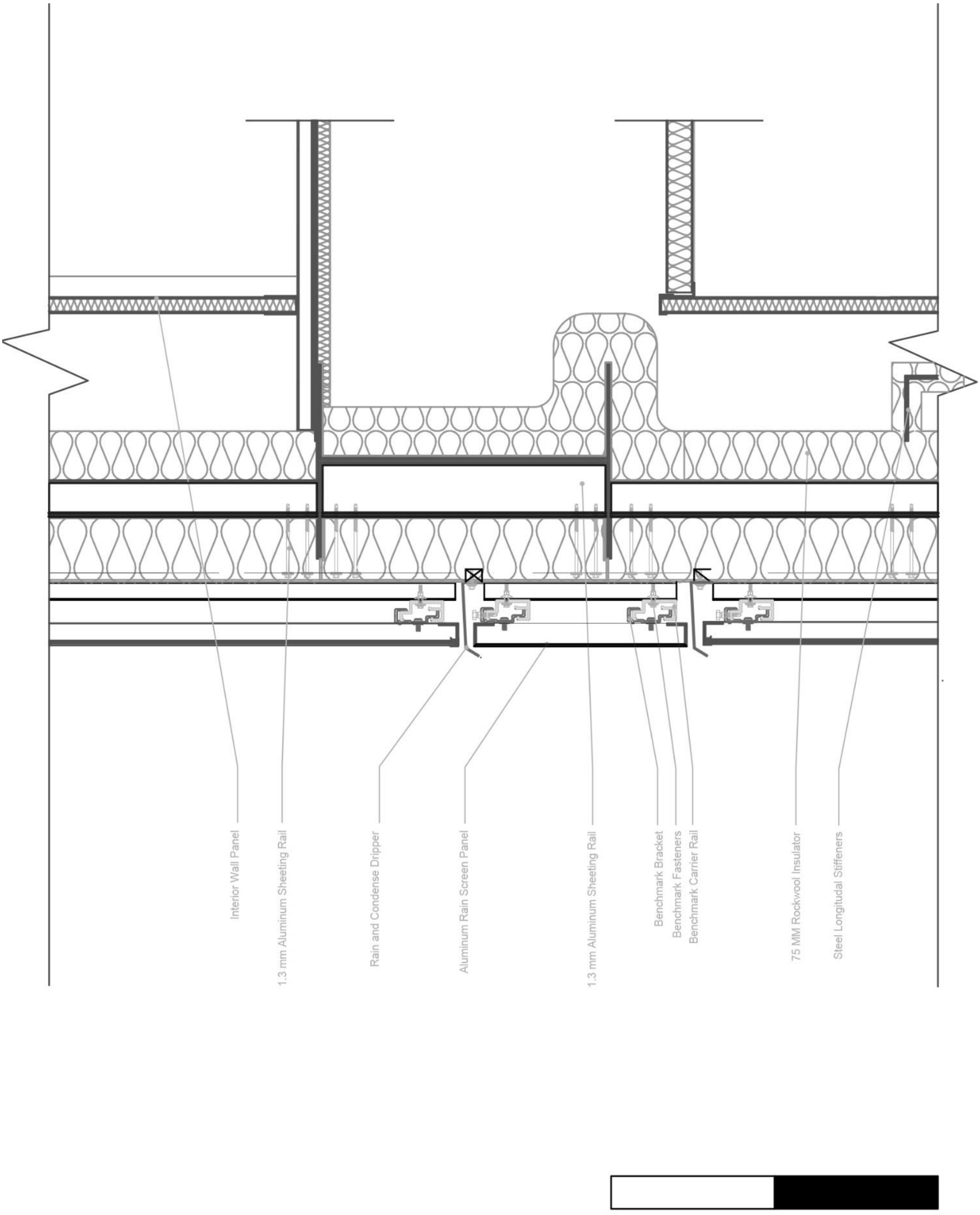
Vertical Details



Detail A1

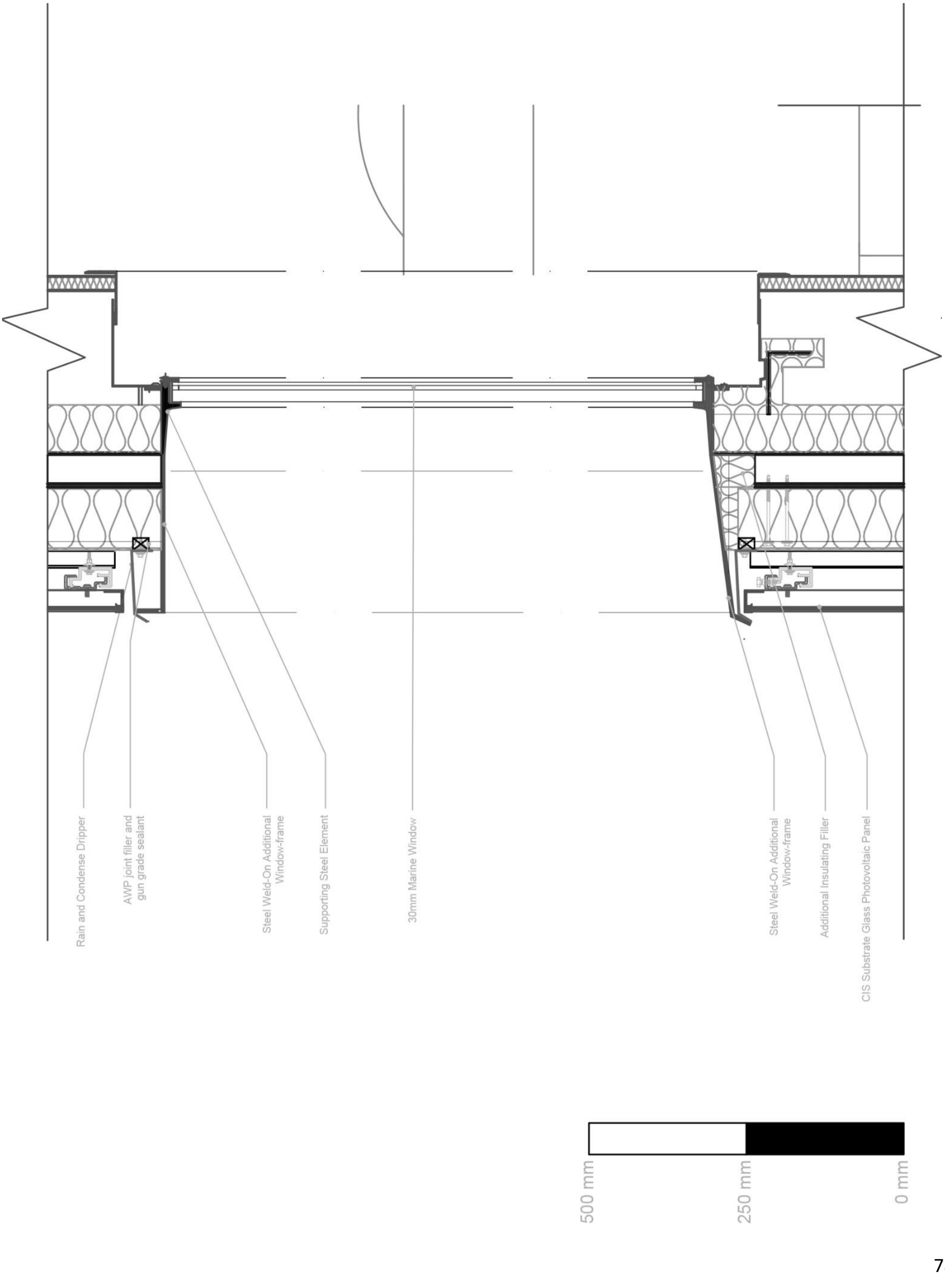

4.5 mm Steel Bulkhead, Original External Facade
1.3 mm Aluminum Sheeting Rail
Benchmark Insulating Panel
CIS Substrate Glass Photovoltaic Panel
Air Seal - Continues Seal of Gun Grade Sealant
Air Seal - Continues Seal of Gun Grade Sealant
Benchmark Bracket
Membrane Lined Insulated Gutter
Aluminum Rain Screen Finishing
HEB - 450
Drilling Rig Deck
500 mm
250 mm
0 mm

Detail A2



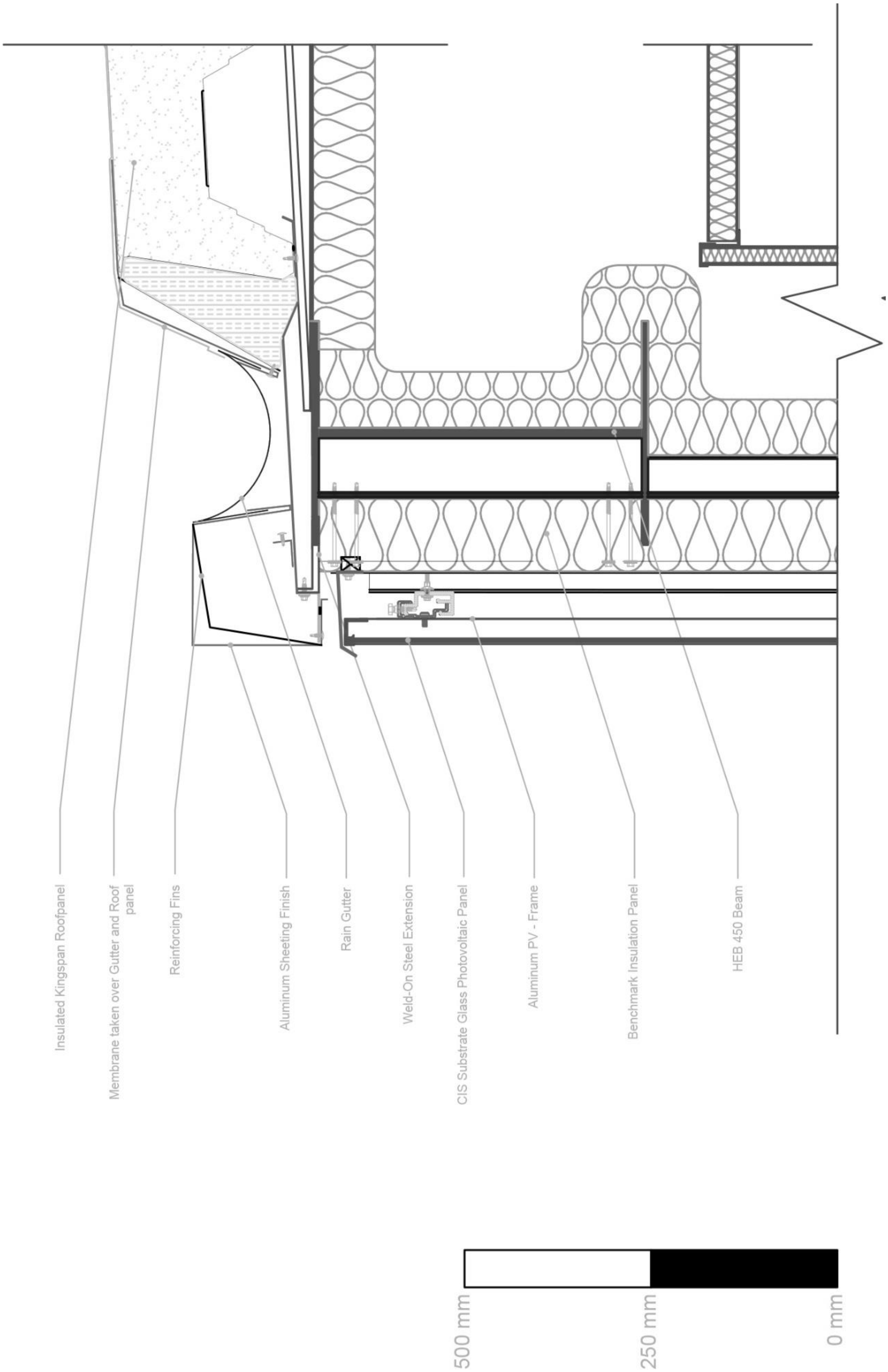
Interior Wall Panel
1.3 mm Aluminum Sheeting Rail
Rain and Condense Dripper
Aluminum Rain Screen Panel
1.3 mm Aluminum Sheeting Rail
Benchmark Bracket
Benchmark Fasteners
Benchmark Carrier Rail
75 MM Rockwool Insulator
Steel Longitudal Stiffeners
500 mm
250 mm
0 mm

Detail A3



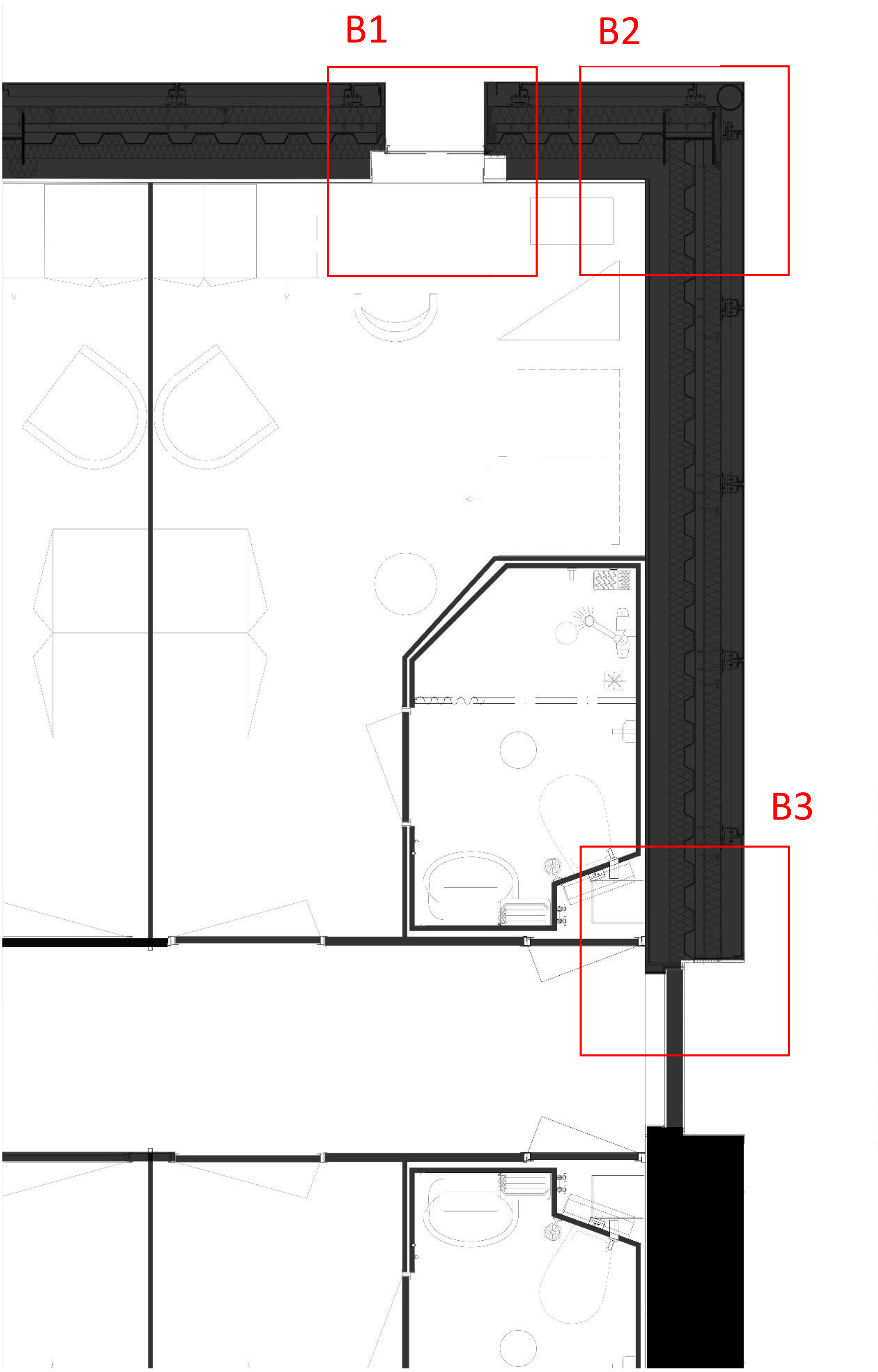
Rain and Condense Dripper
AWP joint filler and gun grade sealant
Steel Weld-On Additional Window-frame
Supporting Steel Element
30mm Marine Window
Steel Weld-On Additional Window-frame
Additional Insulating Filler
CIS Substrate Glass Photovoltaic Panel
500 mm
250 mm
0 mm

Detail A4

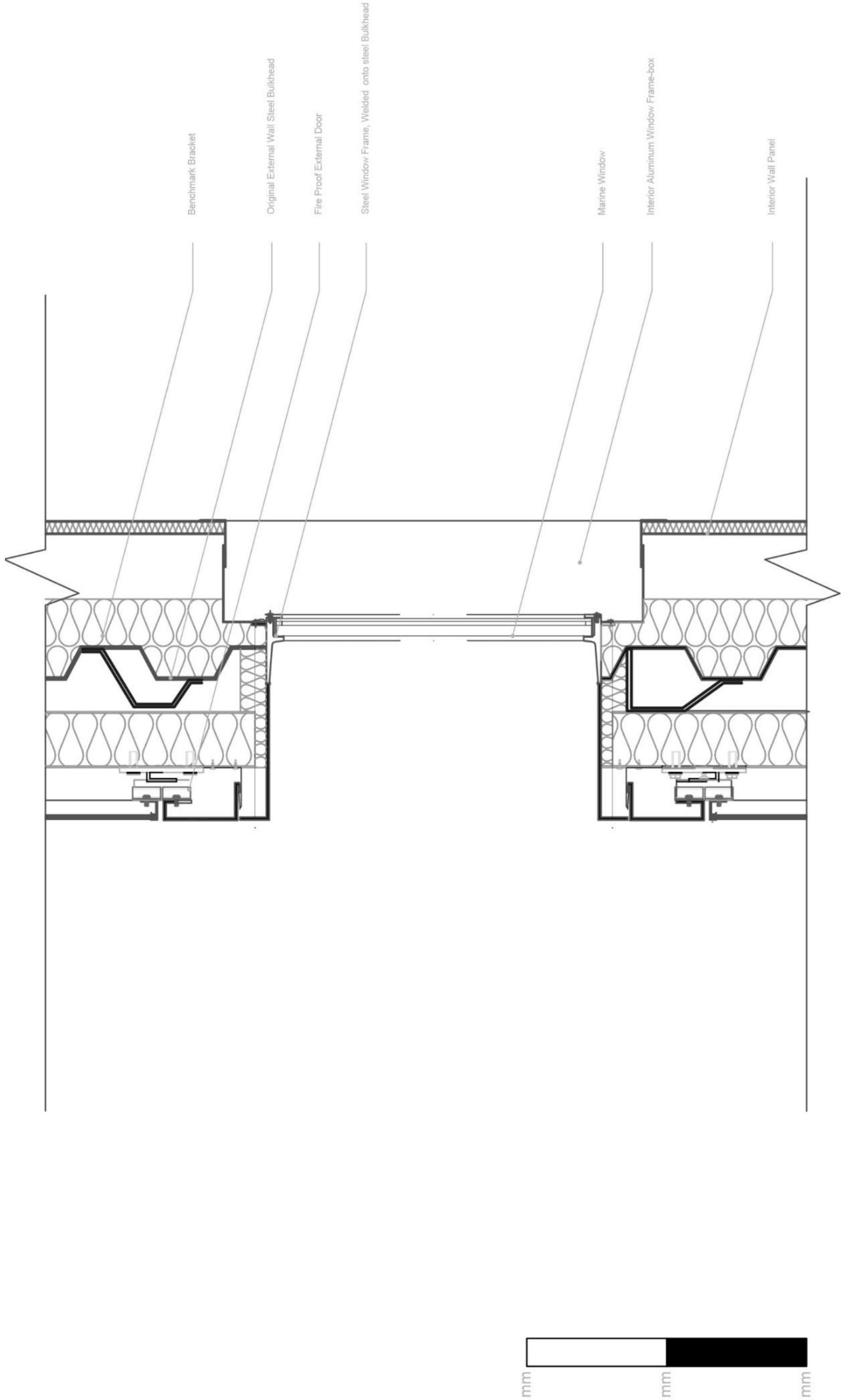


Insulated Kingspan Roofpanel
Membrane taken over Gutter and Roof panel
Reinforcing Fins
Aluminum Sheeting Finish
Rain Gutter
Weld-On Steel Extension
CIS Substrate Glass Photovoltaic Panel
Aluminum PV - Frame
Benchmark Insulation Panel
HEB 450 Beam
500 mm
250 mm
0 mm

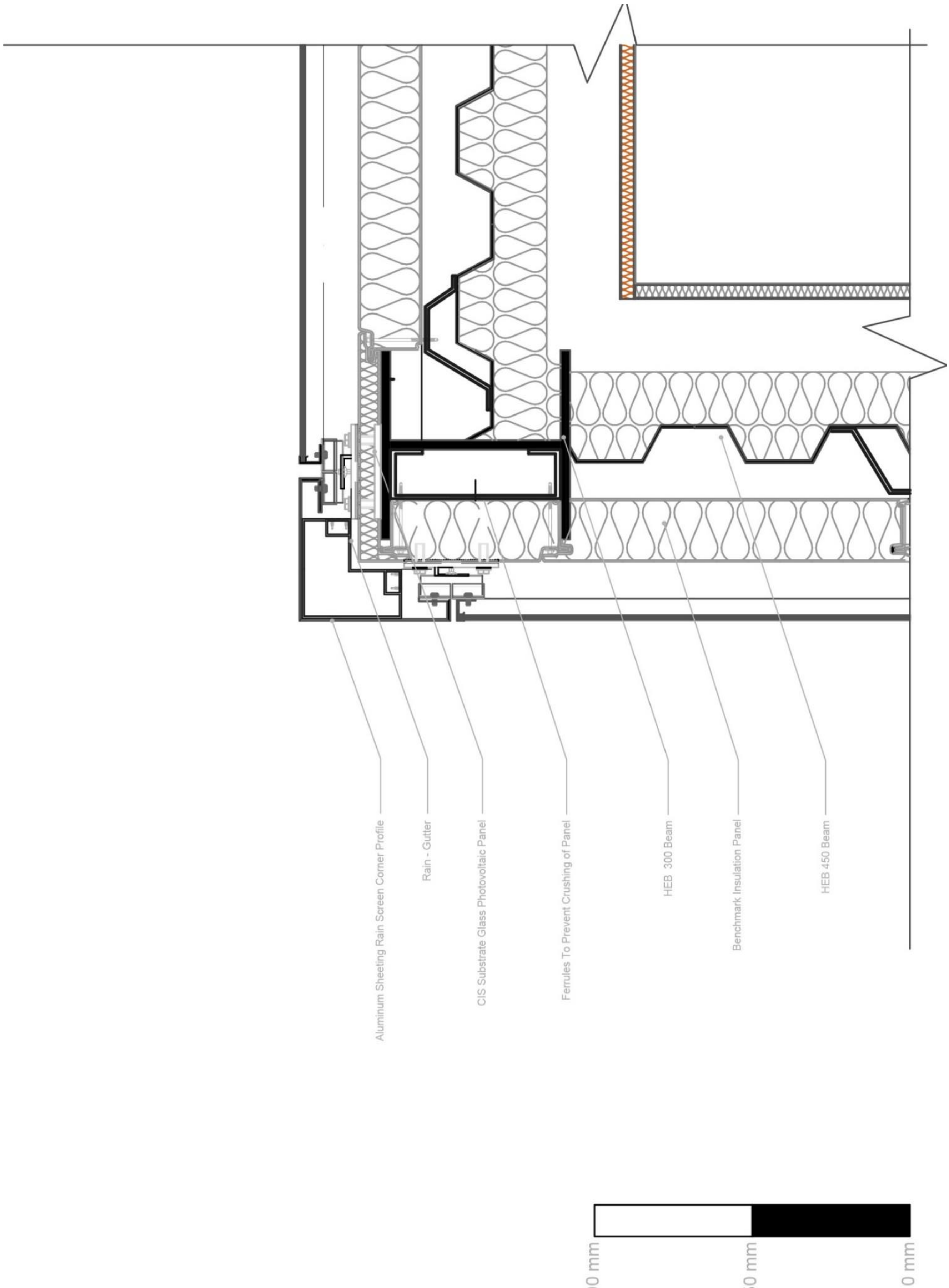
Horizontal Details



Detail B1

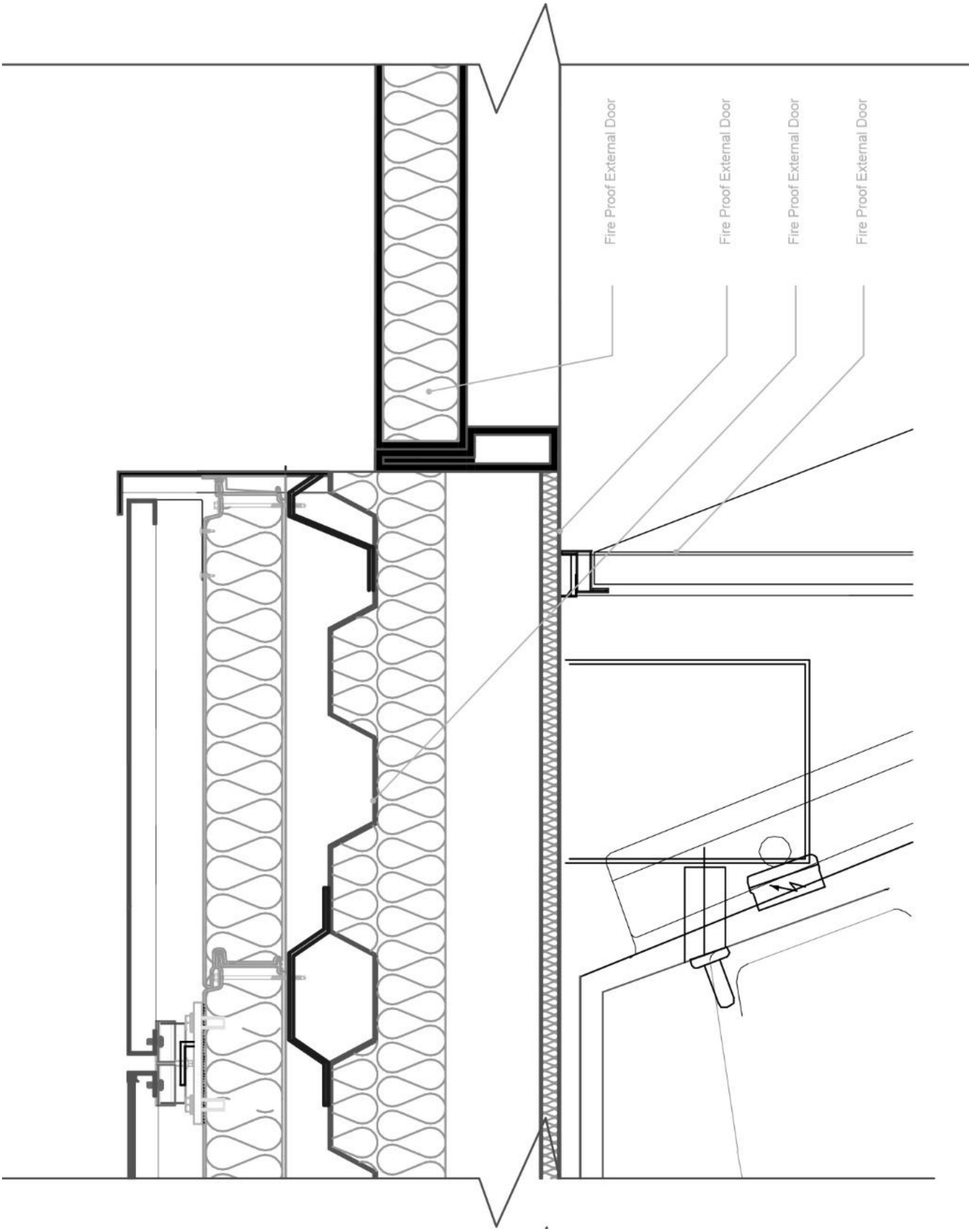

Benchmark Bracket
Original External Wall Steel Bulkhead
Fire Proof External Door
Steel Window Frame, Welded onto steel Bulkhead
Marine Window
Interior Aluminum Window Frame-box
Interior Wall Panel
500 mm
250 mm
0 mm

Detail B2



Aluminum Sheeting Rain Screen Corner Profile
Rain - Gutter
CIS Substrate Glass Photovoltaic Panel
Ferrules To Prevent Crushing of Panel
HEB 300 Beam
Benchmark Insulation Panel
HEB 450 Beam
500 mm
250 mm
0 mm

Detail B3


Fire Proof External Door
Fire Proof External Door
Fire Proof External Door
Fire Proof External Door

8 Conclusion

The research builds further on older research by Keppel Verolme and the TU Delft, in which the possibility of an sustainable offshore accommodation is explored. Several strategies are shown to have an impact on the energy use aboard an offshore accommodation; like the use of LED-lighting, thicker insulation and natural ventilation.

With this information it was concluded that a difference had to be made between the different kinds of energy input and output of the offshore accommodation in order to divine the research scope individually. The division was made between active/passive energy generation, and energy demand/losses. In which it was decided to further elaborate on the losses of the offshore accommodation. Which meant a focus on reducing heat losses through the walls and solar heat gain through the windows/walls.

The offshore industry was then analyzed in order to get a grasp of the different regulations and how it was built. it became clear that fire-safety and weather proof design were important aspects of the addition to the walls. A study case was developed based on two currently existing offshore stations, the GlobalTech 1 and the MPU block, of which one was available at the Keppel Verolme shipyard. These two were combined in a study case model of three floors with the dimensions of 16 meter by 20 meter and a height of 8 meter.

This design was also the base of a simulated model in which the energy use of the offshore accommodation is broken down into different areas. This gave insight into the total energy-use and energy use of heating/cooling, heat loss through the walls and solar radiation in two different locations. The locations considered were the North Sea and the Gulf of Mexico, picked because of the representation of a tropic climate and cold climate. The total heating/cooling energy use in the North Sea was **36.2 MWh** and **23.6 MWh** in the Gulf of Mexico.

During the concept development, three different sustainable strategies came forward. It was thought that thickening the insulation, applying shading elements and additional energy generation would be able to reduce the energy costs significantly. However, the savings achieved when applying the insulation and shading were lower than expected, with a maximum of **7%** on the total when applying an extra R-value of 7 in the North Sea, and even consuming more energy **(-1.9%)** when the same insulation was applied in the Gulf of Mexico.

However for the final design it was chosen to implement all strategies in order to save the maximum possible. This system consisted of an addition of insulation, a rain screen of aluminum panels, in combination with PV-panels, a particular strength of this concept would be the possibility of global implementation.

The design features aluminum panels, which cover areas where PV-panels are not implemented, which is mainly on the North Side and in between the floors on the East, West and South side. After calculation it became clear that this system would save up to **120 MWh** in the North Sea and **124 MWh** in the Gulf of Mexico. Respectively **30%** and **48%** of the total heating/cooling costs, assuming the PV-panels provide energy directly to the HVAC system.

The costs of the system can be broken down in two parts; the part where an aluminum panel is covering the insulation, and a part where the PV-panel is covering the insulation. Relative to the original facade, the costs of the aluminum coverage system is **141 %** more expensive and the costs of the PV-panel covered system is **391%.** Which results in a total costs of **409%** of the original façade costs.

The payback of the system is related to the location of the station, where the North Sea provides a pay-back of 9 years and the Gulf of Mexico a pay-back of around 10 years, which could be a benefit, considering the lifetime of the system of 30 years.

Bibliography

(2015, december 16). Retrieved from ProSafe: http://www.prosafe.com/the-environment/category915.html

(2015, 12 29). Retrieved from Cepheus: http://www.cepheus.de/eng/index.html

(2016, 01 14). Retrieved from Inhabitat: http://inhabitat.com/wp-content/blogs.dir/1/files/2013/03/GreenDot-Animo-Lennox-Charter-High-School-Brooks+Scarpa-Architects-6.jpg

ABS. (2012). *Crew HAbitability on Mobile Offshore Drilling Units (MODU's).* Houston: American Bureau of Shipping.

Advantages of Underfloor Heating. (2015, 12 21). Retrieved from Ice Energy: http://www.iceenergy.co.uk/advantages-of-underfloor-heating/

ARUP. (2014). *Decommissioning in the North Sea.* Glasgow: Scottish Enterprise.

ASHRAE. (2013). Thermal Environmental Conditions for Human Occupancy. *ANSI/ASHRAE Standard 55-2013*.

Boer, K. W. (2016, 01 12). *Solar Cells*. Retrieved from ChemistryExplained: http://www.chemistryexplained.com/Ru-Sp/Solar-Cells.html

Burdick, A. (2011). *Strategy Guideline: Accurate Heating and Cooling Load Calculations.* Oak Ridge: US department of Energy.

Capital Expenditure. (2015, 12 22). Retrieved from Investopedia: http://www.investopedia.com/terms/c/capitalexpenditure.asp

CAT. (2016, 04 12). *Diesel Generator Sets*. Retrieved from Cat.com: http://www.cat.com/en_US/products/new/power-systems/electric-power-generation/diesel-generator-sets/18321430.html

Colt International Ltd. (2016, 10 01). *Solar Shading Design Considerations*. Retrieved from Coltinfo: http://www.coltinfo.co.uk/solar-shading-design-considerations.html

Department of Energy . (2015, 12 23). *insulation*. Retrieved from Ornl.gov: http://web.ornl.gov/sci/roofs+walls/insulation/ins_02.html

DesignBuilder. (2015, 12 28). Retrieved from DesignBuilder: http://www.designbuilder.co.uk/

DesignBuilder. (2015, 07 15). DesignBuilder Manual v4.5. *DesignBuilder EnergyPlus Simulation Documentation for DesignBuilder v4.5*. DesignBuilder.

EERE. (2016, 04 12). *EnergyPlus*. Retrieved from EERE: http://apps1.eere.energy.gov/buildings/energyplus/

Feist, W. (2016, 01 12). *Passive House Insulation*. Retrieved from passiv: http://passiv.de/former_conferences/Passive_House_E/Passive_house_insulation.html

Fire Protection Measures. (2015, December 22). Retrieved from Electrical Engineering Portal: http://electrical-engineering-portal.com/fire-protection-measures

GlobalTechOne. (2015, 12 28). *About: GlobalTech 1*. Retrieved from GlobalTech 1: http://www.globaltechone.de/en/about/

Gorse, C. A. (2012). Thermal Bridge. *Oxford Dictionary of Construction, Surveying, and Civil Engineering*, 440 - 441.

Grondahl, M., & Gates, G. (2010, September 25). *The Secrets of a Passive House*. Retrieved from The New York Times: http://www.nytimes.com/interactive/2010/09/26/business/smart.html?_r=0

Hausladen, G. &. (2010, 06 21). *Interiors Construction Manual: Integrated Planning, Finishings and Fitting-out, Technical Services.* Berlin: Birkhauser Verlag. Retrieved from Educate Sustainability: https://www.educate-sustainability.eu/kb/sites/www.educate-sustainability.eu.portal/files/images/2-6-2%20[Konvertiert].png

Hines, J. (2012, October). Offshore Regulatory Issues. *Standard Bulletin: Offshore Special Edition*, p. 7.

IDES Floor. (2015, 12 21). Retrieved from Cepezed: http://www.cepezed.nl/en/projects/149-ides-floor

ISSF. (n.d.). *Case Study .*

Kingspan. (2016, 12 04). *Datablad Benchmark Karrier.* Retrieved from Kingspanpanels.nl: http://www.kingspanpanels.nl/Media-centre/Resource-Centre/Databladen-Instructies/Databladen/DATABLAD-BSP

Kingspan. (2016, 12 11). *Fire Brochure.* Retrieved from kingspanpanels.nl: http://www.kingspanpanels.nl/Fire/Brochures/Not-All-Insulation-is-the-Same-Brochure-2015-Updat

Kingspan. (2016, 05 12). *XL Forte 1008UK.* Retrieved from vandenbergjoure.nl: http://www.vandenbergjoure.nl/images/pdf/XL_Forte_1008UK.pdf

Lopez, P. B. (2011). *Solar Thermal Collector in Facades.* Delft: TuDelft Repository.

Lopez, P. B. (2011). *Solar Thermal Collector in Facades.* Delft: Tu Delft Repository.

Lundberg, A. (2015). Thermal Bridge Assessment and Competency - a look at the UK context. *Planning & Building Control Today*, -.

Maguire, D. (2008). *The Business Benefits of GIS: an ROI approach.* Redlands: ESRI Press.

Maritime Battery Forum. (n.d.). *New dutch Hybrid Ferry*. Retrieved from Maritime Battery Forum: http://maritimebatteryforum.com/news/new-dutch-hybrid-ferry

McLendon, R. (2016, 01 11). *Types of offshore oil rigs*. Retrieved from MNN: http://www.mnn.com/earth-matters/energy/stories/types-of-offshore-oil-rigs

NORAC AC. (2015, 12 22). Marine Interior Systems - Product Manual. *Marine Interior Systems*.

NORSOK. (2006). *NORSOK standard C-001.* Lysaker: Standards Norway.

NORSOK. (2006). *NORSOK Standards C-002 Architectural components and equipment.* Lysaker: Standards Norway.

Offshore Accommodation and Workspace Modules. (2015, 12 21). Retrieved from http://www.ferguson-group.com: http://www.ferguson-group.com/ferguson-modular/

Otheguy, M. (2014). Designing with Flows: Energy-Efficient Offshore Accommodations. *KOMtech Technology Review* .

P. Torcellini, S. P. (2006). *Lessons Learned from Case-studies of six High Performance Buildings.* Golden: National Renewable Energy Laboratory.

Peters, A. (2016, 01 06). *The top 10 most innovative sustainable buildings of 2014*. Retrieved from FastCoexits: http://www.fastcoexist.com/3029434/the-top-10-most-innovative-sustainable-buildings-of-2014

Price Industries. (2011). *Natural Ventilation Engineering Guide.*

Prosafe. (2016, 06 20). *Regalia*. Retrieved from Prosafe: http://www.prosafe.com/regalia/category137.html

PVGis. (n.d.). *PV estimation*. Retrieved from Europe.eu: http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php.

Ragheb, A. E.-S. (2015). *Green Architecture: A Concept of Sustainability.* Mansoura: Elsevier Ltd.

RSCP. (2016, 01 13). *R Value Table*. Retrieved from Residential Shipping Container Primer: http://www.residentialshippingcontainerprimer.com/R%20Value%20Table

Simon Roberts, N. G. (2003). *Building Itntegrated Photovoltaics - A Handbook.* Basel: Brkhäuser Verlag AG.

Sneep, T. (2014). *Energy-Efficient Offshore Accommodations, research paper toward warm areas.*

Solar Frontier. (n.d.). *Solar Frontier 170Wp*. Retrieved from Sinnetechnyk: https://www.sinnetechnyk.nl/wp-content/uploads/2015/01/SinneTechnyk_Solar-Frontier-170Wp.pdf

sun position calculator. (n.d.). Retrieved from Pveducation: http://www.pveducation.org/pvcdrom/properties-of-sunlight/sun-position-calculator

SunPower. (2016, 12 01). *X Series Panels*. Retrieved from SunPower: http://us.sunpower.com/solar-panels-technology/x-series-solar-panels/

TU Delft. (2014). Extreme Project Introduction. TU Delft.

Ueno, K. (2010). *Residential Exterior Wall Superinsulation Retrofit Details and Analysis.*

Vella, H. (2015, 12 22). *Offshore Savety Design, Preventing The Next Deepwater Horizon*. Retrieved from Offshore-Technology: http://www.offshore-technology.com/features/featureoffshore-fire-safety-design-preventing-deepwater-horizon/

Wikipedia - albedo. (2016, 06 06). *Albedo*. Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Albedo

Wikipedia. (2016, 01 12). *Building Insulation Materials*. Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Building_insulation_materials

Wikipedia. (2016, 01 11). *Bulkhead*. Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Bulkhead_(partition)#Fire-resistance

Wikipedia. (2016, 01 11). *Flotel*. Retrieved from Wikipedia : https://en.wikipedia.org/wiki/Flotel

Wikipedia. (2016, 01 13). *R Value*. Retrieved from Wikipedia: https://en.wikipedia.org/wiki/R-value_(insulation)

Wikipedia. (2016, 11 01). *Solar Gain*. Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Solar_gain

Wikipedia. (2016, 11 01). *Soundproofing*. Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Soundproofing

Zeegers, A. (2006). Warmte, Warmtetransport, thermische isolatie. In A. v. Linden, *Bouwfysica* (pp. 3-10). Utrecht/Zutphen: Thiememeulenhoff.

Zeller, T. (2010, September 26). Beyond Fossil Fuel: Can We Build in a Brighter Shade of Green. *New York Times*.