MASTER THESIS
THY NATIONAL PARK VISITOR CENTER

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Title: Thy National Park Visitor Center
Semester: A&D Msc04
Theme: Master Thesis
Period:February to May 2015

Project group: 11
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Pages: 93
Appendix: 14

PREFACE

Presented project report of Master Thesis was developed by group 11 at the 4th semester of Architecture M.Sc. program at Architecture and Design, Aalborg University.

The project report is the outcome of the Project Module 04: Master Thesis with the focus on sustainable architecture.

The project covers the period from the 2nd of February to the 28th of May 2015.

ABSTRACT

Master Thesis project report presents the entire process of developing the design of Thy National Park Visitor Center in Nørre Vorupør, including analysis, main presentation and design process. Thy is the first Danish National Park founded in 2008, that awaits the visitor center since development of local plan in 2010.

The project task focuses on designing a mixed-use visitor center, which not only serves tourism needs, but foremost is dedicated to local community, dissemination of knowledge about natural phenomenons present in the park and increasing the economical potential of the region. Furthermore, the project seeks to achieve nearly zero energy performance as en exemplary buidlign which performs in accordance with environment, thus providing the good indoor quality and high functionality.

The project takes it's starting point in assuming the attitude and understanding of terms "Nordic" and "Sustainability", using it as a background for further design. The thourough analysis depicts the qualities and challenges of the site with regard to surroundings and climatic conditions, as well as cultural conotations, local community needs and goals set by the Board of park.

The concept is to strongly refer to the surroundings, with respect to local context, nature and exisitng local habits. Hence, aiming to become a point of fusion between town's heritage, nature and people.

The result is a unique Visitor Center that works as a gateway to the Thy National Park, by its outstanding architecture, which blends with the dunes. The design also includes redevelopment of the main plaza, what makes the entire project coherent and attractive for both visitors and local residents.

METHODOLOGY

The presented project is an outcome of an iterative proces based on critical analysis and design method „The integrated design proces" described by Mary-Ann Knudstrup [Knudstrup, 2004] That method is chosen upon it's ability to integrate aesthetical, functional and technical aspects of architecture, already in the early design stages, which helps to develop well balanced and sensible design. The method is devided into five main phases which flow smoothly one into another creating design loops.

Problem phase

The design proces begins with critical analysis made in order to instill a position according to sustainability and Nordic architecture. Problem formulation is based upon empirical experiences from the multiple visits at the site as well as challenges, possibilities and ambitions presented by the local community and Park Authorities. Solid problém based design is deepen by thorough analysis of case studies of both nordic and sustainable architecture.

Analysis phase

Problem phase smoothly flows into the analysis , which focuses on the project location and context with a view to developing principles based on environmental, contextual and cultural aspects. Analysis is carried out in order to set up architectural opportunities, but also the challenges which lead to creation of sustainable Nordic design rooted in land and context.

The empirical experiance and discovering of sense of place is carried out by multiple visits to the National Park in order to feel on the own skin the surrounding nature, to understand the local community. It is also supplemented by the artistic expression of different light moods by painting watercolors in order to derive the spirit of nature.

Furthermore, for depper understanding of the building site analysis in plan, sections and 3d model is applied with focus on views, natural resources and landscape challenges. Further analysis is made to investigate climate conditionos with special focus on the wind, but also history and culture of the park and its inhabitants, finally trying to understand the needs of different groups of visitors.

Sketching phase

The sketching phase involves many variuos studies including hand drawings, watercolor paintings, physical modeling as well as digital sketching tools. The process becomes iterative between different forms such as plans, sections, perspectives and impressions, but also various scales – master view, landscape, space building and detail, always having in mind a low energy performance of the building. During this phase many ideas emerge and are selected to evolve into the idee fixe and a main concept of the project. All of the sketches are performed in relation to the previous phases thus complementing the phase with the critical and analytical approach.

Synthesis phase

In the synthesis phase the main concept transforms further into a tangible design proposal. In this phase more digital tools are implemented in form of 3d modelling with visualisations, but most importantly in formo f various tests using programs helping to develop the sustainable solutions with focus on good indoor climate and low energy performance. It progresses the design by adding more aspects into the iterations between functionality, aesthetics and technical aspects remembering the signifikance of detailing.

Presentation phase

This phase puts focus on developing the presentation materials in graphical and written form as well as in physical modelling, which is so important due to its impact on further dissemination and overal understanding of the design.

The Integrated Design Process encourages to brak with the traditional linear approach, proposing instead a non chronological method creting iterative loops between phases. All in al lit is crucial to keep in mind that not everything can be analyzed or calculated – it is often the immesureable that determines the final design „spirit".
[Knudstrup,2004]

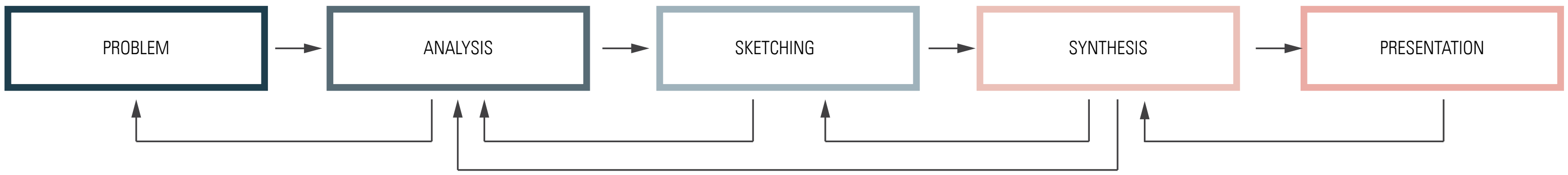


Fig.1 Methodology diagram [Knudstrup,2004]

CONTENT

01 INTRODUCTION

Fig.2 Watercolor impression of Thy

INTRODUCTION

Thy National Park is the first Danish national park founded in August 2008. It is a unique place at Thy western coastline stretching by the North Sea, where the largest wilderness spreads its untamed forces. It's characteristic, unspoiled dune heaths formed by the sea, the wind, the salt and the sand create an outstanding landscape where the animals and plants have adapted to these extreme living conditions and where the resident's life unfolds in harmony with the nature being always deeply rooted in their minds. [Nationalpark Thy, n.d.]

This exceptional spot on the map of Denmark deserves am outstanding National Park Center that will serve the thousands of tourists coming every year, as well as Park authorities and residents, but most importantly by the close interaction with environment will enhance the beauty of surrounding nature. The Park authorities ambition is to create a gateway to the national park that combines the best of adventure destination with a learning facility build as a locally based platform in an innovative and sustainable way, in order to provide visitors with an unforgettable experience, simultaneously boosting the local commitment in the dissemination of natural and cultural history of Thy National Park.

The assignment raises this initial question:

How to develop a sustainable building rooted in Nordic context of one of the Danish most scenic areas that enhances the surrounding beauty and strengthens the local community?

SUSTAINABILITY

In light of contemporary greatest humanity issues such as environmental degradation, global warming, overconsumption and a pursuit of economic growth the recently fashionable idea of sustainability is continuously questioned and has as many supporters as opponents. Despite it's weaknesses the sustainability is an utopic idea, which can be transformed into reality only by tangible examples.

The word sustainability has roots in the Latin sustinere (tenere, to hold; sub, up). Sustain means "support", "maintain" or "endure". [Dictionary, n.d.] In the 80s the most popular definition of sustainability was formulated by Brundtland Commission as:

"*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*"

[Brundtland Commision, 1983]

If this sentence is supposed to be referred to the project development than it becomes a conscious choice that focus should be oriented towards sustaining natural environment and renewable energy sources. Nevertheless, as formulated in World Summit Outcome Document during the 2005 World Summit on Social Development three pillars of sustainability were distinguished – environmental, economical and social. Furthermore, sustainability entails innovation and responsible decision-making, while diminishing the negative impact on environment and ensures balance between economic growth, ecological resilience and a cultural vibrancy in order to maintain attractive planet for all species in the present and in the future. [Magee, 2013]

Environmental Sustainability

Environmental sustainability as one of the main focal points of the project, which in more general terms is ability to minimize the influence of the spatial practice and human activity on the environment, thus leading to retaining the diverse and productive ecosystems. It not only focuses on passive strategies providing good indoor climate and using renewable sources of energy, but also on educational aspect of broadening the knowledge and awareness of contemporary environmental issues.

Economic sustainability

In Thisted Kommune's business strategy the National Park was called „*one of four engines of growth*", thus putting their hope in the Visitor Center as a local business hub. In the municipality of Thisted and in Thy Business Forum aroused high awareness that spreading the good word about Thy, based on nature as a resource is an essential contribution in the attraction and settlement of skilled labor and entrepreneurs. The Center should strengthen this story and thus contribute to an overall marketing of Thy and promotion of local stakeholders, also becoming a driver for new business opportunities for the benefit of local community, for example in bicycle or surfing tourism.
[Board of Thy National Park 1, 2015]

Social sustainability

In the overall outskirts discourse that nowadays people move to the big cities, as places of greater opportunities Thy is fighting to sustain their local society and respond to this negative movement. The region already offers a number of examples where new perspectives highlight Thy, as a special outskirts, where nature provides the basis for a positive development Not mentioning the National Park itself, another good example is Klitmøller and a Cold Hawaii brand, which is world famous for its surf spots in Agger, Vorupør, Klitmøller and Hanstholm. Thisted Kommune believes that Visitor Center will contribute to the region utilization of the special natural capital and will attract new businesses and new residents who oppose the current migration to the big cities and traditional centers of power, strengthening the sense of community and improving it's interactions.
[Board of Thy National Park 1, 2015]

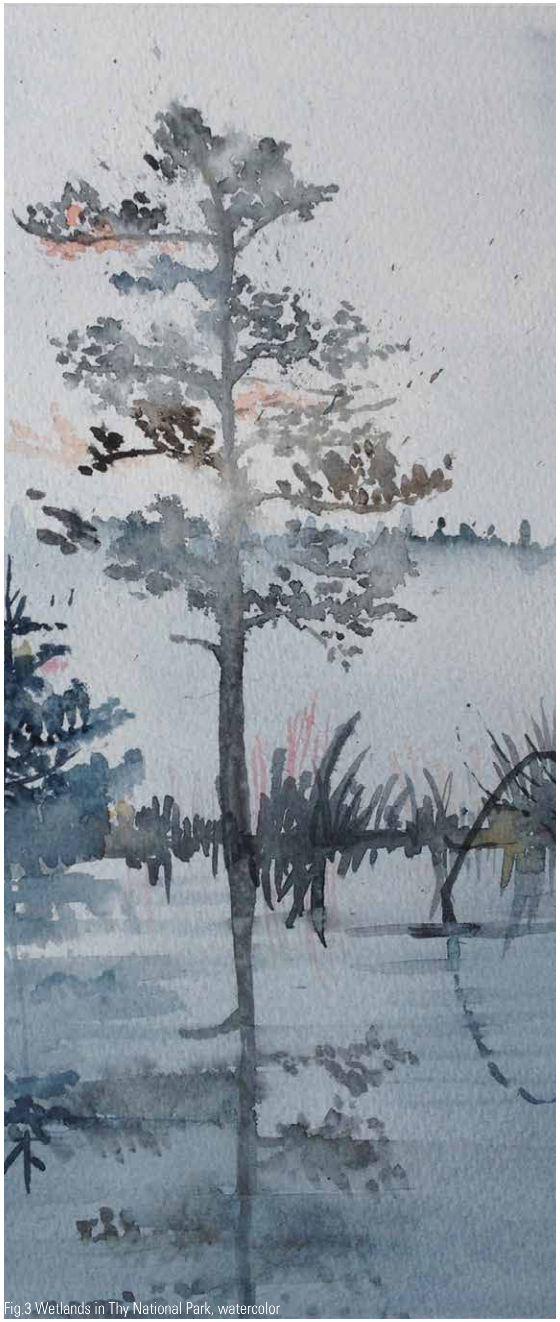


Fig.3 Wetlands in Thy National Park, watercolor


Fig. 4 Nordic sky in Norre Vorupør, watercolor

NORDIC

What briefly defines Nordic lands is exceptional light and it's eerie ability to create moods. Nordic sky, especially on the coast is so unpredictable and volatile that it provides new experiences to observers every day and was a great source of inspiration to artist for many years. As Norberg-Schulz mentioned in „Nightlands" – „(...) *it is precisely light that defines the Nordic world and infuses all things with mood. Light informs us instantly that we are no longer in the South*" [Norberg, 1996, p. 8]. Ever changing light with the „performance" of clouds emphasizes the power and majesty of sky, which becomes especially powerful in the flat lands like Denmark. It is not only light that defines Nordic moods, but also a harsh weather, including the beauty of a storm hitting the coast, driving clouds and afterwards bringing the alleviating sunlight. Therefore in design of Nordic architecture it is so crucial to utilize this natural quality and let the sun enter spaces.

Thus, here in Denmark – in the open land of hill and dale, exposed to the howling winds inhabitants were focused on creating a safe dwelling, therefore the home and humanistic approach to architecture have become a main drivers of Nordic architecture. [Norberg, 1996] This can be recognized in building forms, scale, materials and detailing. As Norberg describes Danish architecture „ (...) *building adapts topographic movement and rhythm, presupposing small, low units: earth-hugging, one-story houses* (...)", which shows how Danish interpretation of Nordic architecture mimics the surrounding landscape creating safe dwellings in the hollows with well balanced functionality and minimalistic expression. It's low set form with resistant and well ageing structure of bricks supplemented by wooden elements have become a material choice driven from natural resources and ability to shield from strong winds and changeable weather. Materials are natural and simple, sensitively arranged together into tactile and appealing to eye details.

Finally, Norberg delineates one of the most important characteristics of Nordic architecture, that „*Danish settlement creates, rather, a soft passage toward the open land through the use of gardens and vegetation. Nearness to nature is thus a characteristic quality.*" [Norberg, 1996] Nordic means indissoluble with nature, just like it's architecture, which is rooted in the landscape and sensitivity to the context.

Nevertheless, Nordic architecture is no longer identical to how it was perceived by Norberg –Schulz. It has enriched with contemporary interpretations of architecture in 2000s named New Wave, strongly affected by globalization and a mixture of foreign cultures. New Nordic tendencies are not solely based on evolving from landscape and forming a shelter, serving as an aesthetical „object", but rather solving the contemporary issues by understanding it's own time. The main point is to focus on pragmatic architecture that serves people taking into consideration contemporary problems such as climate issues, economic recession, limited resources and IT revolution. [Weiss, 2012]

Despite the quite large skepticism of the New Wave in general the contemporary understanding of Nordic architecture emerges from these two approaches – on one side strongly rooted in context and landscape, but on another responding to the present problems with the sustainability foremost.

Fig.5 Trollstiegen Visitor Center

Fig.6 Trollstiegen Visitor Center

TROLLSTIEGEN VISITOR CENTER

Trollstiegen Visitor Center can be described as one of the finest examples of New Nordic architecture contributing to the enhancement of nature's beauty. The building designed by Reiulf Ramstad Architects as an addition to the existing viewing platform forms part of the National Tourist Routes in Norway. Situated in breathtaking landscape of Norwegian mountain pass Center highlights the experience of location and surrounding breathtaking nature.

The centrally located part of the building includes café and tourist information, while the other wing contains gift shop, kiosk and service facilities. The design was made to remind of shapes of mountain peaks and slopes, constructed of two shells built from steel and concrete, which visually intersect each other in order to create a safe, but glass-walled shelter in the harsh mountain climate. Concrete frame filled with glass provides spectacular views and break the boundaries between interior and nature.
[Reiulf Ramstad Arkitekter, 2012]

Moreover, the water as a dynamic component becomes a key element of the design. Building is supplemented by series of stepped ponds filled with running water that help control the flow of the river. As Reiulf Ramstad, author of the building says:

"*Much of the uniqueness of Nordic culture, and Norwegian culture in particular, is based on our relationship to water"* than he adds that "*At Trollstigen, water can be experienced as snow on the mountains, as a glistening mirror, as a swirling but controlled cascade or as a dramatic waterfall, all of which is reflected in the Visitor Centre's design.*"
[Wallpaper, 2012]

Raw concrete interior finishes do not attract visitor's attention, the opposite by its slightly reflective, cantilevered ceiling surfaces it directs eyes to the outside to strengthen the nature's effect on the observers.

Fig.7 Trollstiegen Visitor Center elevations


Fig.8 Skagen Odde Naturcenter


Fig.9 Skagen Odde Naturcenter

SKAGEN ODDE NATURCENTER

" A building must have a soul that corresponds to the mood you are in; be in tune with what you are doing " - Jørn Utzon

[Quoted in ArcSpace, 2013]

Skagen Odde Nature Center is a museum devoted to natural elements – wind, water, sand and light – situated three kilometers from the center of Skagen, in the hilly dune landscape, right at the north tip of Denmark where two straits, Skagerak and Kattegat, meet. Building designed by Jørn Utzon in 1989 and finished in 2000 by his son Jan Utzon, has become a one of the kind project praising the natural elements, which were fundamental to Utzon's work throughout all his life. [Skagen Natur, 2015] The main concept was driven from the idea of architecture growing out from the landscape, emphasizing the „soul" of the place characterized by it's tranquility, isolation and contemplative mood.

Center is called the „Dessert Fortress" as the 4 000 square meters complex is wrapped around by the 4 meter high brick wall, which works as shield from the wind and sand. Inside, the activity area consists of small pavilions topped with pyramidal roofs with skylights. In between them, there are cozy courtyards, walkways, ponds and viewpoints into the surrounding landscape. The color palette is rather restrained and natural, including gray concrete, gray brick walls and black felted roof, which all smoothly merges with the landscape's natural hues. [Skagen Natur, 2015]

Utzon summarizes the design himself:

"With its free-standing high walls with their powerful buttresses, the complex achieves the peace and simplicity that bring it into harmony with the grandeur of nature, the surf and the sky."

[Quoted in Weston, 2001, p. 363]

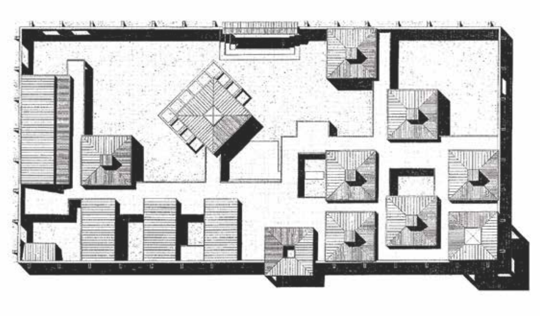


Fig. 10 Skagen Odde Naturcenter, roof plan

MOTIVATION AND GOALS

"The center must be perceived as an attractive, vibrant and inspiring entrance to the national park, giving visitors the desire to discover the national park's unique values"
[Nationalpark Fond Thy, 2010]

Thy National Park – a first Danish national park - created by natural phenomenon such as the North Sea, wind, salt and sand is a distinctive area of country's greatest wilderness, which deserves a proper Visitor Center. Board of the park has stated in the Park Development Plan that *"(...) Visitor Center must at the same time be a nature supporting and professionally managed institution that disseminates an understanding and commitment to the protection of the values that the National Park offers, but also that promotes development of the local business."* moreover *"(...) It is essential for the national park's success to find a lively workshop and communication place operating throughout the entire year and around the whole park".*
[Nationalpark Fond Thy, 2010]

Dissemination:
As the dissemination becomes the major motivation behind the Visitor Centre it's goal is to through experiences, nature guidance and communication increase the guest's understanding of the area's natural, cultural and recreational values and thus boost the desire to protect and preserve it through an active response. Nevertheless, it rarely occurs just by visiting the park, nor by reading leaflets, thus National Park Centre must inspire action and provide the knowledge about nature, landscape and culture trails, in order to make visitors be able to learn something new about the national park and even promote the effort towards supporting the nature. [Board of Thy National Park 2, 2015]

Dissemination criteria:
- to motivate and serve visitors to seek out and explore the national park's various gems
- to motivate visitors to actively take responsibility for nature
- to make the Center an integral part of the national park's overall communication platform, flexibly adaptable to varying user needs and target groups through the use of physical and virtual instruments

Tourism:
The establishment of the National Park Visitor Centre should fulfill a great need among tourists for information about the National Park. At the same time the Visitor Center by cooperating with Tourist Association and Thy Museum could provide a more comprehensive, united and visible offer to visitors in the area, as touristic opportunities are not properly advertised. Therefore there must be a focus on the development and visibility of the offers so it's easy to find information on activities and to find guidance on how to take the first steps out into the park's wilderness.

Goals towards tourism:
- to promote and strengthen all year round tourism in Thy
- to promote special tourist products that demand further knowledge and understanding of the area's natural and cultural history
- to contribute to the promotion of sustainable tourism in Thy
- to ensure high quality experience to visitors

Bussines:
Visitors to the national park will naturally demand a range of other services in connection with their stay. By placing the center at the edge of Vorupor, which has various shops, bicycle rental, lodging, restaurants, etc. the Park Center is able to refer to local traders rather than having to serve needs of every visitor, which obviously reinforces the local entrepreneurs. The center should strengthen the flattering story about Thy as land of opportunities based on nature as a resource and thus contribute to an overall marketing of Thy.

The goals towards business:
- to spread the good narration about the area and thereby contribute to increased settlement
- to become a showcase to Thy National Park partners in the food, non-food and communication businesses
- companies that use the Center in their marketing, will be coached to become more sustainable, including deeper environmental awareness and utilization of the local resources
[Board of Thy National Park 2, 2015]

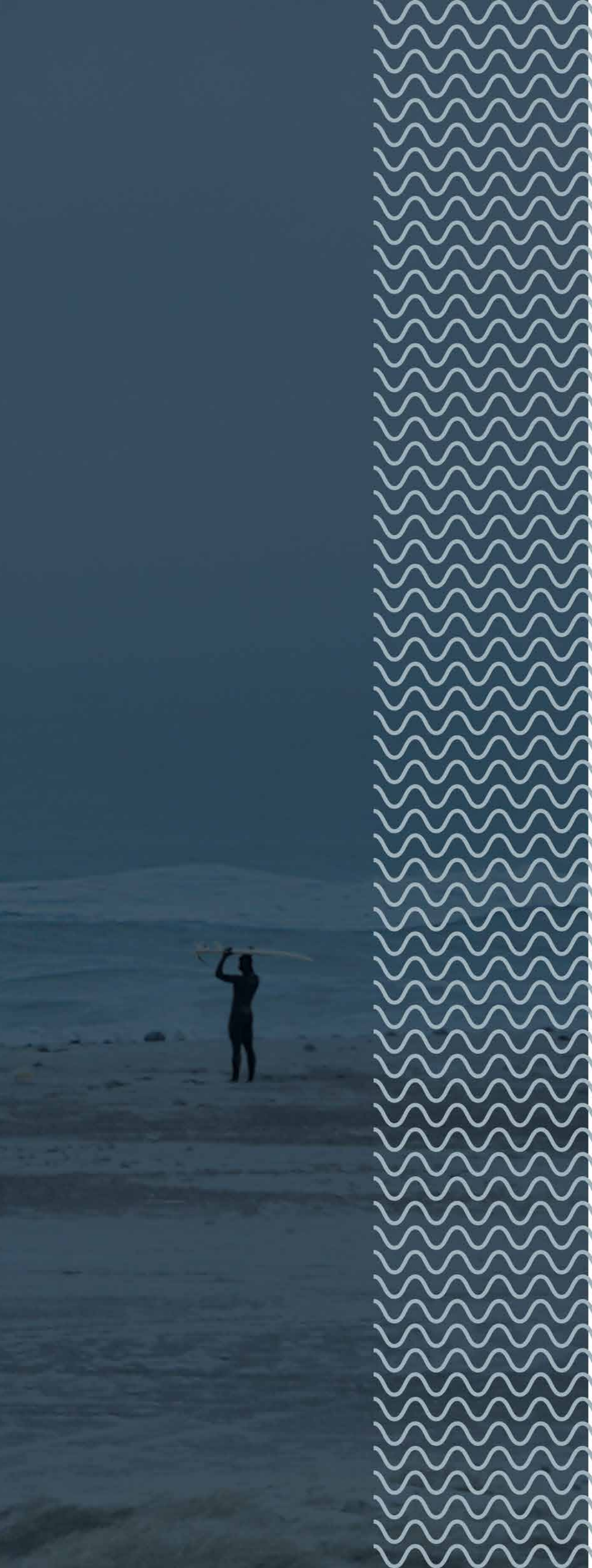
SUMMARY AND VISION

Through understanding of terms „Nordic" and „Sustainability", analysis of chosen case studies as well as objectives delineated by Board of Thy National Park vision for the design begins to clarify itself. In addition to that the theory of human aesthetics presented by Jay Appleton in *The Experience of Landscape* comes as a useful thought. He claimed the prospect-refuge theory based on analysis of various art pieces, form where he derived the observation about successful aesthetics in both art and architecture that need to fulfill two human inborn desires – of opportunity (prospect) and safety (refuge). It means that humans are attracted to spaces, where they can have broad unoccluded vistas, while being on the edge, where their back is protected and at the same time being covered from the open sky, giving the feeling of security. [Appleton, 1979] The theory seems convincing when rendered into the laws of wildlife or primary human instincts. Therefore, the design is intended to fulfill the sense of safety in the open, dramatic landscape, while providing with the views and possibilities of perceiving the natural beauty of surroundings.

Furthermore, the northern light, ever-changing weather conditions and moods arising from these fleeting experiences should define the architectural expression of the building that in accordance with nature will become a design united with landscape and reflecting it's moods. Visitor Center is intended to become an inspiring gateway to the national park that will combine the best of adventure destination with learning facility that through it's design will communicate it's affection for local cultural heritage and willingness to demonstrate how to develop a sustainable building in one of the country's most scenic areas.

Presented reflections lead to the formulation of the vision:

The design is aspired to create a learning and experiential facility rooted in it's natural environment and cultural context for the benefit of nature, local community and visitors.
The aim is to enhance the qualities of Nordic landscape and heritage, while setting the example of sensible, sustainable architecture.



02 ANALYSIS

DANISH NATIONAL PARKS

In Denmark national parks are rather new phenomenon. It all started with opening of the first Danish national park in August 2008 – located in Thy. Somewhat later the others followed Thy's footsteps, so in 2009 Mols Bjerge park was opened and afterwards in 2010 WaddenSea park. Already two new areas were nominated to join in, nevertheless prior to those nominations very profound process involving a lot of effort from local community has been taken place. Nonetheless, it is worth all that work, as Danish national parks are unique areas with valuable landscape and species, which need special care and attention. Their aim is to demonstrate the most significant pieces of Danish nature, to root the sensitivity to nature in people and spread the knowledge about them. However, parks are nothing like museums – they are a real evidence of human life in harmony with nature. National parks are areas where people live and cultivate, where people work and rest, but they also give back and take a great care of nature.
[Danmarks Nationalparker, n.d]

Fig.11 Map of Denmark with National Parks

Fig.12 Map of Thy National Park

THY NATIONAL PARK
DENMARK'S GREATEST WILDERNESS

Thy National Park is located in the west of Thy and has been planned as the first Danish national park. It stretches along the west coastline of North Sea from Agger Tange in the south to the Hanstholm at its north. It is vast and pristine natural landscape of around 244km2, where people, plants and animals unfold their lives in harmony.

The harsh wind conditions work as a region's hallmark creating a unique character of the dune heaths landscape. The weather and nature are very changeable, ranging from windswept exposed dunes with the sound of roaring waves into stillness and safety in the dense pine forests. Within the national park there are more than 50 km of picturesque sandy beaches and crystal clear lakes, where the sunny summer days can be spent enjoying the parks greatest values.
[Naturlstyrelsen, n.d.]

The governmental Forest and Nature Agency states:

"A Danish national park contains the most unique and characteristic Danish nature. (...) The idea is about improving and strengthening the Danish nature, and giving both local and foreign visitors better possibilities to experience, use and get knowledge about nature, the landscape and the history of civilization."

[Naturlstyrelsen, n.d.]

Fig.13 Lake in Thy National Park

NØRRE VORUPØR

Thisted Kommune has donated a space for the project in Nørre Vorupør – the capital of tourism in Thy. Norre Vorupor is a small town at the North Sea coast, inhabited by 591 residents. The town is one of the few places in Denmark where the local fishing trade is still alive, combined with the atmosphere of classic seaside resort and surf village Vorupør thrives as a vibrant and relaxed place. Therefore it has all the potential to host the park's Visitor Center. [Visit Thy, n.b.]

The chosen site at Hawblink is related not only to the nature, by hilly terrain, the view over the entire town and the sea, but also to the location right at the main landing place. Furthermore, the decision was driven by the proximity to a number of significant local entrepreneurs and many various touristic facilities, not mentioning that Norre Vorupor is the most visited town in the park and has a great number of surfers coming all year round. It gives an exceptional basis for interaction with park users and potential increase of the number of visitors. All in all, the close relation to Thy National Park and the architectural heritage of the fishing village means that the site requires work with great attention to the local resources in the form of context matching, natural landscape and cultural heritage. [Board of Thy National Park 1, 2015]

Fig.14 Norre Vorupør mapping diagram

Fig.15 View over Norre Vorupør

Fig.16 Nørre Vorupør beach

SITE VIEWS

If one approaches the site from the town's center, it gives an impression that piece of nature has broken into the settlement, while being tempting to explore. Gently sloping grassy dune invites to reach it's peak and to look around. (Fig.17) View from the top is uninterrupted and stretches until the horizon. From here one can see the entire town with it's fishing buildings and summerhouses hidden in between the hillocks (Fig.19), when looking to the east lunar landscape of heather dunes opens up., finally when turning north teh North Sea proudly presents it's infinite possibilities and dramatic character. (Fig.21) As the fresh breeze starts to blow i tis better to climb down and admire the place from the protected space.

Fig.17 View towards the site

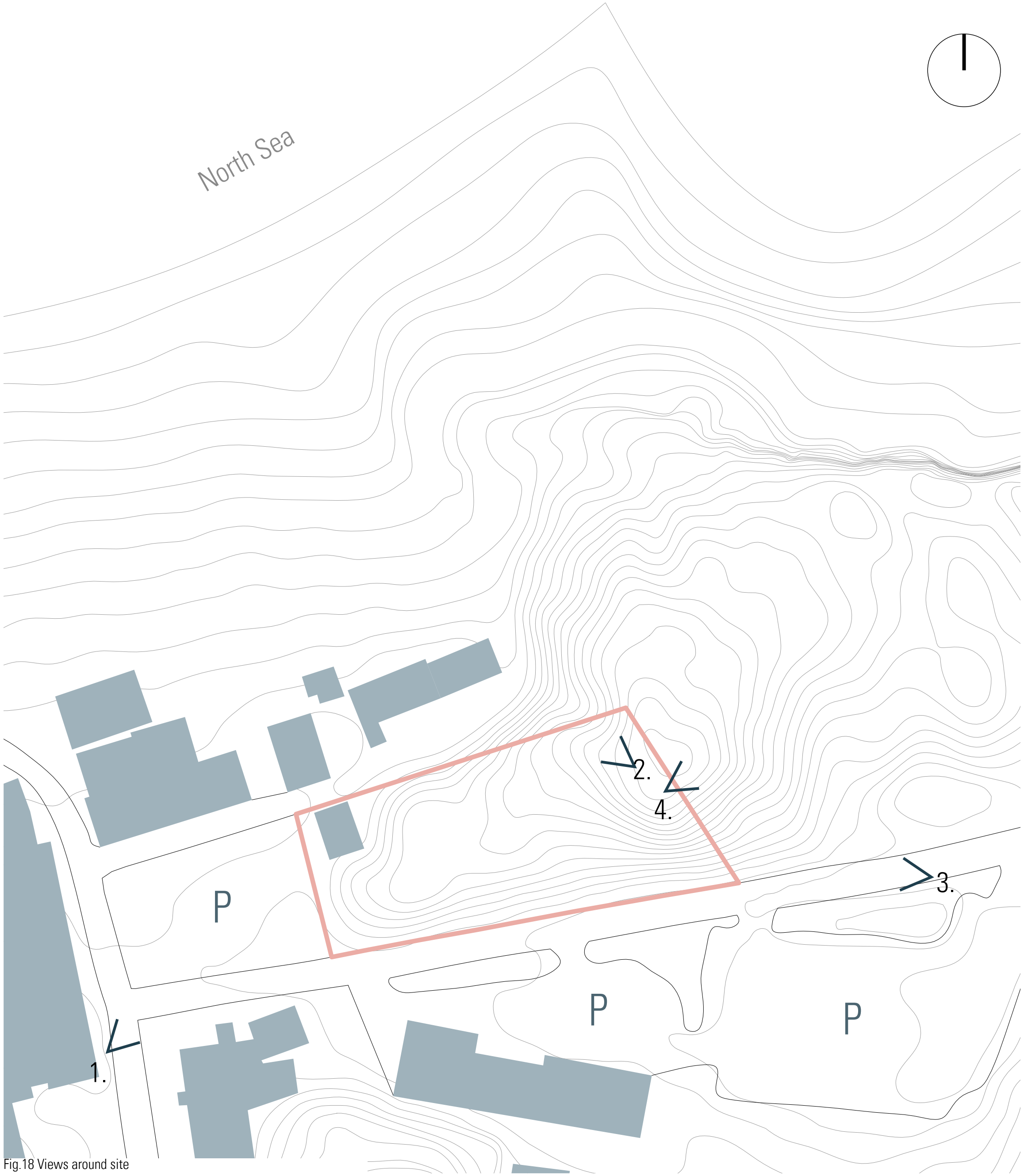


Fig.18 Views around site

2.

Fig.19 View from the top of the site

3.

Fig.20 View towards the site

Fig.21 View from the top of the site

4.

SENSE OF PLACE

Genius loci – contemporary defined as "*spirit of a place*" is a phenomenon depicted by Christian Norberg-Shulz in his book Genius Loci: Towards a Phenomenology of Architecture. He claims that in order to recognize the real structure of a place it "*(...) ought to be described in terms of "landscape" and "settlement*", and analyzed by means of the categories "space" and "character" ", therefore Norre Vorupor and it's surroundings has undergone a phenomenological investigation. [Norberg, 1979 p.11]

When approaching the town from main road landscape appears as smooth and gently riffling, with it's grassy hills stretching to the horizon, covered in fog and surprisingly peaceful. This is not an eternal state though, as Norberg mentions „*(...) the character of a place is a function of time; it changes with the seasons, the course of the day and the weather, factors which above all determine different conditions of light.*" [Norberg, 1979, p.14] It doesn't take long until the first gust of wind can be felt and the entire ambiance begins to turn. Clouds run faster and wind starts to gently move the tall grass, so that it creates various patterns on the surface of the dunes, and on top of that the setting sun opens up with full range of colors to bring drama into the place.

On the other side there is a little fishing settlement, so typical for Danish landscape and aptly described by Norberg - „*In Denmark where the scale is human and idyllic, dwelling means to settle between the low mounds, under the large trees, embraced by the changing sky.*" [Norberg, 1979, p.42] In Nørre Vorupør, where houses are scattered in between the hillocks in safe hollows surrounded by coniferous trees, which create the natural barrier from the wind and savage weather conditions. The spirit of Thy reveals in this interface between heaven and earth – the latter closely related to human, giving him refuge and feeling of safety, contrasted with environmental interplay of forces, ever-changing sky, unpredictable sea, instability and constant motion.


Fig.22 Sky over North Sea, watercolor impression


Fig. 23 View from the site, watercolor

SURROUNDINGS

The given site is located right at the main landing point in Nørre Vorupør – which is a heart of the town. Along the southern edge runs the main access road with the bike path on the side, which on one side gives good permeability, but on the other creates a strong boundary from the sunny side. The plot is surrounded from three sides by existing buildings of different functions, mainly touristic facilities such as fish shops, gift shops, restaurants, cafes and a small aquarium, further away are located family hotels, camping and excessive areas filled with summer houses scattered between dunes. Moreover the site has a direct connection with the parking lot for 84 cars in the east-south corner and another one at the western edge for 36 cars. The latter parking located exactly in the center, which gives this space a great potential of being recreated into inviting urban plaza with strong connection to the Visitor Center. Finally, a small existing building housing toilets and changing rooms stands in the west-north corner of the site and is planned to be demolished, while it's functions will be included inside of the Visitor Center.

Fig. 24 Function diagram

Fig. 25 View from the site towards landing place

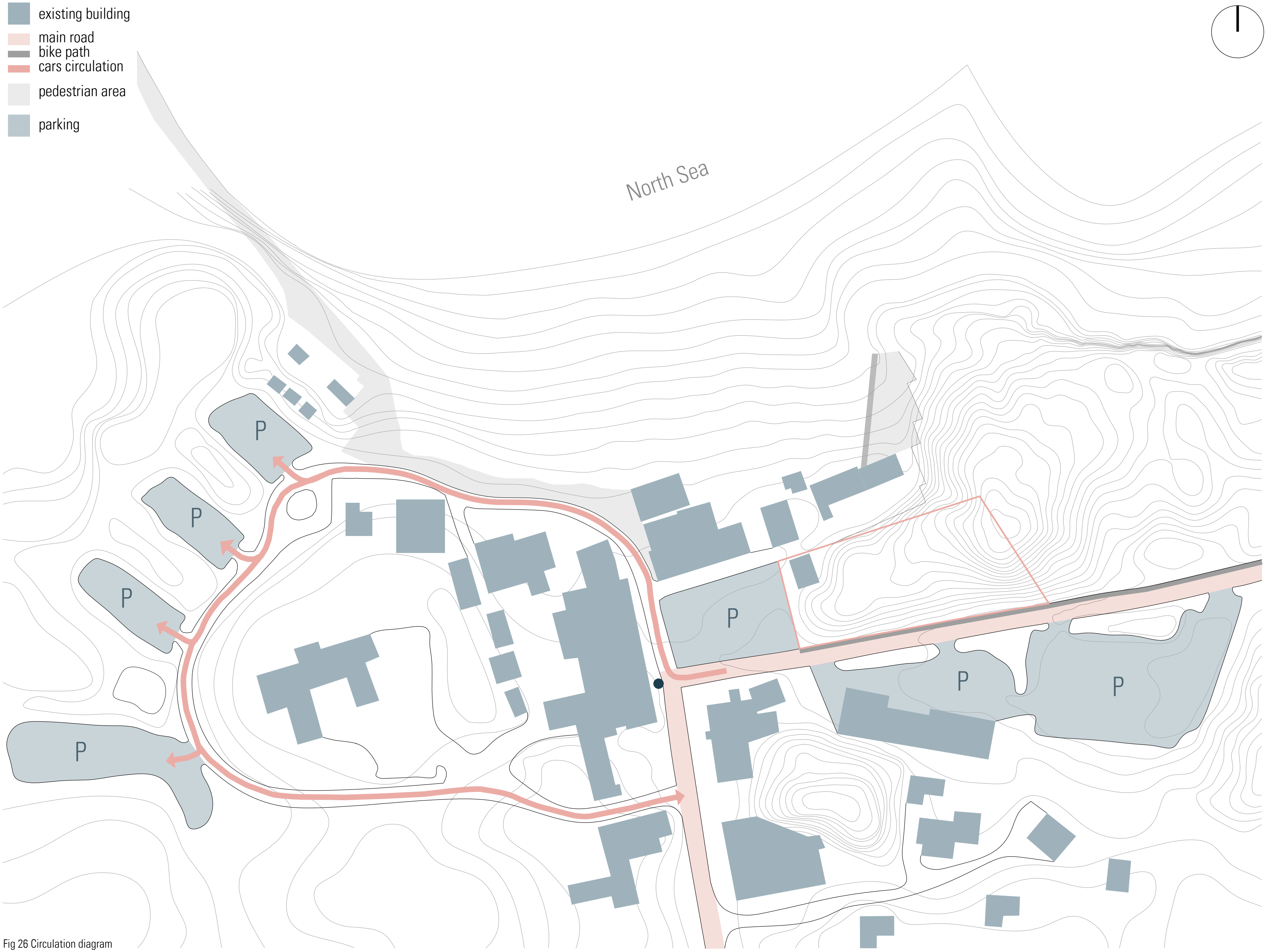


Fig 26 Circulation diagram

CULTURE

The culture of Thy with the architecture foremost is inextricably connected to the geographical location and unpredictible climate conditions, such as strong winds, high humidity, and salt spray. The unique Thy culture is defined by charming fishing villages placed along the coast and farmhouses scattered in hollows of hilly landscape. Danish settlements are characterized by one-story, low set buildings in half-brick, half-timbered construction with hatched roofs. Organized as repetitive, simple volumes placed around the closed yard. [Norberg, 1981] One of the finest examples of earthbound architecture in National Park are fishermen's sheds in Stenbjerg Landing. Build around 1900, tiny white brick houses were destined to resist harsh seaside conditions and serve as fishing equipment storage.[Visit Thy, n.d]

In contrast to those earth-hugging dwellings, churches stand out from the landscape. From the Middle Ages hilltops have become a holy ground crowned with temples, usually constructed of stone or brick. [Norberg, 1981] In Thy, is located Scandinavians largest village church – Vestervig Kirke – also called „*Cathedral of the North*", build of stone in XI century. In addition here is also placed Denmark's smallest church – Lodbjerg Kirke –that can only room 50 people is an interesting example of late Gothic style. [Visit Thy, n.d]

MATERIALS

Nørre Vorupør has a very individual ambiance. Build as a fishing village with its small brick houses painted white with pitched roofs covered by black roofing felt, stacked along the main road leading to the landing place at the sandy beach stretching to the horizon. Here at the seaside are placed white smokehouses with it's typical blue doors and windows, but also monumental red brick rescue station. The entire scenery is supplemented by colorful fishing boats pulled to the beach. Further away from the main road, spreads vast area of summer houses, mainly made of wood painted black, grey or blue, scattered in between heather dunes and small pine trees formations. Norre Vorupor can be pictured in natural, slightly faded color palette, and dominated by grays, blues and shades of earth with occasional pop of brighter blue color.

Fig. 27 Fisherman's sheds in Klitmoller

Fig 28 Vestervig Kirke

Fig 29 Lodbjerg Kirke

Fig. 30 Materials collage

TOPOGRAPHY

The given site is placed in the heart of town, on an empty piece of terrain at the main landing place of Nørre Vorupør. The site has curvy landscape, as it includes grassy dunes, which give a lot of potential of concatenating design with the landscape. The highest point of 15 meters above sea level is situated in the eastern part of the plot and this is where the view of the sea and the entire city spreads. Ground slopes gently towards the parking lot in the west. It reaches level of 8 meters there, which gives a total height difference of 7 meters. To the north and south terrain slopes sharply, creating 7 meters high steep hillsides, which give a dramatic and unique character to the site.

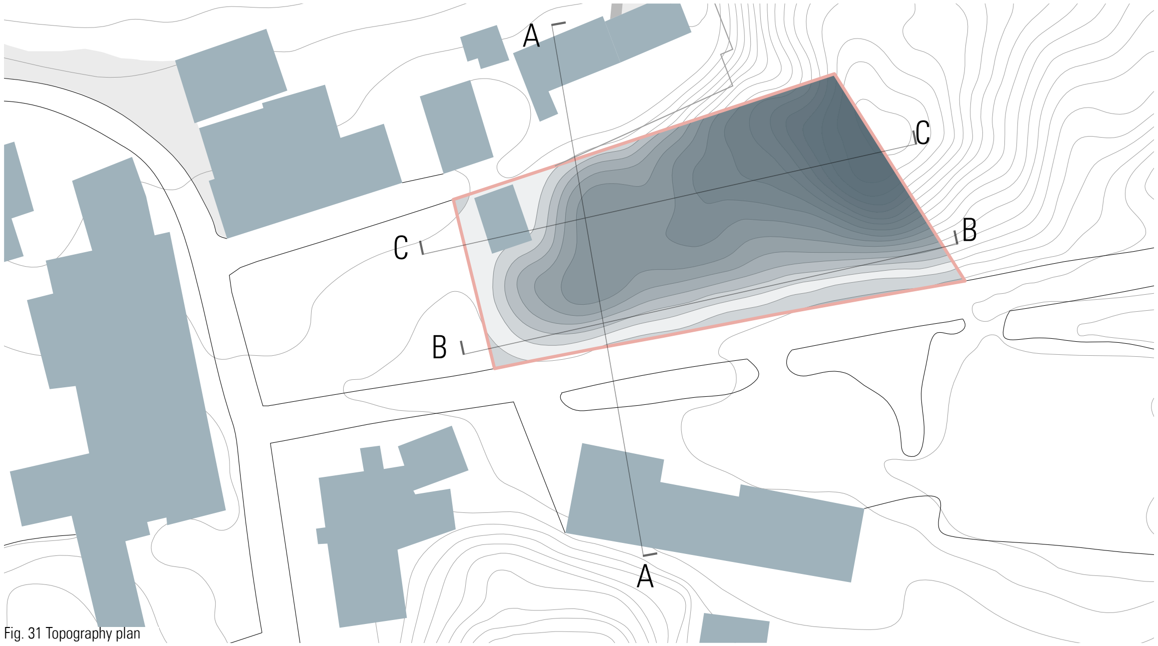


Fig. 31 Topography plan

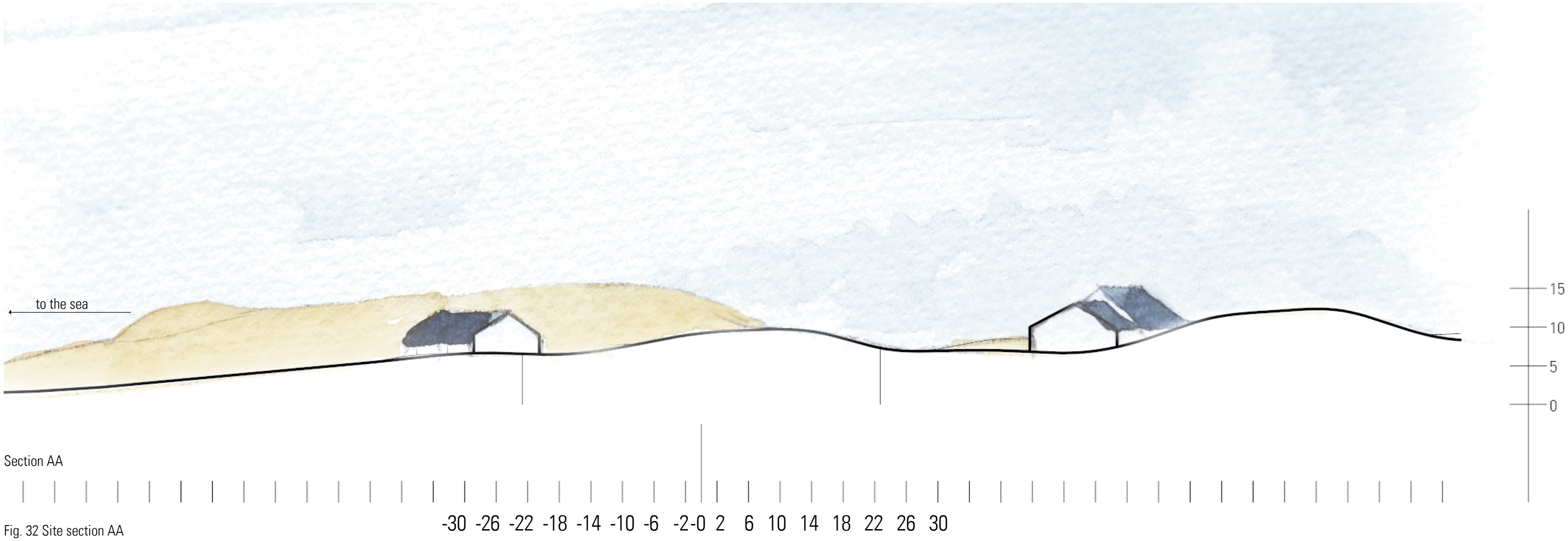


Fig. 32 Site section AA

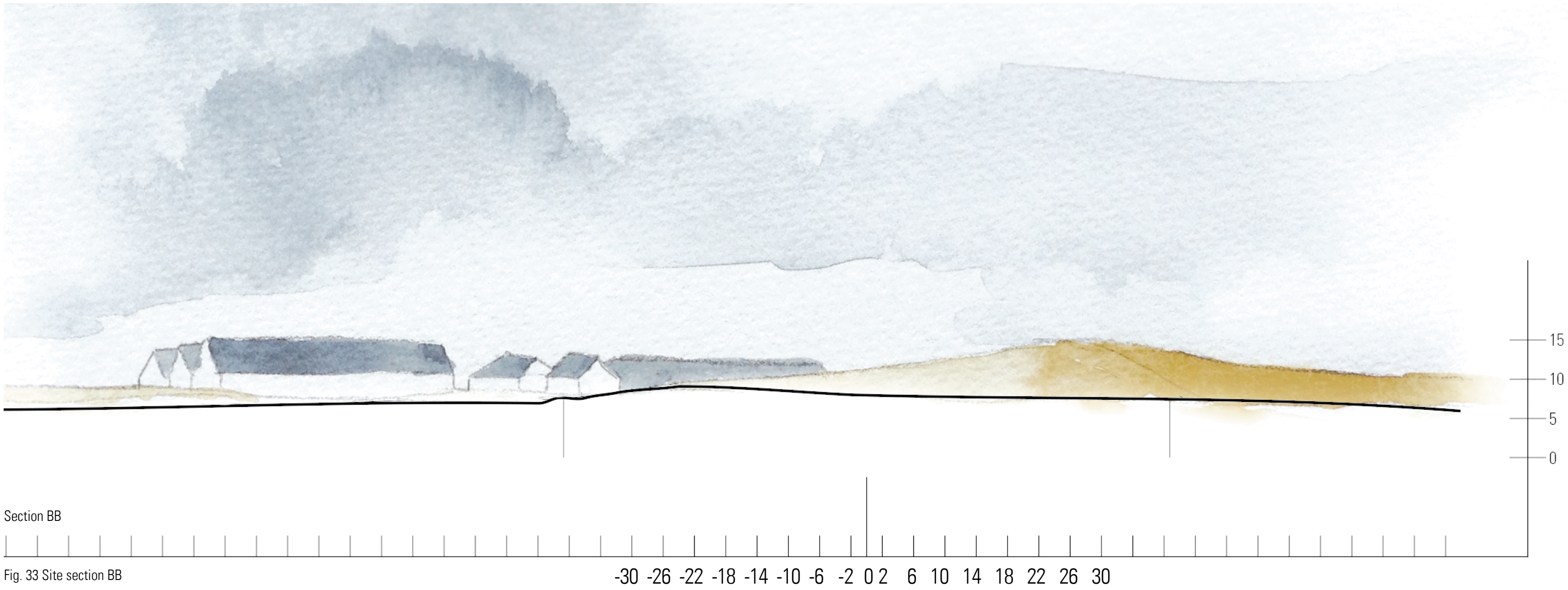


Fig. 33 Site section BB

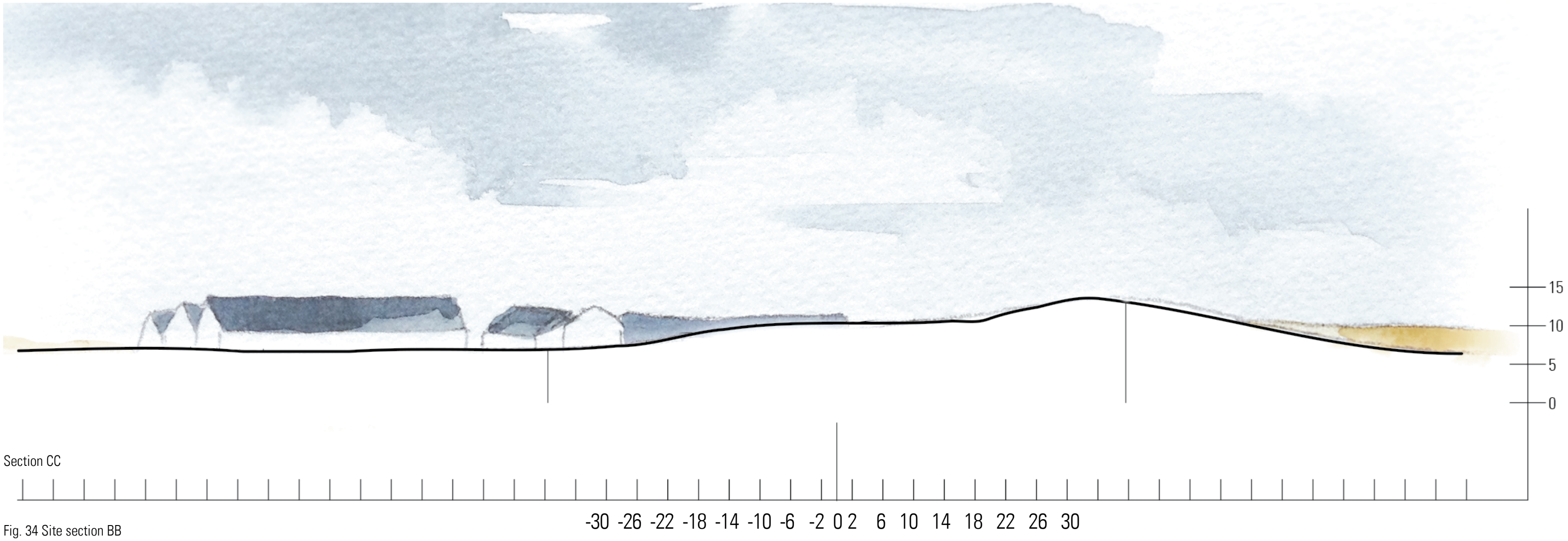


Fig. 34 Site section BB

CLIMATE CONDITIONS

The unique atmosphere of Thy is directly affected by the ever-changing weather conditions and substantial alterations in the amount of daylight throughout the year. Strong winds, humidity, salt spray, differences in height of sun and amount of hours of daylight – it all influences the durability of materials, but foremost energetic performance of the building and indoor climate. That is why it is crucial to include climate considerations as early in the design process as possible.

Nørre Vorupør is located right at the side of North Sea, in the open grassland, which makes it very exposed to the weather fronts often bringing strong winds and heavy rains. In overall, the climate in the region is described as humid with calm warm summers and wet winters, without any dry season. On the average temperatures reach 7 degrees Celsius, with 10 days of rain every month and 4,5 hours of sunshine per day on the average. [DMI, 2015]

Strong winds, so characteristic of Thy are carrying salt and sand – two destructive natural forces, bringing a lot of challenges to the design and choice of materials. Nevertheless, wind can also become a great advantage in planning the efficient ventilation system and providing fresh air to the interior. Furthermore, the height and amount of sunlight also become main determinant of the design – putting focus on providing interior with sufficient sunlight in the wintertime, without causing overheating during long, sunny summer days.

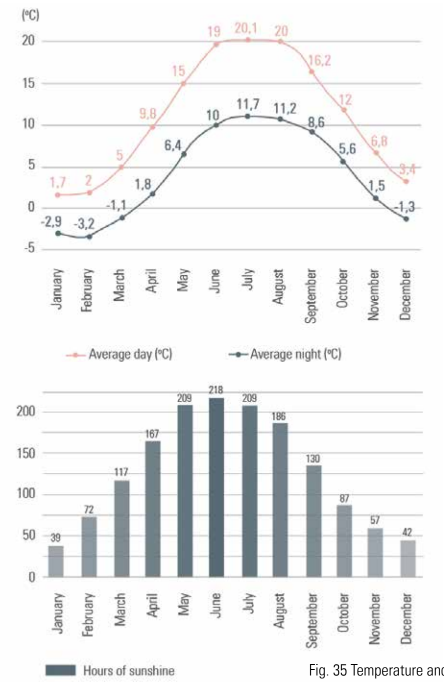


Fig. 35 Temperature and sunlight

TEMPERATURES AND SUNLIGHT

Due to the Nørre Vorupør's location at the North Sea side, temperatures are moderate with the annual average temperature of 7ºC. Throughout the year, daily average temperatures usually stay in the range from -2ºC to 21ºC and almost never rises above 26ºC or drop below -10ºC. In the summer season, the average daily temperature is around 17ºC, while the hottest month of the year July with the average high temperature of 21ºC. In the cold season, which spans from November 20 to March 22 temperatures rarely exceed 6ºC, and the coldest month of the year is February, with the average low temperature of -2ºC. [weaterspark.com, 2015]

The amount of hours of sunshine varies significantly over the course of the year with the most sunny period in the June reaching 218 hours of sunshine, which gives on the average 7,26 hours per day. In contrast, the most overcast month is January with only 39 hours of sunshine, giving on the average 1,26 hours per day. [DMI, 2015]

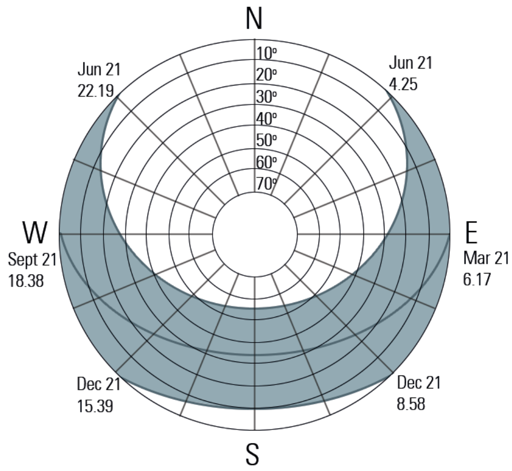


Fig. 36 Sunpath diagram

SUNPATH

The amount of daylight and position of sun also varies noticeably throughout the year. The longest day of the year is 20th of June reaching 17.55 hours of daylight with the sun shining at the angle of 56 degrees. On the contrary, the shortest day of the year is 22nd of December having only 6.42 hours of daylight with the sun barely rising above the horizon, at the angle of 9.6 degrees, casting very long shadows.
[Time and date, 2015]

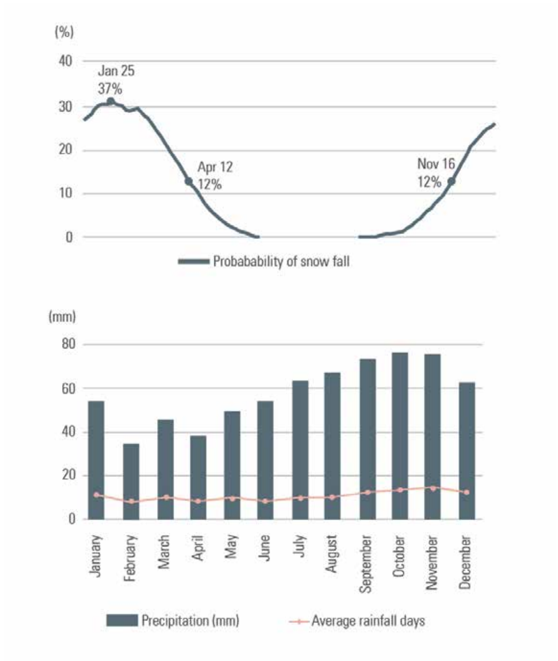


Fig. 37 Precipitations diagram

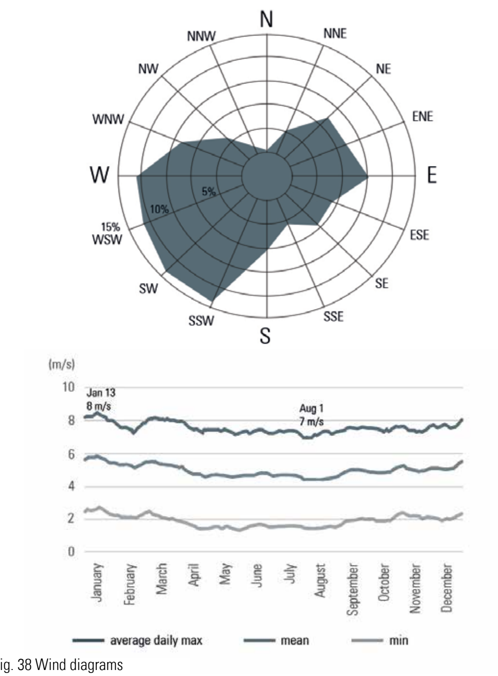


Fig. 38 Wind diagrams

Fig. 39 Wind on site diagram

PRECIPITATIONS

The climate of Thy is described as humid, not only because of the close connection to the sea, but also due to considerably often rains. There is over 30% chance that rain will occur every day. The rainiest month of the year is November with 14 rainy days, while the least rainy is June with only 8 days of rain per month. [DMI, 2015]

Furthermore, the most common forms of precipitations are moderate rain occurring in 54% of rainy days and light rain in 14% of rainy days. It is also possible for the snow to fall in 13% of days with precipitations, with the highest probability around January, occurring in 37% of days.
[Weatherspark, 2015]

WIND SPEED AND DIRECTION

In the region of Thy wind is definitely a frequent phenomenon and is also relatively strong. Over the entire year the typical wind speed vary from 1 m/s to 8 m/s, which can be described as light air to fresh breeze, sometimes it exceeds 14 m/s, which is already considered a high wind. The highest wind speed is registered in January reaching the average wind speed of 6 m/s with maximum average of 8 m/s. The most common direction of wind is southwest and west, but during the spring it occurs more often from the eastern directions. The least common direction is straight north or southeast.
[Windfinder, n.d.]

It opens up a possibility of creating a sheltered, shielded from winds, sunny outdoor area southeast oriented.

WIND ON SITE

The site is rather exposed to the strong winds, due to the location at the seaside and lack of any natural or built in wind barriers. Despite the breathtaking view, the top of dunes is particularly unprotected from the wind, however the bottom levels of the plot, oriented west are slightly shielded from the western winds by surrounding buildings.

Therefore, the design requires very conscious and thorough placement of the building and the overall design in order to create the durable yet welcoming project.

FLORA AND FAUNA

Not without reason Thy National Park is called Denmark's largest wilderness Here the North Sea waves break at the sandy beaches from which the wind carries the sand grains up and forms the high dunes. Behind them, the countryside unfolds into the heath dunes cowered by hardy plants, able to survive in the low nutrient soil and wetlands, such as heather, willow crow berries and bog berries. Further inland lie large, contiguous forests dominated by pine trees and spruces, which create a mysterious environment both dark and impassable. This relatively desolated land provides the framework for some of the country's most unique natural habitats, some of which are rare on an international scale. Park is inhabited by big population of red deer and roe deer. Finally, Thy is the land of birds – numerous wetlands are filled with hordes of cranes and wood sandpipers. [Naturstyrelsen, n.d]


Fig. 40 Cranes in the dunes


Fig. 41 Heather dunes

Fig. 42 Victor Fernandez-Lopez during PWA World Cup

TOURISM

Thy National Park does not only have one particular attraction, but many charming places that offer experience and close interaction with nature and culture. National park unique spots are like pearls on a string starting from Agger Tange in the south up to Hanstholm in the north, where everyone can find something truly special. Therefore a new study of the number of visits in Thy National Park shows that the national park was visited by between 1.1 and 1.4 million times in 2013. [Board of Thy National Park 1, 2015] The study also shows that nature in Thy National Park is the main attraction, nevertheless it is not only appealing to locals who live in the municipality and enjoy nature on the regular basis, but is also an attraction for external visitors who come to spend holidays here or just take a one day trip. Moreover the study reveals that the vast majority of visitors come to simply enjoy nature by hiking, cycling, bird watching fishing and bathing in lakes or the sea, however the great touristic group consists of surfers and windsurfers, who called the place Cold Hawaii – as it is one of the finest places to practice those sports in Northern Europe. [Thy Nationalpark, n.d]

Fig. 43 Hiking Tour in Thy National Park.

COMMUNITY OF THY - INITIAL PROGRAM

Humans have never been so disconnected and alienated from the nature as it is happening nowadays. Therefore, in addition to the demand of creating a Visitor Center as a touristic point of interest, Park Authorities in cooperation with Thisted Kommune have many expectations and ambitions concerning the new Center. Since the opening of park in 2008 community has been waiting to obtain a permanent place of dissemination, educational facility and a gathering place all in one.

With National Park Center visitors will have an unique chance to get their experience with nature started as well as to encounter a peculiar history demonstrating live in close connection with nature and surviving in it's roughest conditions. In overall, the ambition is to create a gateway to the Park, which significantly arouses interest and understanding of nature and thus becomes a basis for the necessary interaction, that modern man should be incorporated with – which means to act responsibly and sustainably in relation to nature and society.

In a local context, the ambition is that National Park Center also contributes to the new and positive discourse of the area, where the values rooted in nature and history, helps strengthen the land's identity to the benefit of retaining and attracting new citizens, business, research and education.

The National Park Center ambition is finally to reinforce the already high involvement of local human resources and the pride of the unique nature and exceptional cultural history, which is a major driving force for the involved.

The Board of Park has formulated their vision, which summarizes the community's voice:

„National Centre must through knowledge and dissemination of the park's nature, geology, history and culture strengthen the cooperation between various stakeholders – in education, research, outdoor recreation, tourism and business. National Centre must also strengthen the sense of community, local commitment, but also contribute to the sustainable utilization and protection of Thy National Park."
[Board of Thy National Park 1, 2015]

The table below presents list of general functions with proposed approximate areas in square meters requested by the Board of Park and more specified for design purposes:

DISSEMINATION	580
Entrance hall	20
Cloak room	10
Exhibition area:	450
- permanent exhibition	
- temporary exhibition	20
Tourist infromation	30
Gift Shop	20
Restroom	20
Storage	

OFFICES	200
Offices for approx. 8 people	100
Meeting Room	25
Wardrobe	5
Restroom	10
Storage	10
Kitchen/ Dining	20
Technical rooms	30

BEACH SERVICE	
Showers/Restroom/Changing room	80

EDUCATION	260
School room/ Conference	100
Multiworkshop	100
Restroom	20
Storage	20

DINING	150
Kitchen/Cafe	30
Open dining area	120

TOTAL	1240

Fig. 44 Functions table with areas

PROGRAM SPATIAL ANALYSIS

The function diagram below represents program requirements divided into five areas of interest with indication of their size and connections:

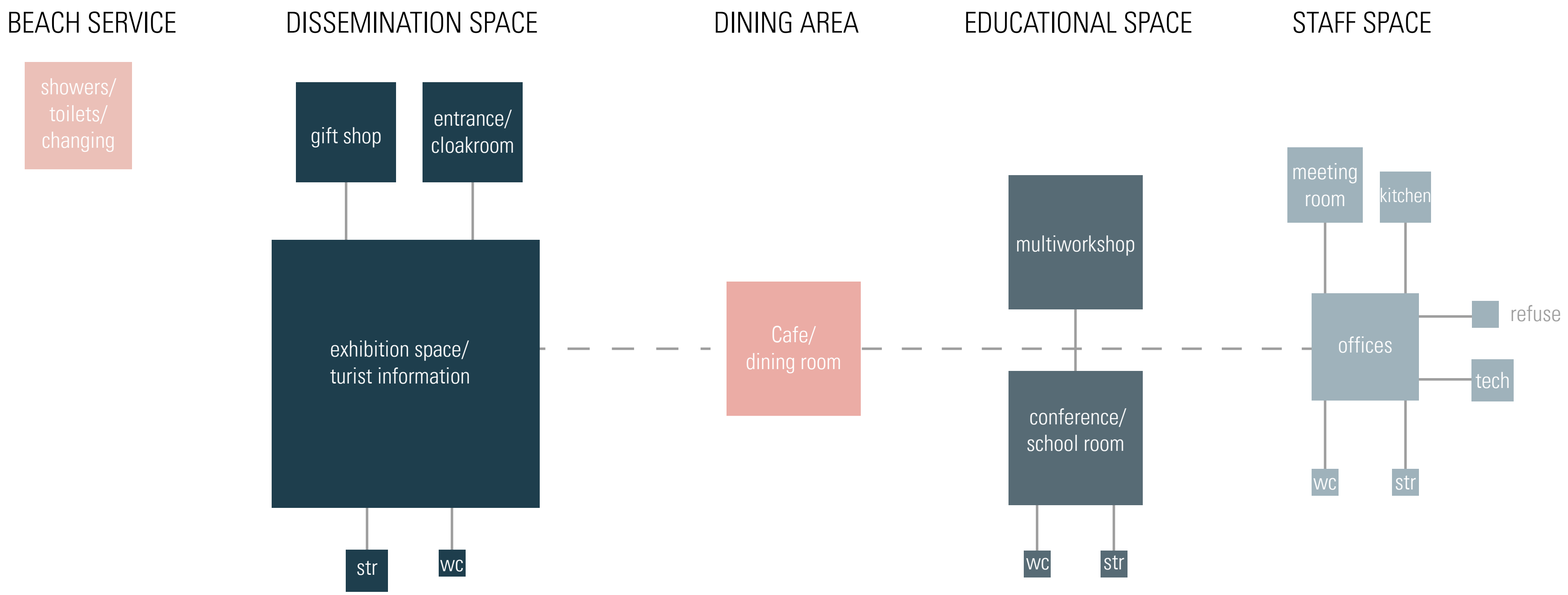


Fig. 45 Program distribution diagram

TECHNICAL DEMANDS

The aim of the design is to create a building with the lowest possible impact on the environment, including nearly zero energy consumption without compromising the quality of indoor climate or aesthetical and functional values, while using as much as possible of passive technologies and renewables. Thus, the design is following Danish Building Regulations – BR10 with the annex of low-energy class 2020.

In accordance with these regulations the overall energy performance framework of the building including the coverage of heat loss, heating, cooling, ventilation, domestic hot water and lighting cannot exceed 25 kWh/m^2 of heated floor area per year, while the designed transmission loss through the external surfaces in single-story buildings can be of maximum 3,7 W/ m^2 of the building envelope or 4,7 W/ m^2 for two-story houses.

Low-energy buildings not only decrease the energy consumption, but also bring a number of advantages with the good indoor climate foremost. In order to achieve healthy and comfortable internal environment, listed factors need to be characterized by the best possible performance: air quality including adequate temperature, purity, velocity and humidity; lighting - both natural and artificial; and acoustic comfort. Therefore, to provide it, several requirements need to be fulfilled. Rooms cannot be exposed to overcooling or overheating, thus the requirements fro dwellings can be used as guidelines, meaning maximum of 100 hours above 26°C and maximum of 25 hours above 27°C. To prevent the latter ventilation needs to operate within certain frames: in dwellings in general the air change rate must be a minimum of 0,3 l/s/m2, however it increases in kitchens up to – extraction of 20 l/s and bathrooms – 15 l/s, but also in utility rooms - 10 l/s. Despite the fact that mentioned values are concerning dwellings, they can work as primary guidelines for further calculations of ventilation rate based on indoor climate requirements and number of users. Furthermore, in rooms dedicated for educational purposes air change must be a minimum of 5l/s/person + 0,35l/s/m2, while the maximum C02 concentration cannot exceed 0,1% for extended periods.
[BR10 class 2020, 2010]

As lighting plays an essential role in indoor quality perception, thus the satisfactory light, without causing unnecessary heat loads is required. In workrooms the glazed area of the side surfaces must be a minimum of 10% of floor area, or in case of roof lights a minimum of 7%, including the assumption that light transmittance of the glass is not lower than 0.75. All in all, daylight is considered sufficient if it reaches a daylight factor of 2%. Accordingly, in workplaces the artificial lighting is considered sufficient if it reaches 200 lux.
[BR10 class 2020, 2010]

DESIGN CRITERIA

Social, cultural and functional objectives

- to design with a focus on health, comfort and high user satisfaction
- to ensure a high degree of user involvement
- to create outdoor spaces which ensure excellent opportunities for relax and rest
- to ensure accessibility for everyone, including those with sensory or motor limitations
- to promote interaction across generations
- to attract many visitors

Aesthetical objectives

- to ensure high aesthetic quality through design solutions and strong concept integrated into the architecture
- to relate to the Nordic architecture
- to integrate into the landscape and enhance its beauty
- to use natural materials in relation to local context

Technical objectives

- to design in low tech profile with focus on passive strategies and natural resources
- to incorporate sustainability early in the process
- to ensure high degree of reusability
- to use environment friendly materials
- to fulfill BR10 class 2020 requirements concerning energy consumption and indoor climate
- to reach nearly zero building energy performance

03 PRESENTATION

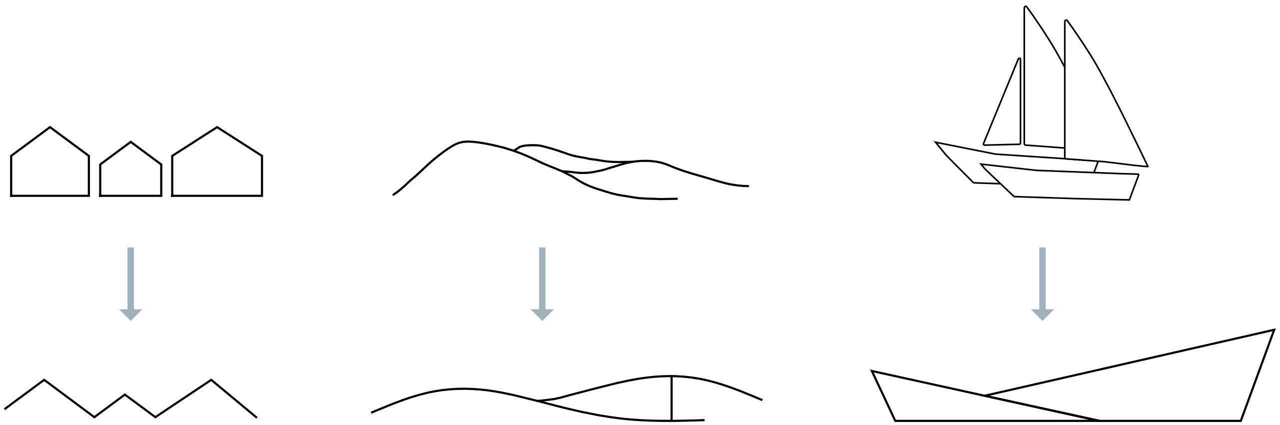


Fig. 46 Primary concept diagram

CONCEPT

Primary design concept emerged from the analysis of the site, as its surroundings provide infinite possibilities and ideas, as well as from the objectives stated by the Board of the Thy National Park. Therefore, the concept is to respectfully refer to closest neighborhood – existing architecture including traditional fisherman houses and wooden summer bungalows, seascape with its grassy dunes stretching to the horizon, and city's hallmark – colorful fishing boats subtly resting on the wide beach of Nørre Vorupør.

Despite its close location to the sea, site does not have the direct connection or view to the water, therefore it is so crucial to create opportunities of visual connection with it and thus present buildings marine character. (Fig.47)

Furthermore, existing paths that people use most commonly and ways of approaching the site have become another key element of building up the powerful concept that harmonizes with present situation and does not force people to change their natural habits. (Fig. 48) Following that stream even further, one of the main features of the site is the dune - which top is the highest viewpoint of the area, but it also serves as an observation spot for surfers. Thus, the concept seeks to provide a building that creates a soft passage from the dune to the landing place and gives the possibility to easily climb up the dune and admire that breathtaking view over the entire area. (Fig. 50)

After all those observations and thorough analysis, the concept of the building clarified itself as a user friendly center that combines the best features of adventure destination with learning facility, that strengthens regions position of being perceived as modern and innovative. Visitor Center also seeks to strongly refer to the surroundings by scale, materiality and visual connections, while respecting existing paths and enhancing dune's natural beauty.

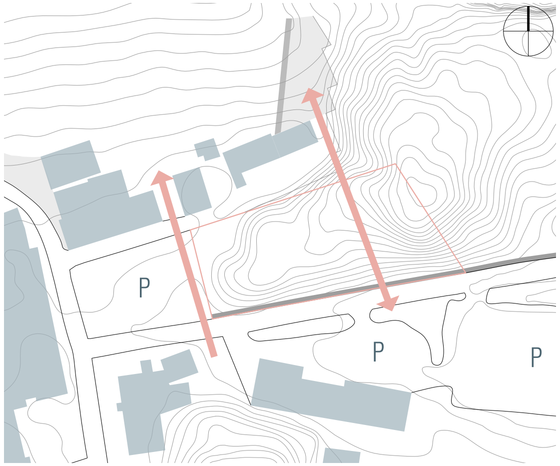


Fig. 47 Sea views on site

Fig. 48 Pedestrains approaching site

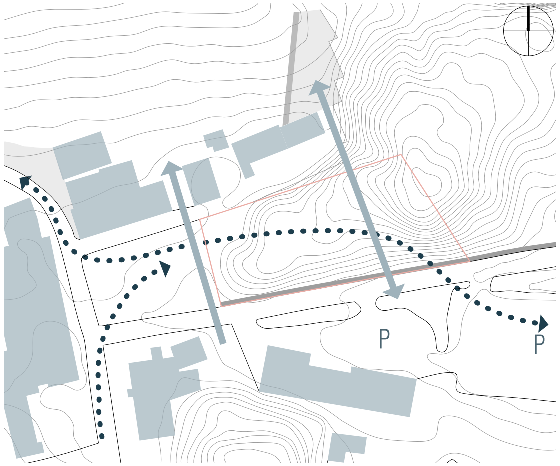


Fig. 49 Main directions on site

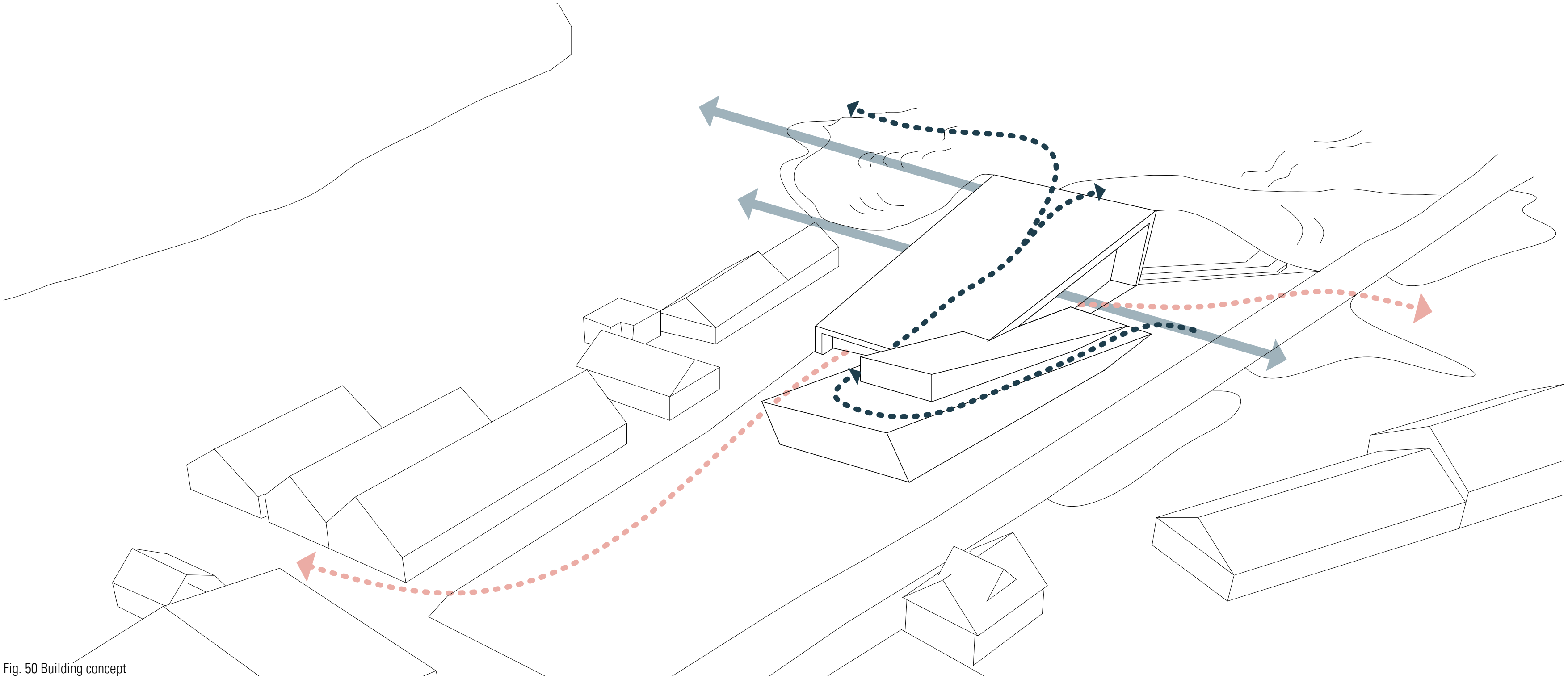


Fig. 50 Building concept

GATEWAY TO THE PARK

Main road to the landing place in Nørre Vorupør leads from east through the picturesque landscape of smooth grassy dunes. At the end of the road appears the outline of the fishing village with its new feature – Thy National Park Visitor Center. When approaching the site, building leaning against the dune, slowly emerges from the sandy hill. At the first glance it already presents itself as strongly connected with the nature, what is more - by integration of the photovoltaic panels with the roof it reveals the attitude towards sustainability. Its wooden envelope adds more natural and local character to the building, evoking positive connotations of holiday destination, while its warm interior, visible through the large windows, invites to discover experiences waiting inside.

Fig. 51 Entrance from Hawblink - visualisation

MASTER PLAN

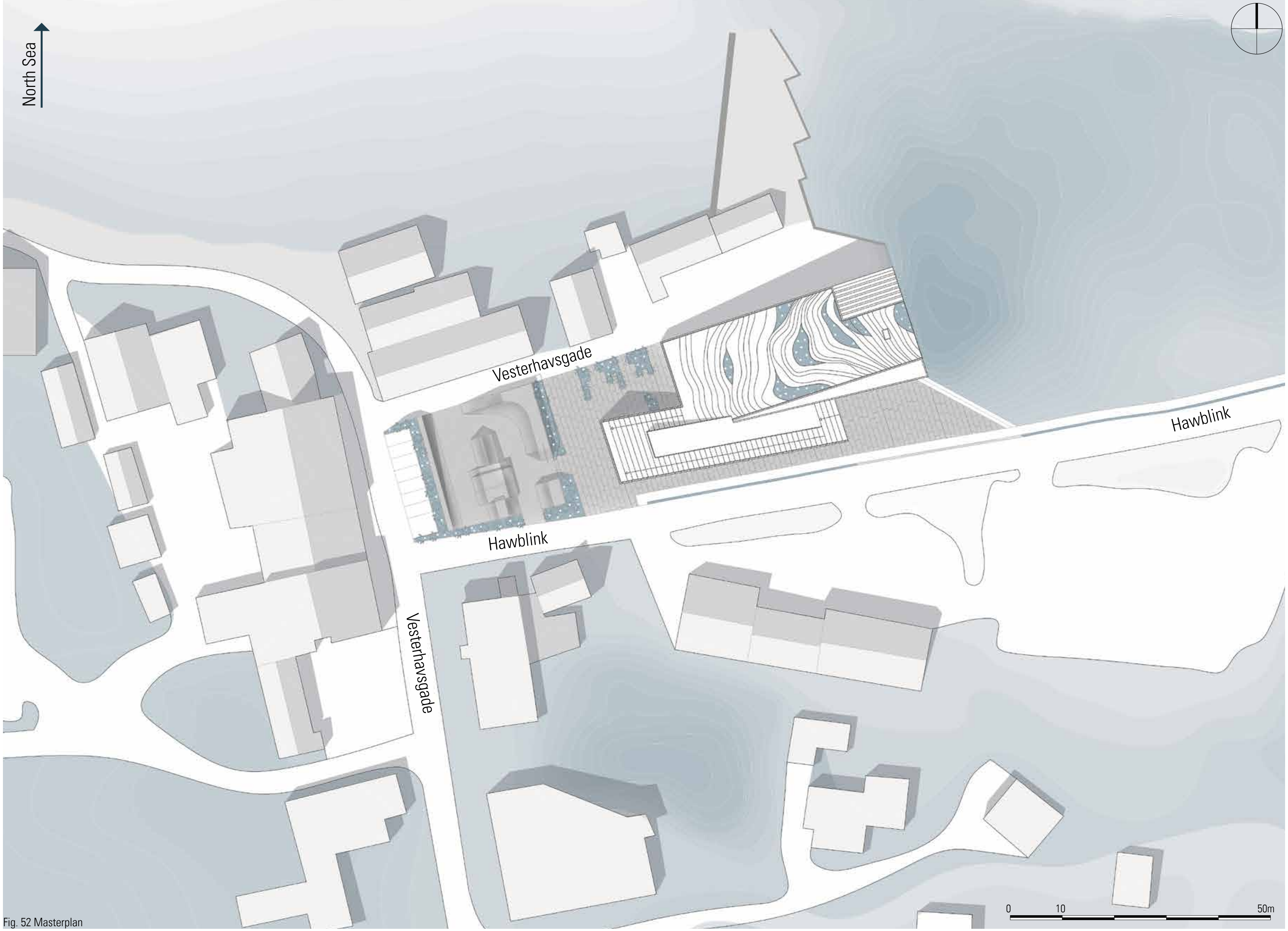


Fig. 52 Masterplan

From the very beginning, the primary concept included drawing the landing place into the project. Existing car parking occupying the entire square has been transformed into an urban plaza that mainly consists of a concrete skate park embraced by the typical local greenery, such as heaters, tall grass or small pines. On the western edge of the square, few of the parking spots has been kept for the local everyday use. However, spots have been hidden by the 1,8 m high ramp covered by the greenery. The square is strongly connected with the Visitor Center by use of the same materials on the floor and leveling, which gives an impression that plaza's floor permeates into the interior of the building. (Fig. 54) Than again, the path running on the roof up to the top of the dune, allows new pedestrian experience for visitors, but also emphasizes the connection with the landscape by designing spots with dune alike vegetation smoothly dissolving into the wooden structure of the roof path.

The entire complex is easily permeable. It provides access by different means of transport and for technical support. Site is surrounded by roads, which lead to existing parking lot that includes approximately 100 parking places. It is also easily accessible by bus or bike, as the bike path arrives all the way to the plaza and two bike parkings are located next to both entrances. Technical access has been located from the north. It is intended to be used by deliveries and refuse collection, but it also allows access for fire engine.

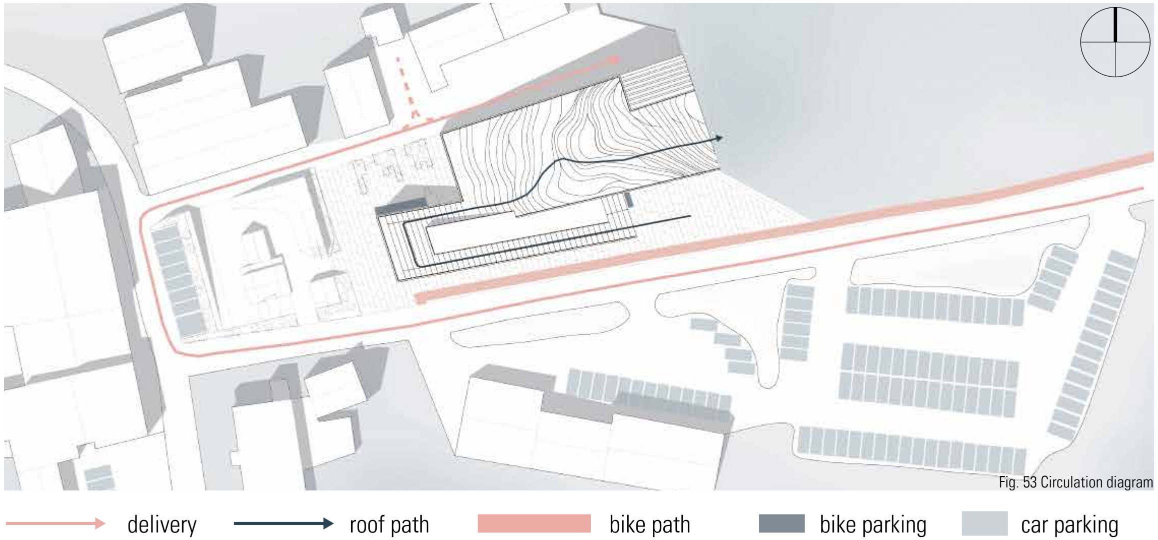


Fig. 53 Circulation diagram

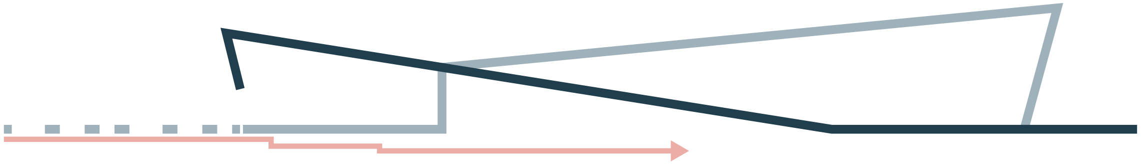


Fig. 54 Permeation of plaza with building diagram

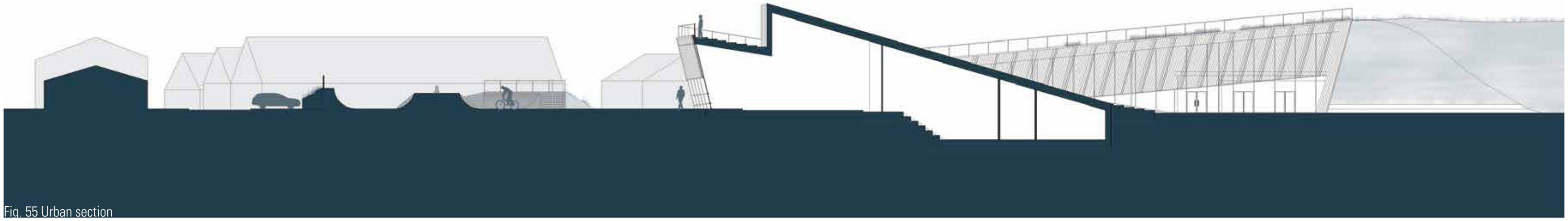


Fig. 55 Urban section

MAIN ENTRANCE

Fig. 56 Main entrance - visualisation

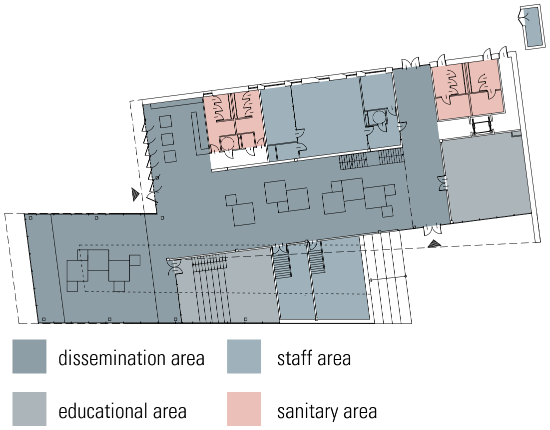


Fig. 57 Functions distribution diagram

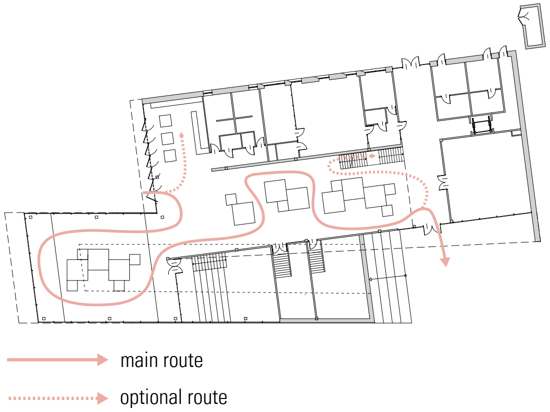


Fig. 58 Exhibition route diagram - version I

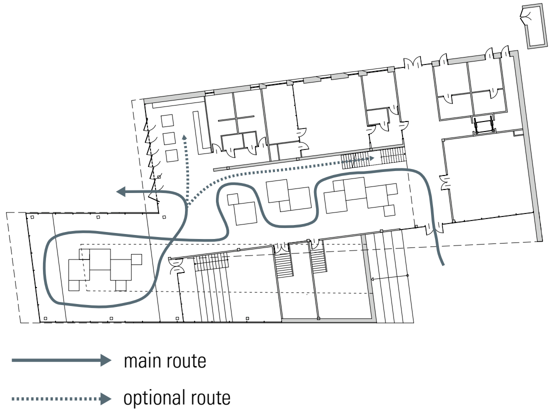


Fig. 59 Exhibition route diagram - version II

FUNCTION DISTRIBUTION

Building is divided into five main groups of functions. First most basic is dissemination area including two exhibitions and gift shop merged with reception and information desk. Those spaces create a core of the building, main areas open for everyone, easily permeable and allowing the free flow of visitors. Second major functional area consists of educational activity rooms, which means workshop located close to the southern entrance and auditorium placed in the opposite part adjoining the temporary exhibition. This layout allows running two separate events at the same time without mutual disturbing. Moreover, the auditorium in combination with temporary exhibition creates perfect space for public events, local trade shows or business related presentations of the region. Not in a far distance are located restrooms and closet to serve during events. On the contrary, the workshop is more dedicated for school arrangements, this is why it obtained the possibility of opening the large glazed door and moving some of the school activities outside.

Furthermore, staff area including offices, meeting room, social room and own restroom is designed as separated from the rest of the building. It is located aside, against the northern wall in order to provide calm working environment away from the lively events. Staff functions also include large exhibition storage and technical room, which stay invisible, as both are located partially underground. First floor mezzanine is dedicated for restaurant with the terrace, bar and kitchen facilities, which can be reached by the elevator or main open staircase. Finally there is a space serving beach users and surfers - two external restrooms and showers located in the northern corner of the site that have separate entrance from the outside with the closest possible connection to the beach.

VISITOR'S ROUTE

Main entrance is located at the northwestern corner of the site, where the plaza seamlessly comes to the inside. Through the large glazed revolving doors visitors can see warm inviting interior with the appealing gift shop in the front and exhibition space in the background. During warm summer days all of the rotating doors can be opened, so that the shop can come outside and integrate with the square and surroundings. Moreover the vegetation in front of the entrance indicates the building close relation with the dune and emphasizes the continuation of the landscape into the square.

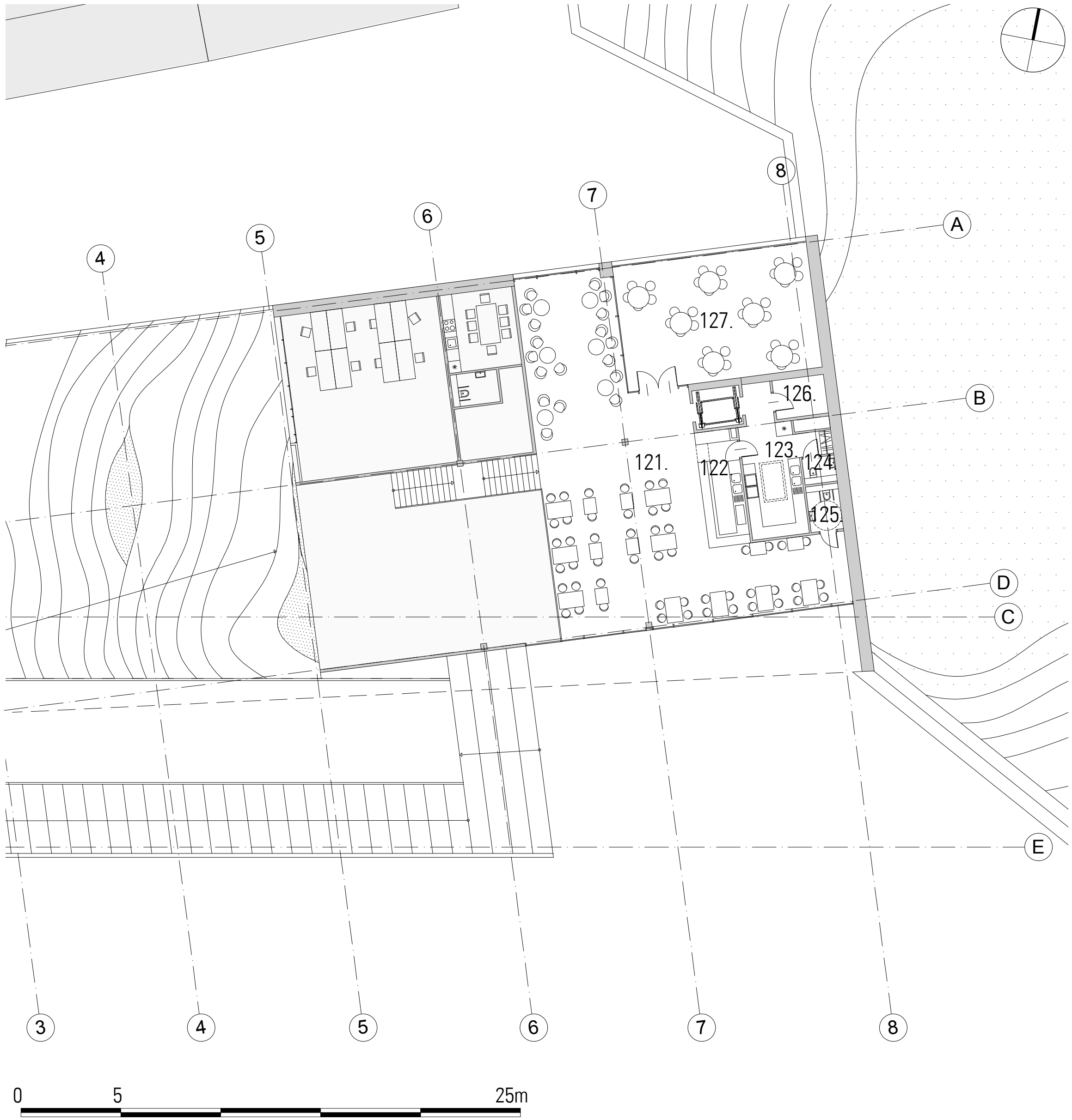
There are two different ways of experiencing Visitor Center. One beginning at the main entrance, from where exhibition tour can take its starting point, including both temporary and permanent exhibition, but also allows a step aside into the gift shop connected with tourist information. At the end of the visitors' route, one can leave the building through the other entrance and continue sightseeing on the roof path or can enjoy a meal in the restaurant located on the mezzanine. First floor provides not only a calm place for break, but also views to the sea or over the town, not mentioning the wind protected terrace with the stretching view of the North Sea. (Fig. 57)

The second way of experiencing Visitor Center is through the entrance from the south, located closest to the parking lot. When passing through the door, visitors can notice a framed view to the sea stretching to the horizon. From this point also starts sightseeing route through both exhibitions, which ends with the gift shop, steps outside or continues upstairs to the restaurant. (Fig. 58) Nevertheless there is no right or wrong way of experiencing the Visitor Center as both routes serve equally interesting tours. Finally, southern doorway is also considered to serve staff and business associates, as it provides the closest connection to the office area.

PLAN GROUND FLOOR

Fig. 60 Ground floor plan

PLAN FIRST FLOOR



Room:	Area (m^2) :
01. Main exhibition	265,3
02. Temporary exhibition	200,3
03. Gift shop/ Tourist information	58,7
04. Auditorium	89,5
05. Female restroom	16
06. Male restroom	16
07. Hendicap restroom	3,3
08. Storage	2,3
09. Offices	67,7
010. Meeting room	22,7
011. Storage	4,7
012. Kitchen	14,5
013. Staff restroom	3,3
014. Staff closet	11,7
015. Beach female restroom	21,9
016. Beach male restroom	21,9
017. Refuse	8,0
018. Workshop	87,3
019. Main storage	34,4
020. Technical room	49,1
121. Restaurant	150
122. Bar	12,1
123. Kitchen	18,5
124. Staff restroom	2,1
125. Guest restroom	3,3
126. Kitchen storage	5,2
127. Balcony	62,5

Fig. 61 First floor plan

SECTIONS

Longitudinal sections AA (Fig. 65) and BB (Fig. 66) present how the roof slopes are designed and how it influences interiors. Section AA shows the design of lowered levels including auditorium recessed into the ground, as well as storage and technical room. Supplemented by the section CC (Fig. 52), it also presents the temporary exhibition in relation to the skylight and exterior floor merging with the inside. Section BB reveals the relation between two opposite sloping roofs and their place of connection as well as position of the mezzanine, while section DD explains the construction of the balcony and its shading elements. Furthermore, the most critical and interesting joints were designed as details presenting construction of building elements such as (page 56): shading structure embracing temporary exhibition (Fig. 67 – detail A); shading structure placed in a further distance from the façade (Fig. 68 – detail B); construction of the retaining wall leaning against the dune (Fig. 69 – detail C); but also principle behind green roof (Fig. 70 – detail D) and ground slab of the building visible on all four drawings. (All details in scale 1:20 available in drawings folder)

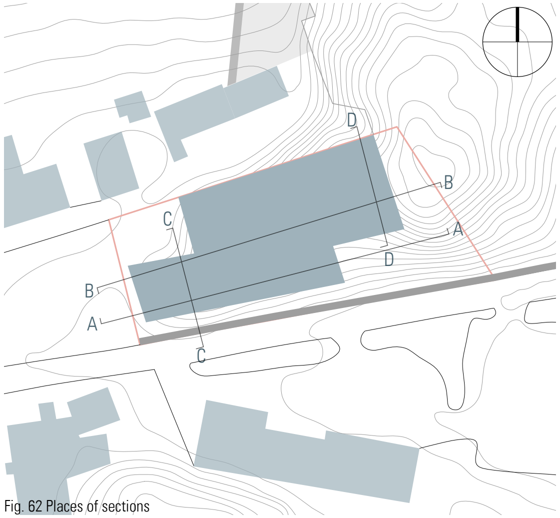


Fig. 62 Places of sections

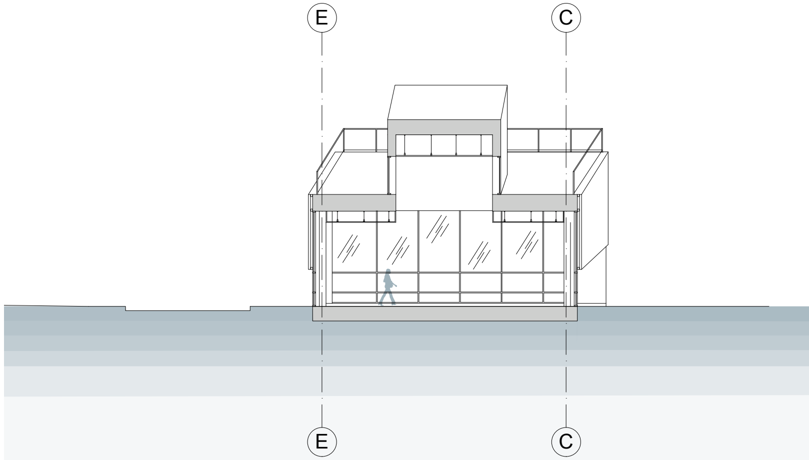


Fig. 63 Section BB

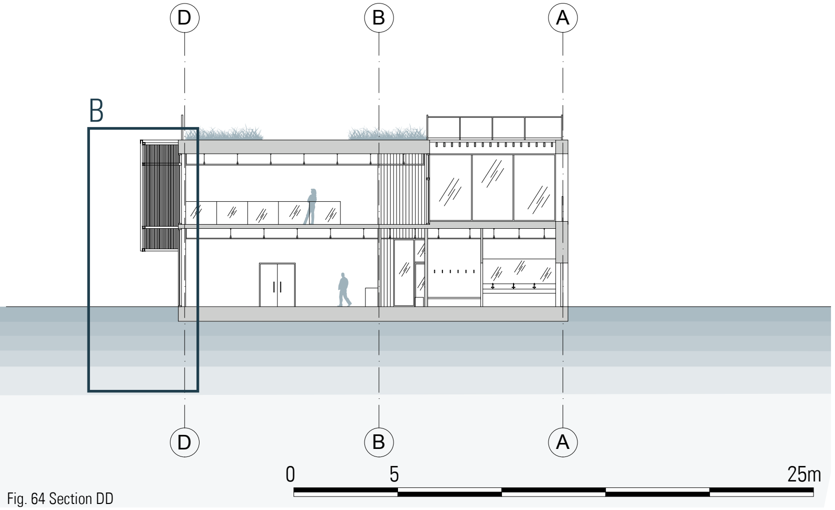


Fig. 64 Section DD

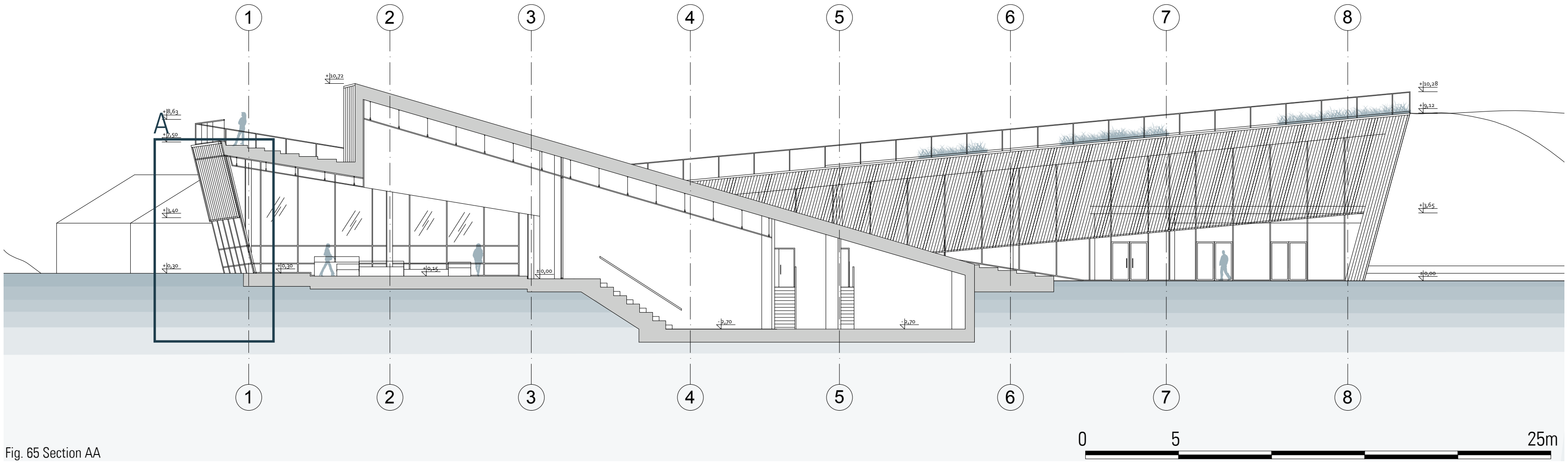


Fig. 65 Section AA

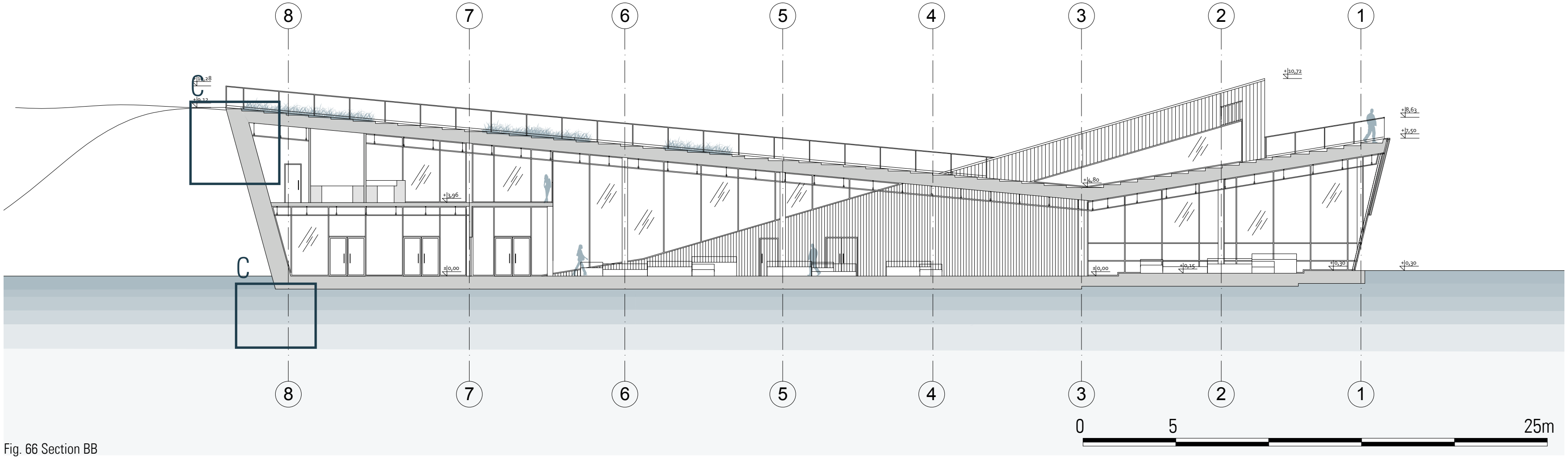


Fig. 66 Section BB

CONSTRUCTION DETAILS

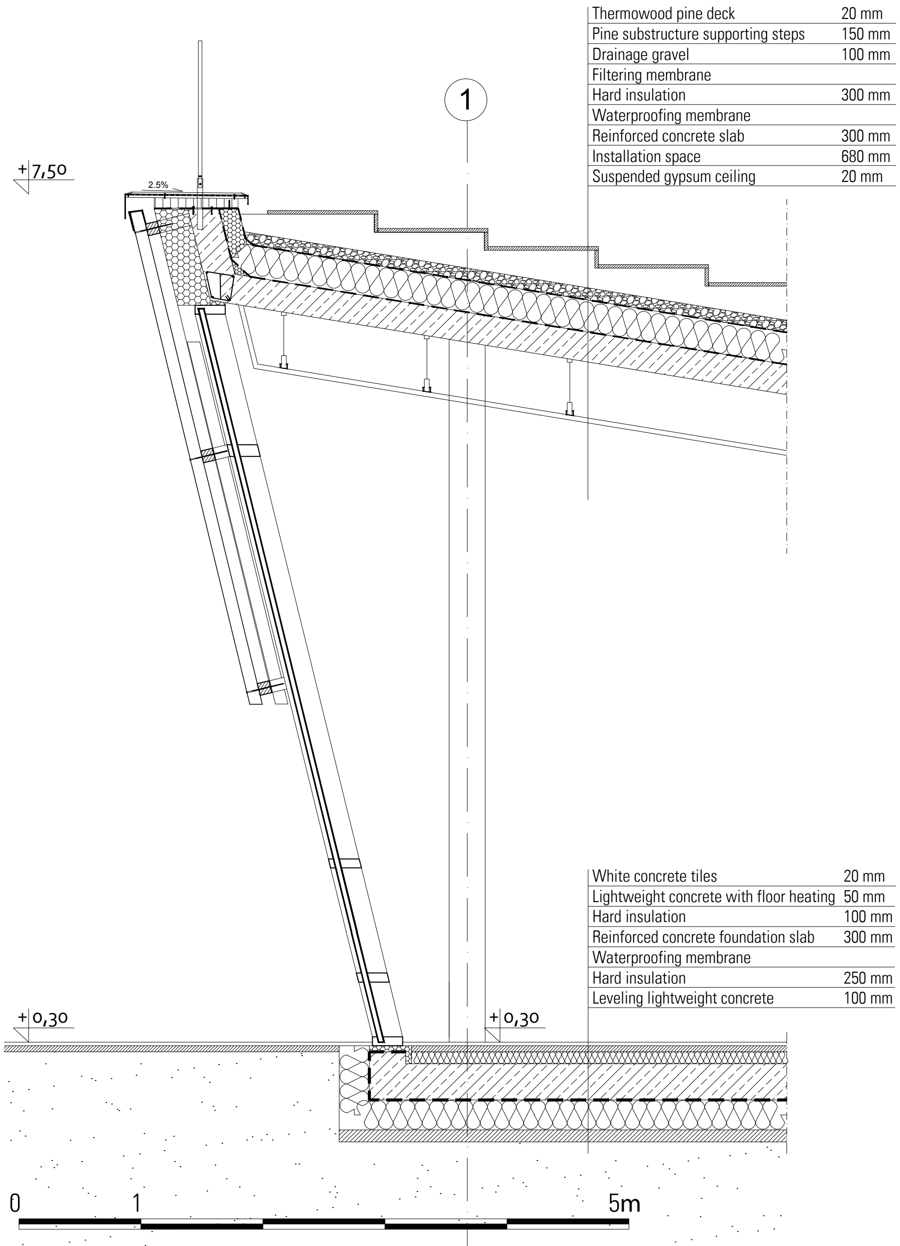


Fig. 67 Detail A

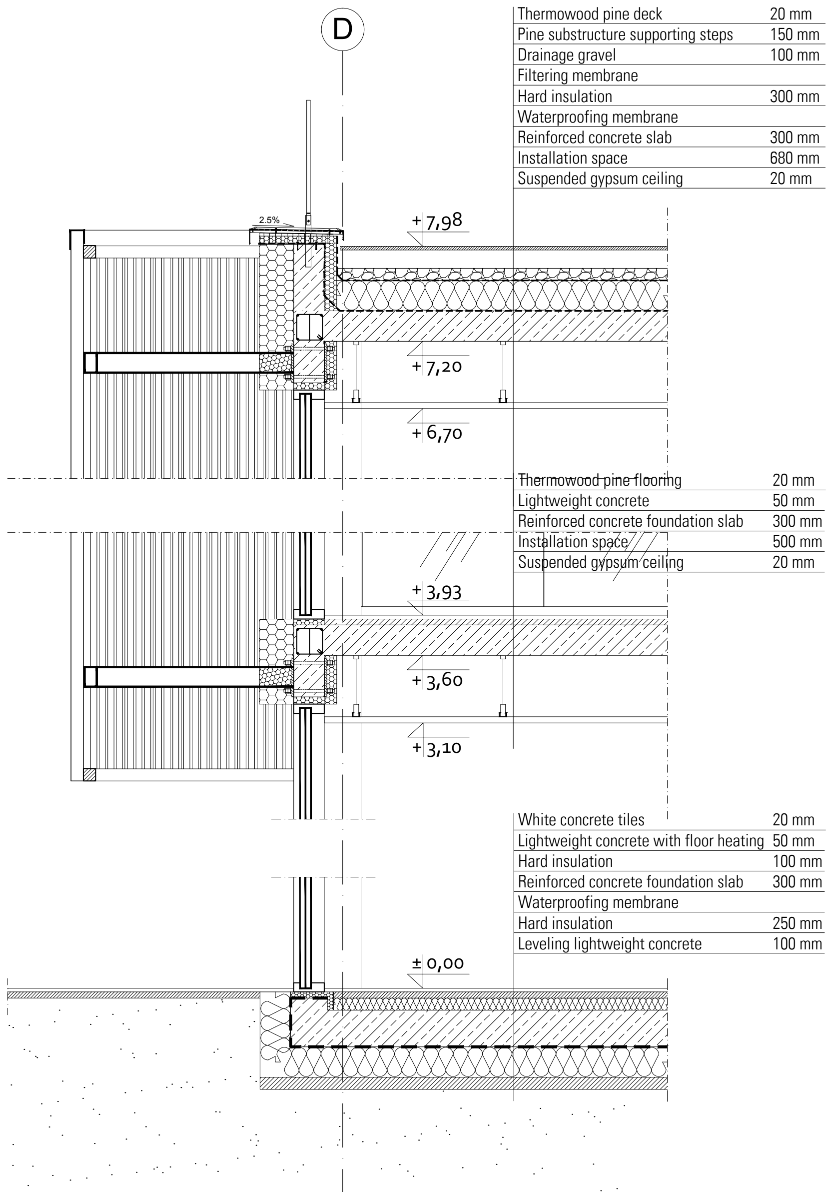


Fig. 68 Detail B

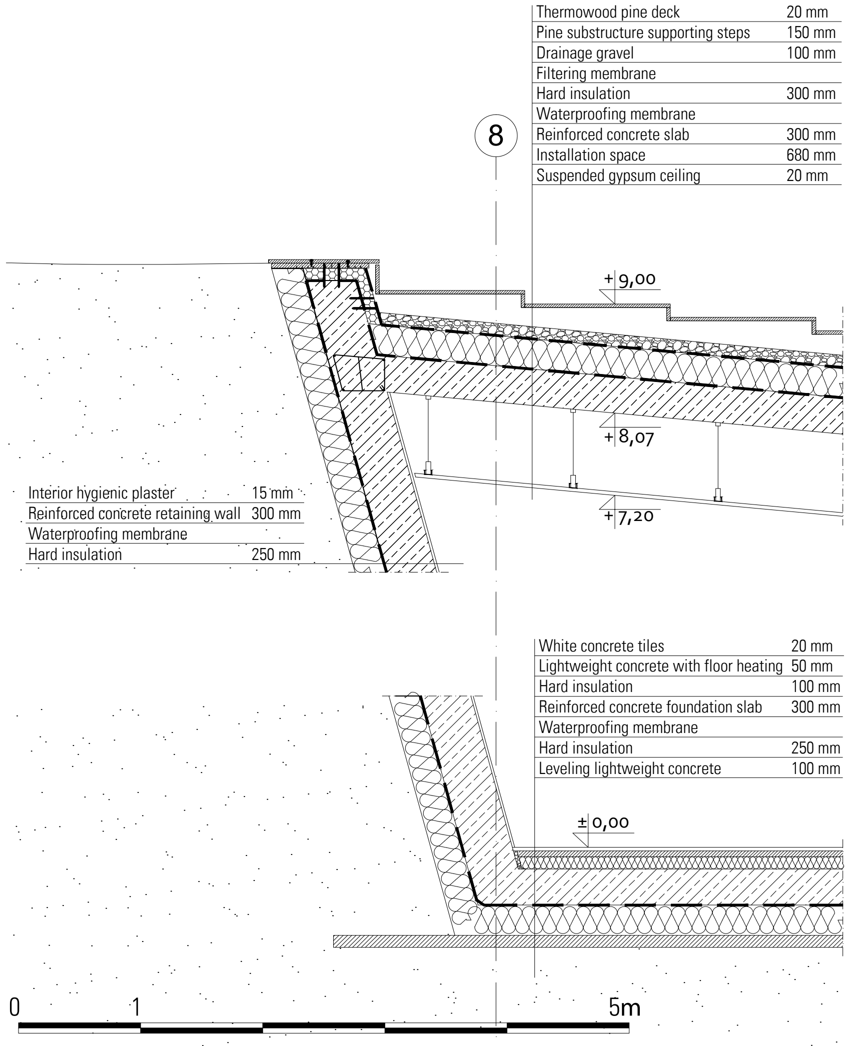


Fig. 69 Detail C

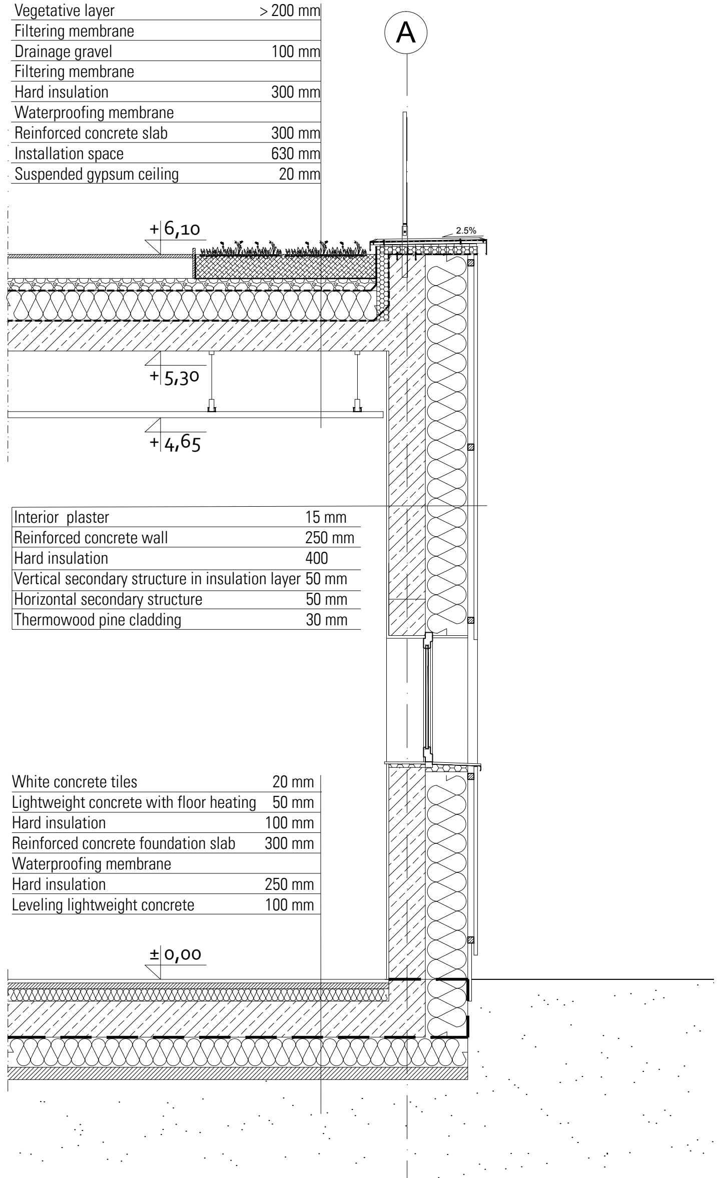


Fig. 70 Detail D

INTERIOR

Interior design puts focus on following the Jay Appleton theory of prospect-refuge described previously in Vision section. The building's aim is to provide visitors with feeling of safety and homelike warmth, which is crucial in such a wild location with harsh weather conditions and unceasing wind. On the contrary, building's objective is to enable unoccluded vistas, while giving feeling of protection and coverage from the open sky. Therefore, building's interiors obtained spruce walls of natural warm hue with structural surface that adds a tactile feeling. Furthermore, building provides many various views – wide-open or framed and directed. For example, temporary exhibition allows the wide view over the square with skate park, as well as front yard, while passage on the ground floor or restaurant on the upper floor allows framed views over the sea. What is more, external shading devices add even more tactile feeling to the interiors by its semi transparent character. Ceiling of all rooms has been designed as white gypsum suspended structure, which gives diffused light and sense of higher space and overall more airy feeling of the space. On the other hand, floor is designed of light-grey, semi-glossy concrete tiles, which continue from the plaza smoothly to the interior. It emphasizes the impression of unity between plaza and visitor center, but also makes it seem like light building resting on a heavy ground. Finally, interiors are finished with airy white and wooden exhibition furniture that complement the space.

Fig. 71 View from Hawblink entrance - visualisation

Fig. 72 Temporary exhibition room - visualisation

Fig. 73 View to the shop from main entrance hall - visualisation

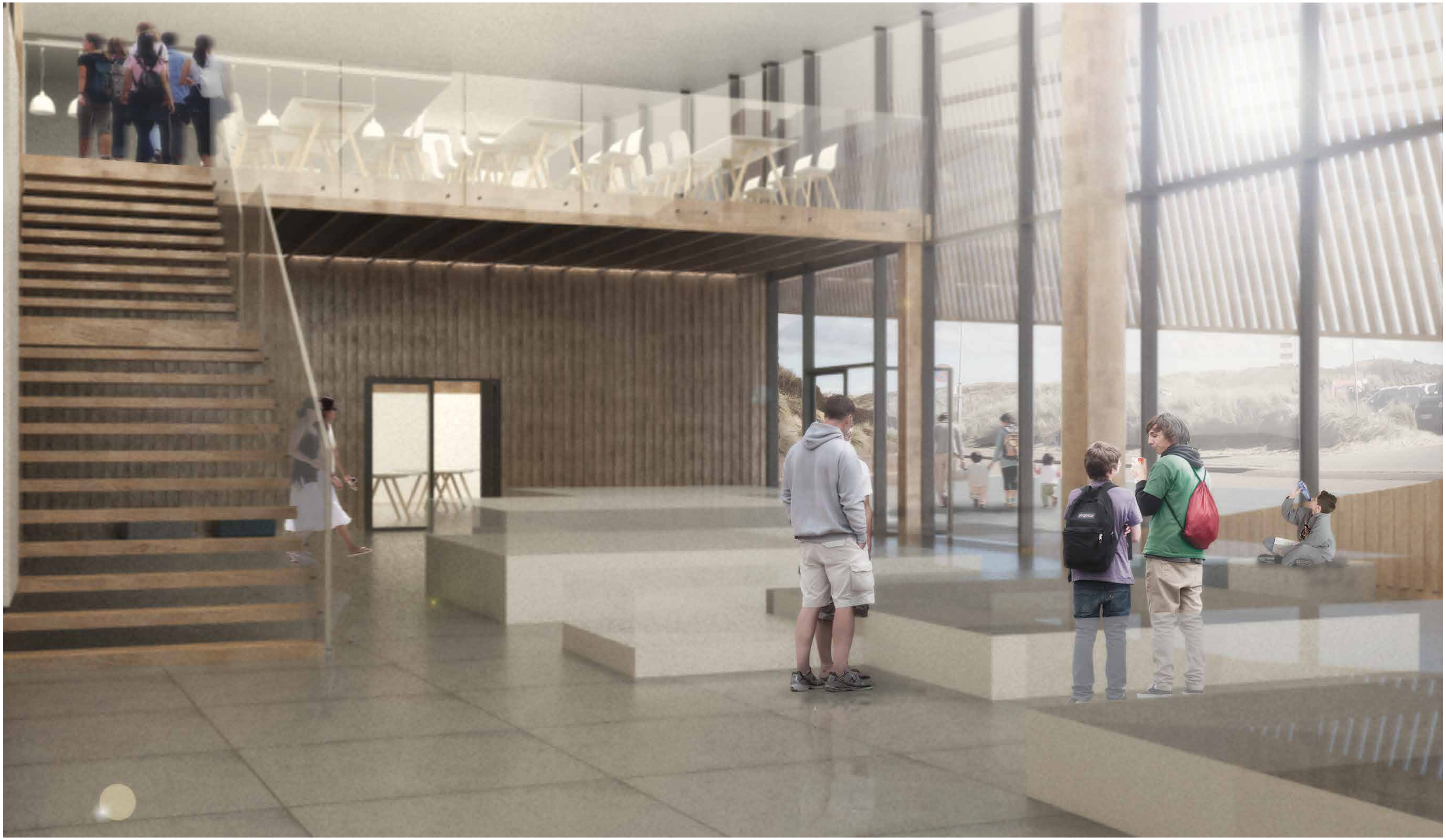


Fig. 74 Main exhibition, view to the mezzanine - visualisation

ELEVATIONS

Elevations are finished with ThermoWood full cladding on northern façade and semi transparent shading structure on western and southern side. ThermoWood is a natural timber subjected to a thermal process, which provides excellent features that are necessary in difficult climatic conditions, such as improved insulating qualities, durability or decreased chance of shrinkage, deformation and damage. As the process does not include any chemicals, ThermoWood is an environmentally friendly product. [MetsaWood, 2015] Furthermore, the southern and western façade embracing the temporary exhibition is equipped with additional movable shading device (Fig.75) that can be unfolded during hot summer days in order to prevent overheating in the room. (Drawings folder, detail A) Finally, the entire building is topped with railing made of stainless steel frame and filled with steel net. Material used for the rail is anti-corrosion steel 316L, which is resistant to damage caused by salty air and water. [Euro Met, 2015]

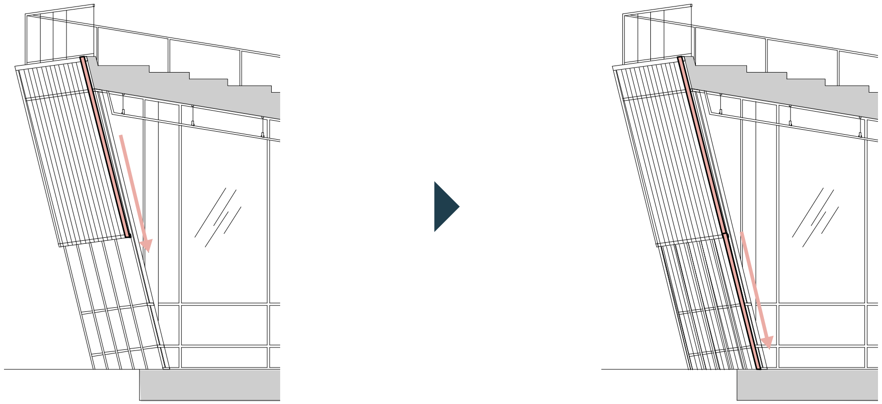


Fig. 75 Movable shading principle diagram

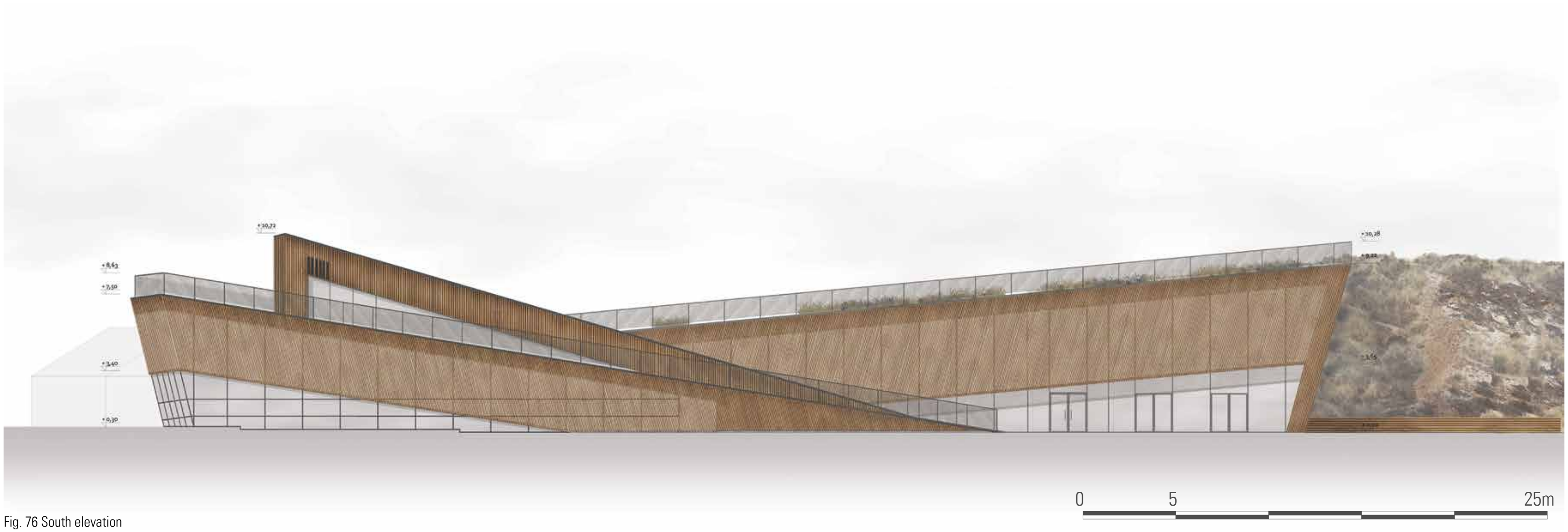


Fig. 76 South elevation

Fig. 77 West elevation

Fig. 78 North elevation

INDOOR AIR QUALITY

Indoor air quality is the basis of the positive overall reception of architecture, as it inevitably influences the comfort and usability of the building. Therefore, an iterative process of finding the best possible solution bringing together healthy conditions without compromising on aesthetical values of the building was held, with help of digital tools such as 24-hour average temperature spreadsheets, ventilation spreadsheets and finally BSim.

The investigation carried out on two main exhibition spaces allowed to achieve results as presented in tables. Temperatures in both rooms never drop below 20 degrees Celsius, at the same time not exceeding 26⁰C for more than 100 hours a year and 27⁰C for more than 25 hours a year. (Fig.80, Fig. 82) Results have been obtained through a system of hybrid ventilation that combines mechanical ventilation operating during colder months (October to April) with natural cross ventilation functioning during summer months (May to September), driven by the wind and thermal buoyancy. The areas greatest natural value, which is regular moderate wind allows to ventilate the space, despite the considerable size of glazing, while an effective system of mechanical ventilation with 85% efficient heat exchanger keeps the air fresh and warm, decreasing a need for heating during the winter time.

Heating has been solved as system combining the floor heating with traditional convective radiators. In the main spaces used by visitors such as exhibitions, gift shop, restrooms and educational rooms, floor heating has been placed under the concrete tiles. This allows spreading the heat evenly in the large open spaces, used by multiple users, without disturbing the neat interiors. Nevertheless, in office area traditional convective radiators have been planed, to allow use of wooden floor finish, as well as in the rooms on the first floor.

Furthermore, the level of CO_2 concentration is stable and rather low throughout the whole year, with the slight increases during the summer months. Nevertheless values stay around 350 ppm, which is similar to the conditions existing outside.
(Fig.81, Fig. 83)

Temperature	January	February	March	April	May	June	July	August	September	October	November	December	Total
>26	0	0	0	0	8	23	28	25	0	0	0	0	84
>27	0	0	0	0	1	7	4	8	0	0	0	0	20
<20	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 79 Main exhibition temperatures table

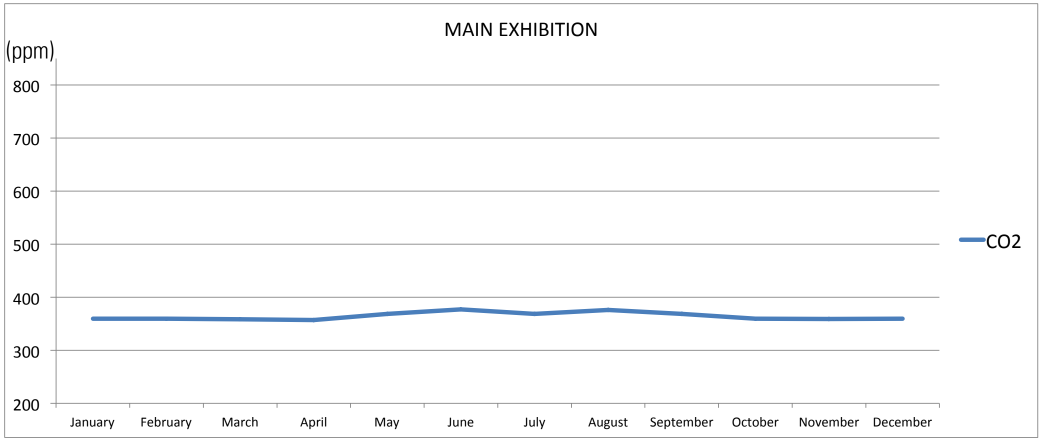


Fig. 80 Main exhibition CO_2 concentration diagram

Temperature	January	February	March	April	May	June	July	August	September	October	November	December	Total/mean
>26	0	0	0	0	2	14	18	24	1	0	0	0	59
>27	0	0	0	0	0	6	4	9	1	0	0	0	20
<20	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 81 Temporary exhibition temperatures table

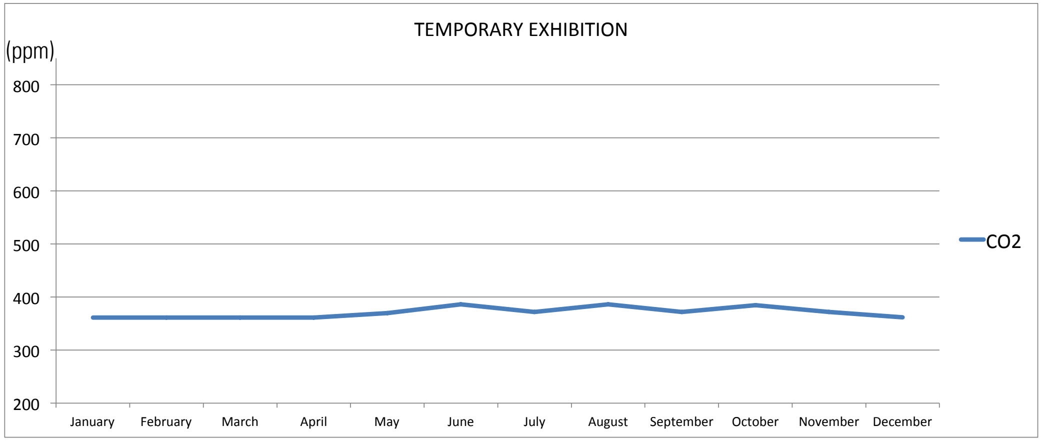


Fig. 82 Temporary exhibition CO_2 concentration diagram

NATURAL VENTILATION

Natural ventilation has been designed to be in use during the warm months, stretching from May to September, but still with the possibility to run mechanical ventilation in most critical rooms if necessary. Natural ventilation is driven by the thermal buoyancy and wind, which constant moderate speed allows providing fresh air. In the open exhibition areas cross ventilation has been planed, while offices and educational rooms obtain only the single-sided ventilation (Fig.85). Nevertheless, office space located in the northern part of the building is not exposed to the overheating and thus typical manually controlled opening of the windows is sufficient, however two of the educational rooms – workshop and auditorium keep the possibility of mechanical ventilation during hours of use the entire year, due to significant user heat load and southern orientation of the windows in both rooms.

Exhibition area despite the cross ventilation, has obtained the possibility of additional ventilation driven by the thermal buoyancy, through openings in the skylight (Fig.83).

As the temporary exhibition is perceived as the most critical room exposed to overheating, the calculation of possible air change rate has been held. The results presented on the diagram (Fig.84) shows that it is easily achievable to naturally ventilate the room regardless the power and direction of the wind. Achieved air change rate is always higher than needed value calculated on the basis of sensory air pollution, which equals 1,64 h^{-1}. (Calculations in Appendix p. 98-99, 104)

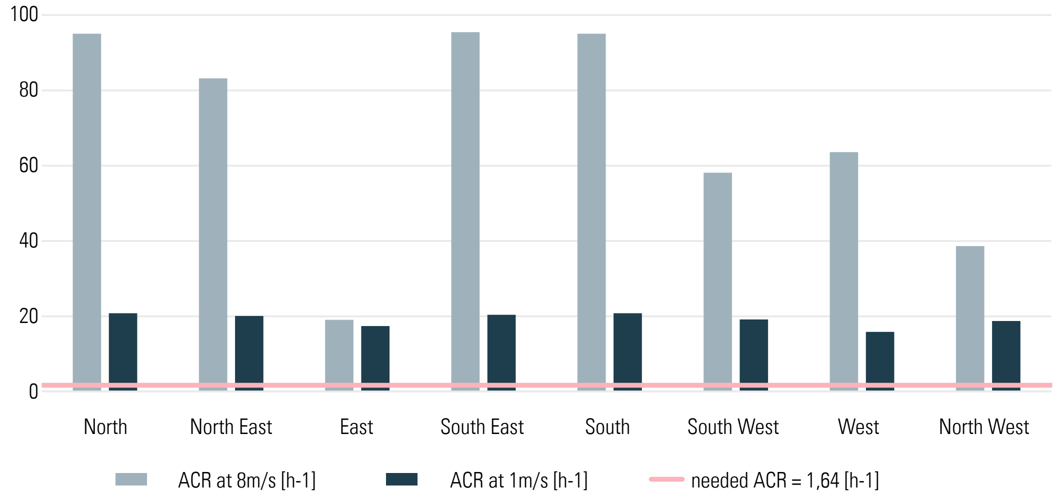


Fig. 84 Air change rate diagram

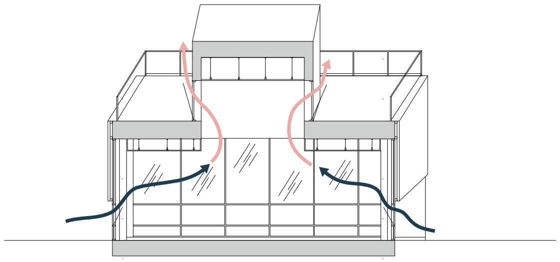


Fig. 83 Natural ventilation diagram - section

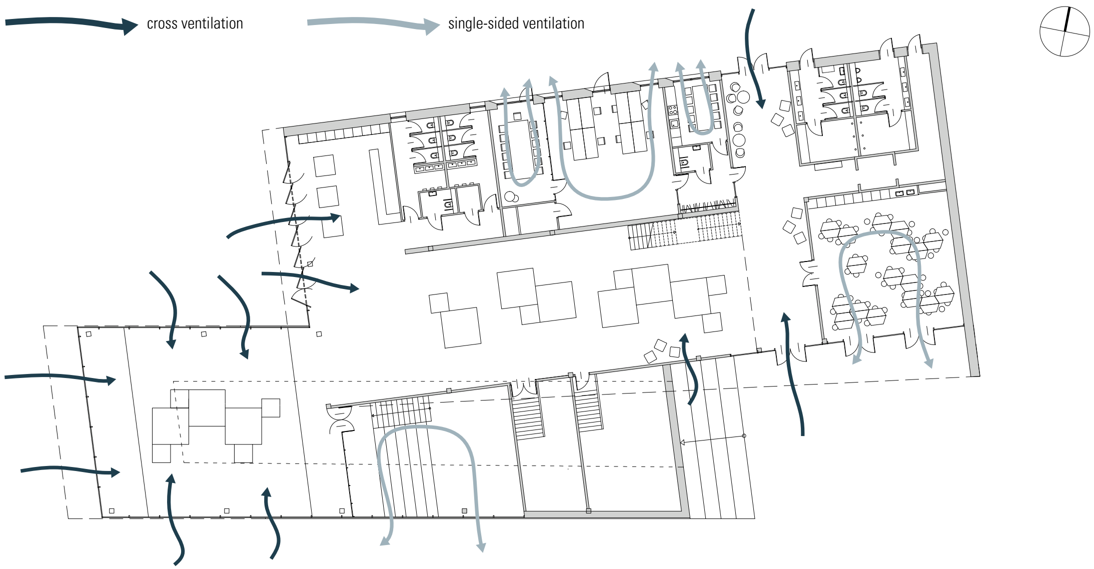


Fig. 85 Natural ventilation diagram - plan

MECHANICAL VENTILATION

Mechanical ventilation is a key factor defining good indoor air quality. In order to support sustainability of the building ventilation is designed as a system with heat recovery, which employs a cross flow of air, where warm extracted air preheats the cold fresh supplied air, in order to save energy by reducing heating requirements. Main ducts , both providing and extracting air are running from the aggregate in the technical room under the ceiling of skylight in the installation space, covered by suspended ceiling, to the ends of ducts located on the sides of the skylight, inlet on the northern side and extract on the southern side, where they stay invisible and integrated into architecture. (Fig.91)

Fresh air is supplied by the system located under the floor slab and with outlets spread in regular distances in the floor, providing evenly distributed clean air. (Fig.86) In order to provide first floor with the same system of floor supply , distribution duct runs under the floor slab to reach the shaft in the corner of workshop and from there run vertically to the floor above. (Fig.87)

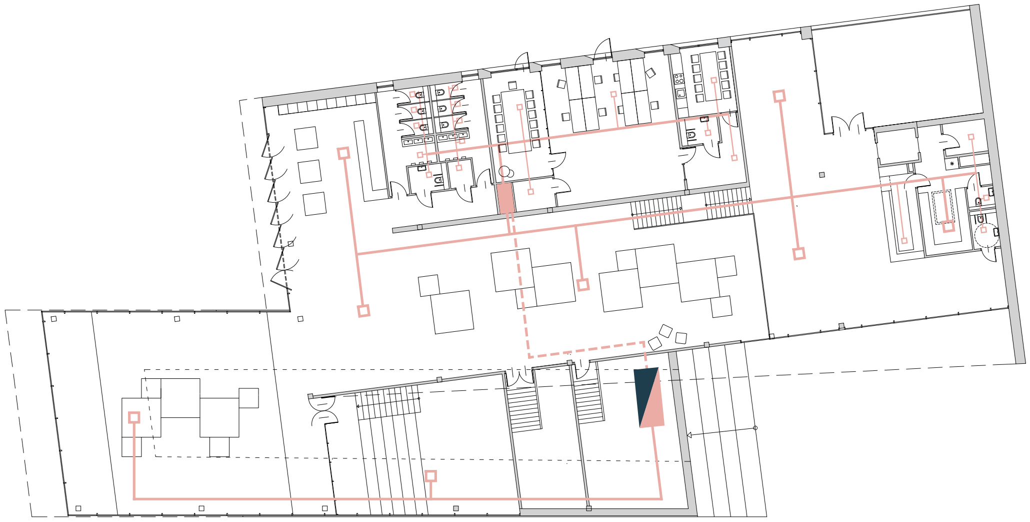
Fresh air after being heated and polluted flows upwards to be extracted by the inlets located in the installation space above suspended ceiling, where it comes back to the heat exchanger and is extracted to the outside.

Main return duct extracting air from the main exhibition, offices and first floor, initially runs under the floor to reach the shaft located in the office area and than run vertically to the installation space under the ceiling. (Fig.88) Meanwhile, rooms under the first floor are connected to the main duct running under the floor to the vertical shaft in the workshop corner, to afterwards extract air from beach restrooms and workshop. (Fig.89)

Calculations of duct sizes available in Appendix p.104-105

Fig. 86 Mechanical ventilation supply layout - ground floor

Fig. 87 Mechanical ventilation supply layout - first floor

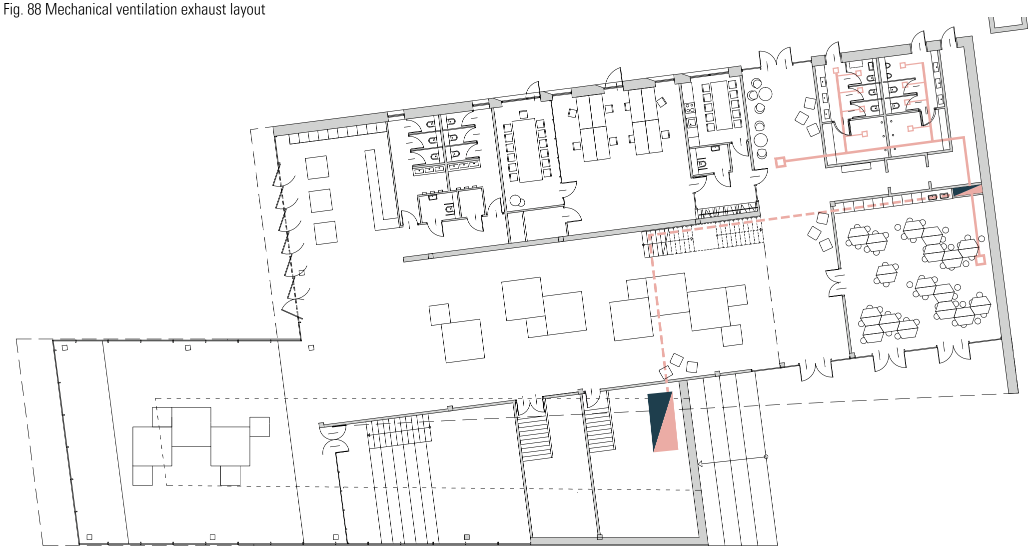


air return pipe — underground return pipe — vertical shaft

Fig. 88 Mechanical ventilation exhaust layout

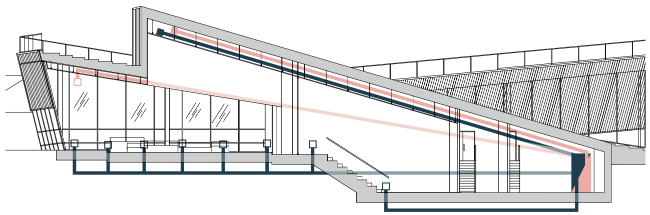
Room	Circular duct diameter (mm)
Main exhibition	420
Temporary exhibition	310
Auditorium	310
Workshop	330
Shop	170
Offices	210
Restaurant	420
Kitchen	100
Restrooms	100
External restroom	125
Main duct rectangular	1200x2400

Fig. 90 Ventilation pipe sizing - table



air return pipe — underground return pipe — vertical shaft

Fig. 89 Mechanical ventilation exhaust layout - ground floor



air supply — air return — ventilation aggregate

Fig. 91 Mechanical ventilation diagram - section

ENERGY PERFORMANCE

Visitor Center of the Thy National Park seeks to become a good example of sensible architecture, while being sustainable and reaching as low energy consumption as possible. In order to fulfill the requirements of Danish Building Regulations BR10 with the annex of low-energy class 2020 the iterative process of design was performed with digital calculation tool – Be10.

The total energy consumption has been calculated taking into consideration building orientation, location and shading; external envelope, ventilation, internal heat supplies from people, appliances and lighting, as well as heat loses from pumps, heating pipes or hot water tank. After primary calculations excluding additional energy sources, total energy requirement has been calculated at 68,5 kWh/m^2 per year, therefore it was necessary to apply photovoltaic panels. By using 168m^2 of solar panels located on the roof of skylight energy performance has dropped down to 13,6 kWh/m^2. This result meets the goal of low-energy class 2020 of being below 25kWh/m^2 and leaves relatively large safety margin within calculations. Moreover, total transmission loss through building envelope excluding windows and doors has reached 3,2 W/m^2, therefore also fulfilling the requirement of maximum loss of 4,7 W/m^2 for two-story buildings.

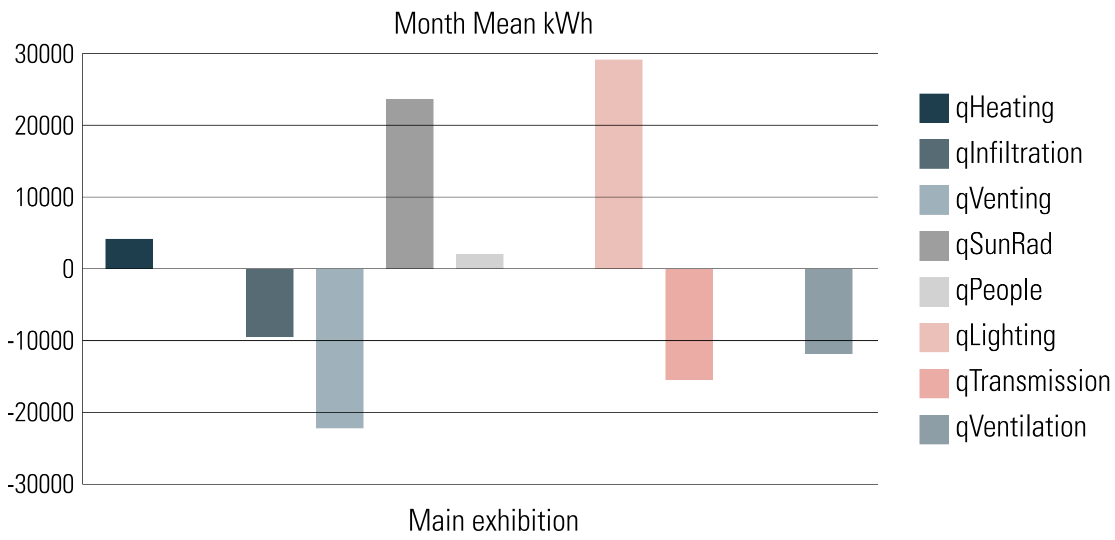


Fig. 92 Energy performance BSim results - main exhibition

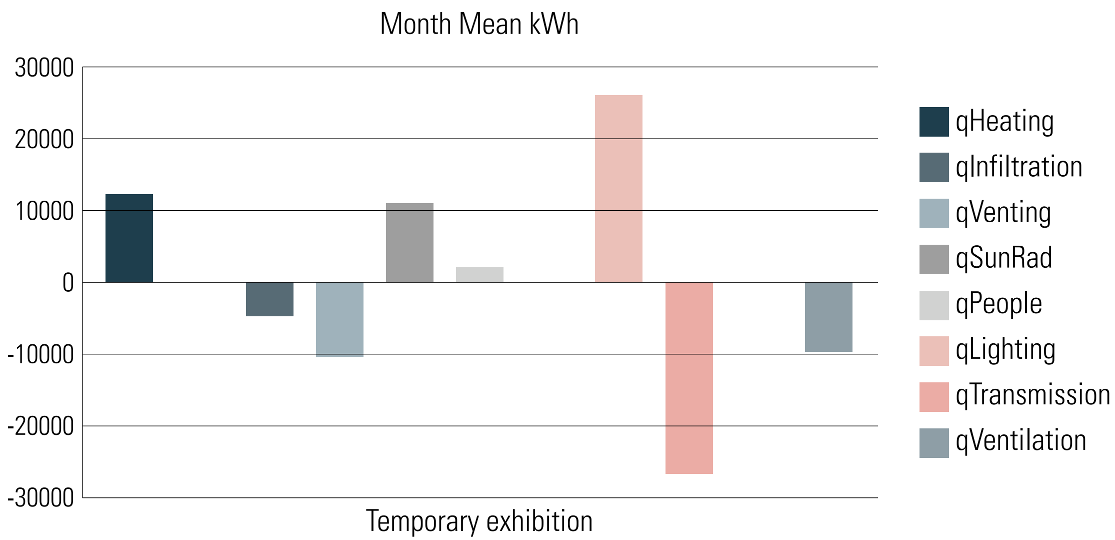
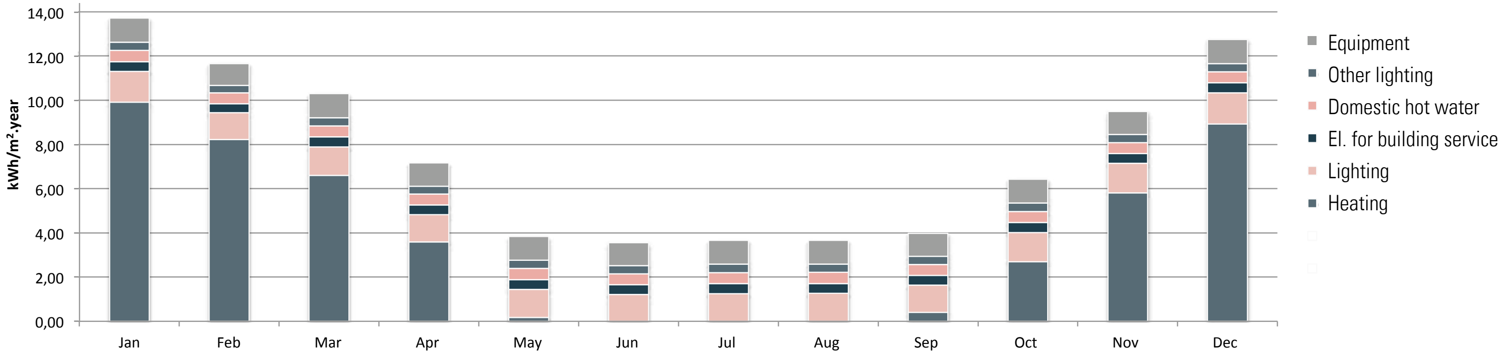


Fig. 93 Energy performance BSim results - temporary exhibition



kWh/m² year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Excess temperature in roon	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Heating	9,91	8,23	6,59	3,60	0,18	0,00	0,00	0,00	0,41	2,69	5,81	8,92	46,33
Cooling	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Lighting	1,39	1,20	1,29	1,22	1,26	1,22	1,26	1,26	1,23	1,33	1,34	1,42	15,42
El for building service	0,45	0,41	0,45	0,44	0,45	0,44	0,45	0,45	0,44	0,45	0,44	0,45	5,32
Domestic hot water	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	5,4
Other lighting	0,37	0,34	0,37	0,36	0,37	0,36	0,37	0,37	0,36	0,37	0,36	0,37	4,38
Equipment	1,08	0,98	1,08	1,05	1,08	1,05	1,08	1,08	1,05	1,08	1,05	1,08	12,77

Fig. 94 Energy performance Be10 results - entire building

Energy frame Buildings 2020

Without supplement	Supplement for special conditions	Total energy frame
25,0	0,0	25,0
Total energy requirement		13,6

Contribution to energy requirement		Net requirement	
Heat	52,0	Room heating	45,4
El. for operation of bulding	20,7	Domestic hot water	5,4
Excessive in rooms	0,0	Cooling	0,0

Selected electricity requirements		Heat loss from installations	
Lighting	15,4	Room heating	0,9
Heating of rooms	0,0	Domestic hot water	0,1
Heating of DHW	0,0		
Heat pump	0,0	Output from special sources	
Ventilators	5,0	Solar heat	0,0
Pumps	0,3	Heat pump	0,0
Cooling	0,0	Solar cells	30,5
Total el. consumption	37,8	Wind mills	0,0

Fig. 95 Be10 results - entire building

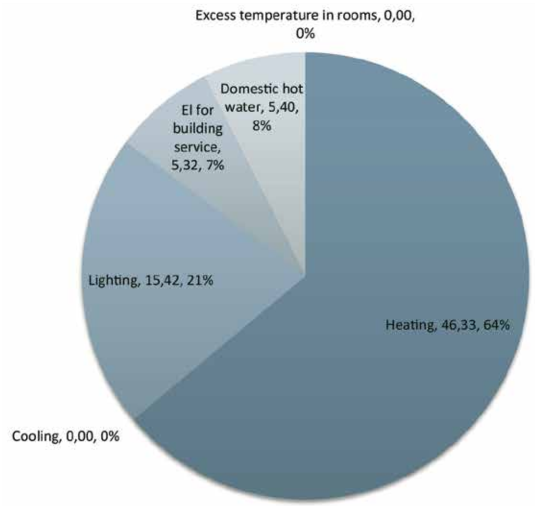


Fig. 96 Be10 results diagram -percentage share of energy consumption

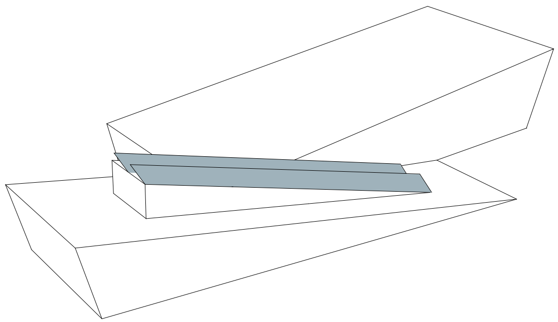


Fig. 97 Photovoltaic panels placement diagram

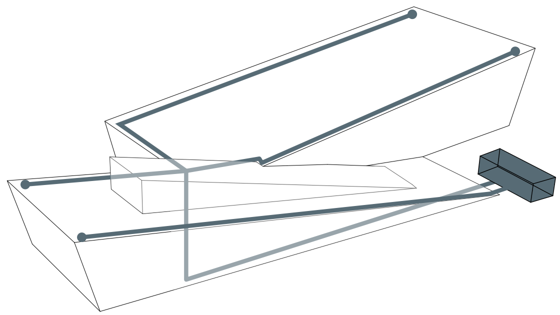


Fig. 98 Rainwater solution diagram

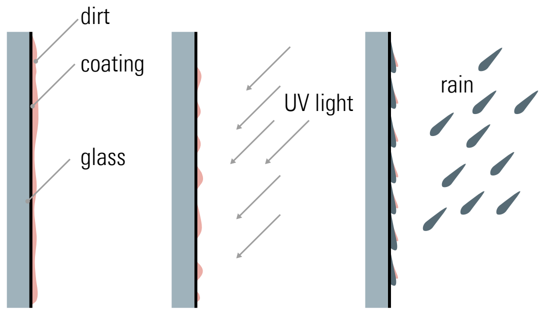


Fig. 99 Self-cleaning windows working principle diagram

PHOTOVOLTAICS

Photovoltaic panels has been designed in order to improve the total energy performance of the building. This method of providing renewable energy has been chosen as it is considered the clean sustainable energy, which is the easiest to gain, and which allows the direct conversion of solar energy into electricity without any emissions.

Photovoltaic panels covering the area of 168m^2 have been installed on the roof of the skylight protruding from the southern part of the building. Chosen panels include monocristalline silicon as a photovoltaic material. They are able to reach peak power of 0,23 kWm^2 with the system efficiency of 85%. In order to achieve the best results panels are installed on a movable sub-construction that automatically changes the panelss angle according to the sun position.

RAINWATER

Slope of the entire roof allows the easy removal of the rainwater. Rainwater runs throught the external gutters located at the edges of the building's roof and afterwards is collected into the underground tank located in the southern part of the plot in front of the entrance.

The objective of retaining water is to supply flushing cisterns in toilets and fire-fighting sprinkle system located on the first floor of the building, but it can also be used for cleaning front yards from the continously returning sand, especially after winter.

SELF-CLEANING WINDOWS

Visitor Center is exposed to the demanding weather conditions, thus in orders to provide the building with wide and clear views of the surroundings, glazed surfaces require special treatment. In order to address this problem, all windows have been equipped with self-cleaning coating.

In the first step called photocatalysis, coating reacts with daylight to decompose the organic dirt. In the second hydrophilic step rainwater spreads evenly on the glass surface, instead of forming droplets, and washes the fragmented dirt, at the same time drying very quickly without leaving streaks.
[Pilkington, 2015]

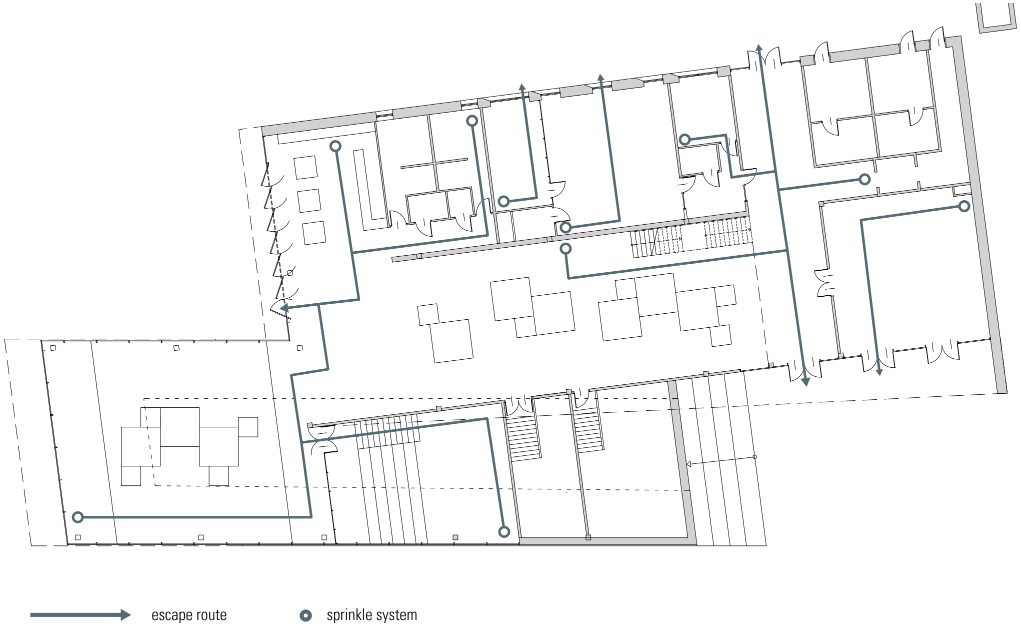


Fig. 100 Fire escape plan - ground floor

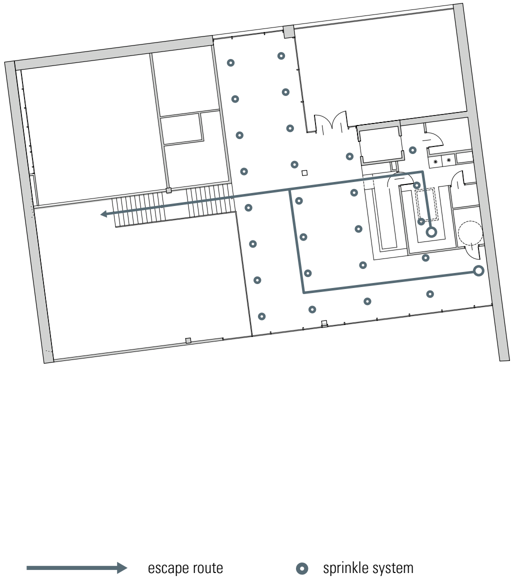


Fig. 101 Fire escape plan - first floor

FIRE SAFETY

As the Visitor Center is a building of considerably small area of 1350 m2 it is possible to provide a standard fire escape of 25 m from every part of the ground floor. The most difficult section of the building is the restaurant on the first floor, which involves longer fire escape including stairs. Therefore, the sprinkler system was implemented, in order to extend possible escape time. Water will be supplied from the rainwater tank.

Furthermore, building is accessible for the fire engine from three sides. It will be possible to reach the building from the main road on the south side, from the delivery road on the north side, but also from the west side, where is located 8-meter wide pedestrian path.

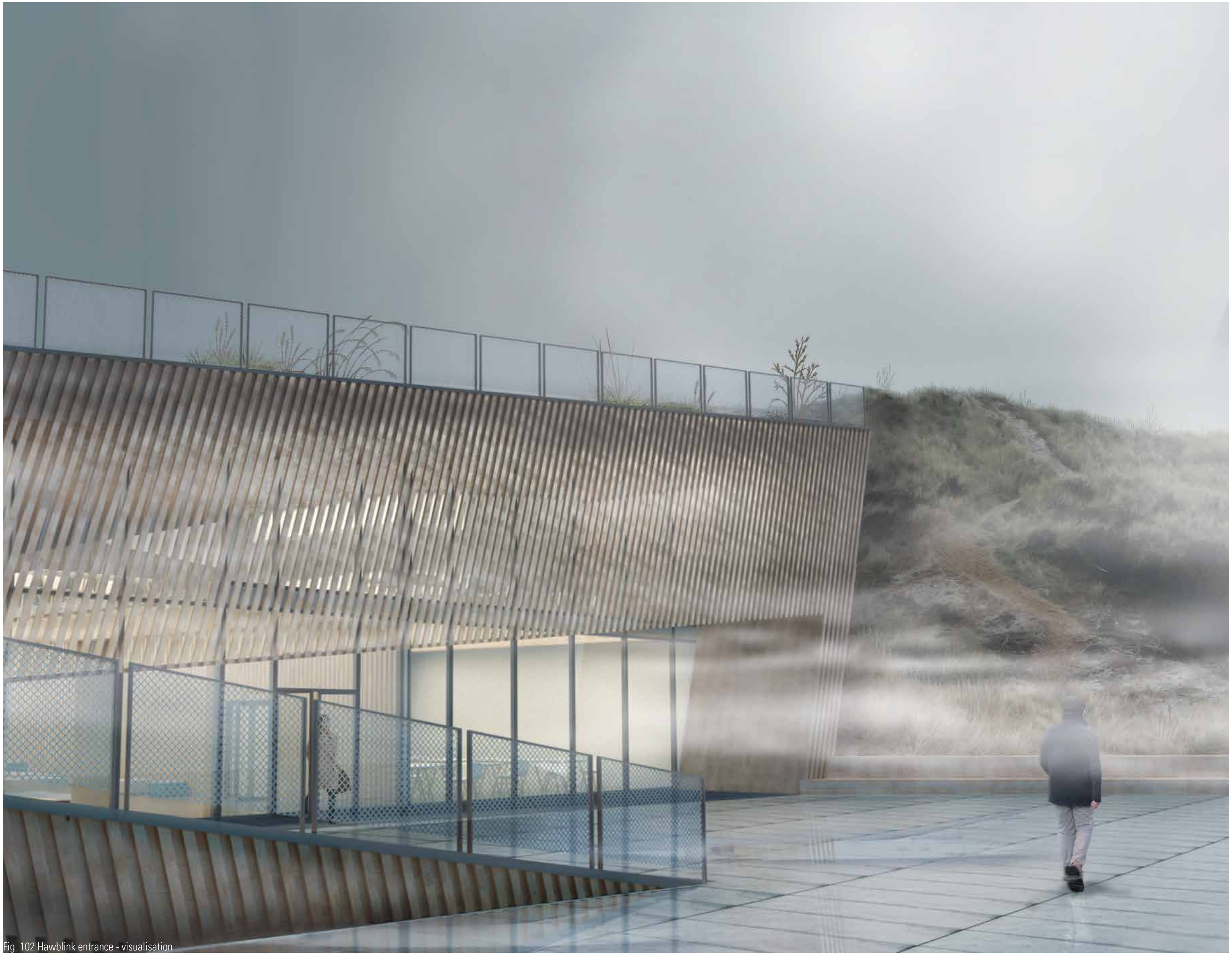


Fig. 102 Hawblink entrance - visualisation

CONCLUSION

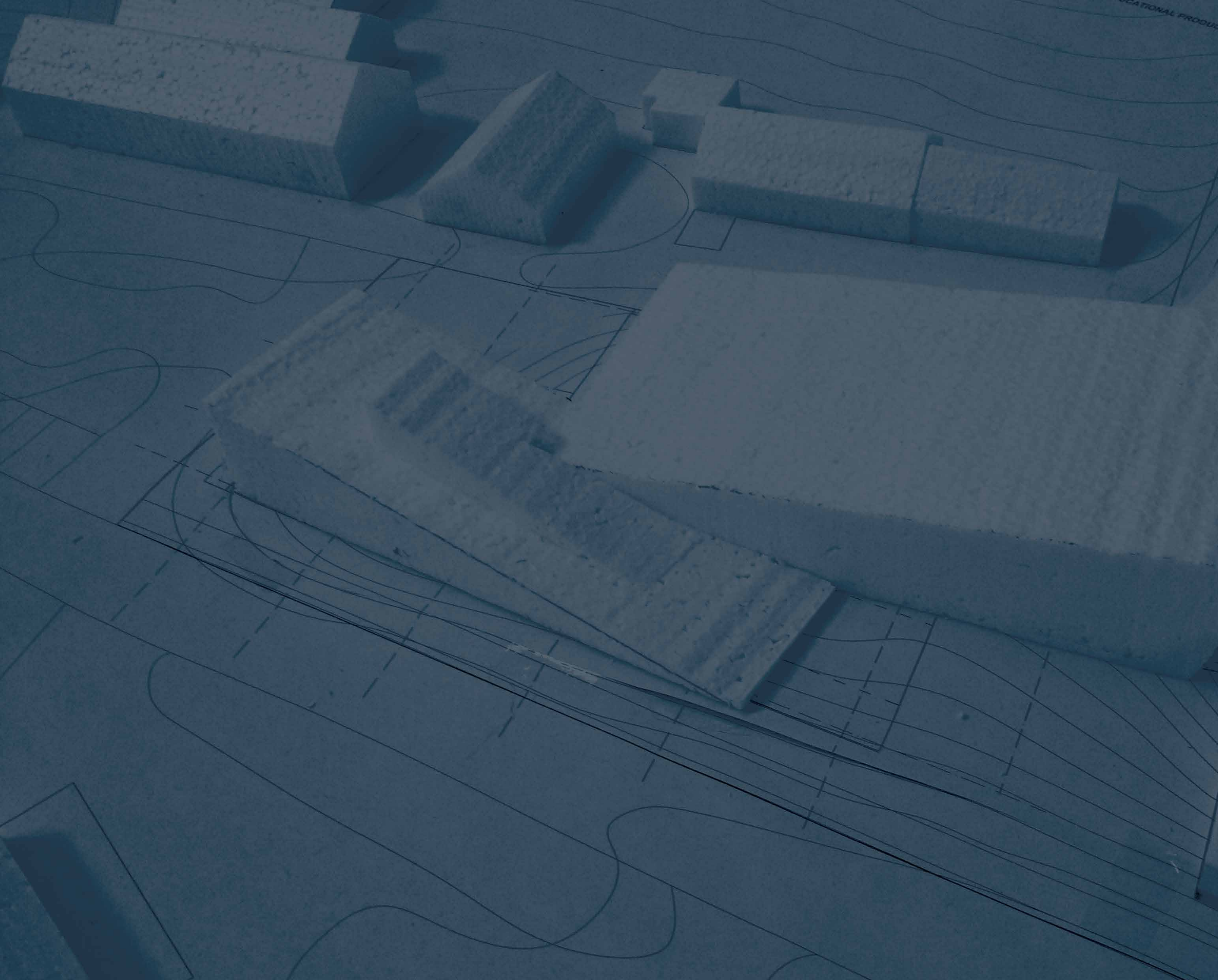
It all started with a demanding site, in the most visited town of the region – Nørre Vorupør, right at the main landing place, however completely covered by 9-meter tall dune. It opened up a lot of potentials, as well as obstructions. From the very beginning the leading ambition was to create a Visitor Center that is an attractive and inspiring gateway to the Thy National Park. The Visitor Center seeked to give tourists the desire to discover the park's unique nature, but foremost to become a lively workshop and place of communication that promotes and strengthens the region and local businesses.

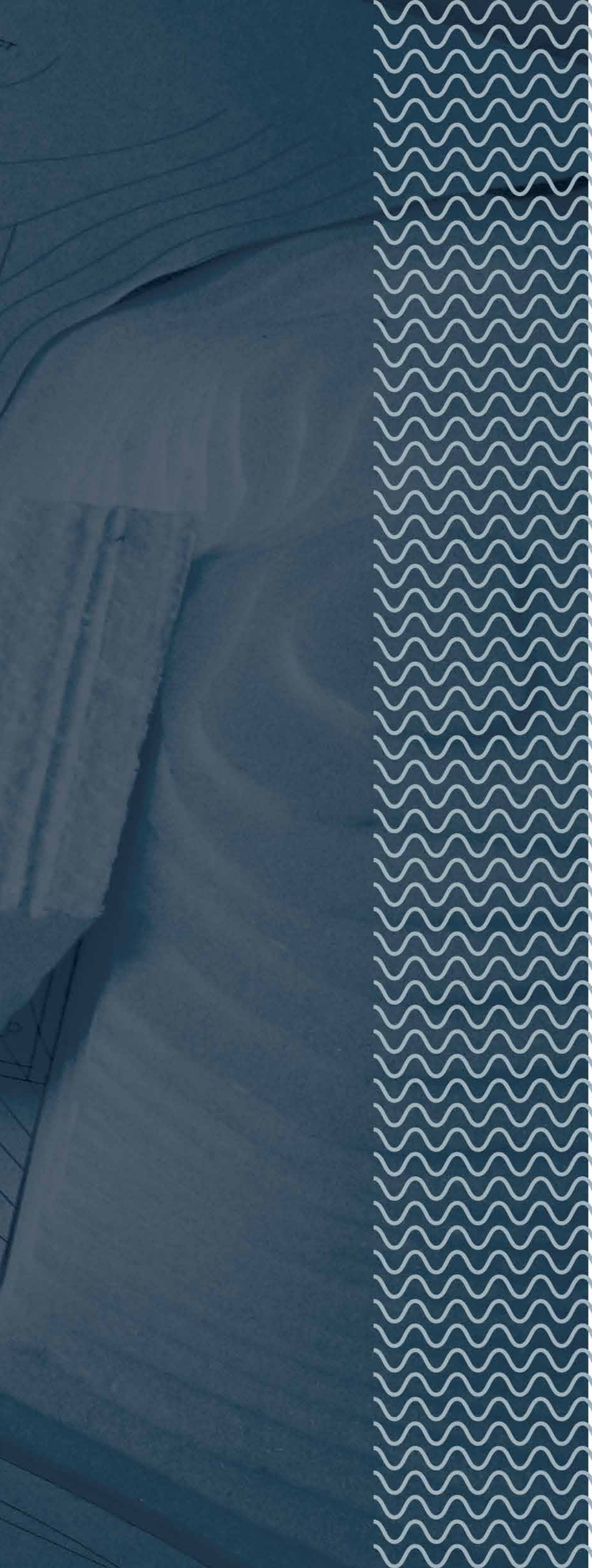
As the building is located in the first Danish National Park, in such a pristine wilderness the design put focus on fulfilling the most primary human desire of prospect and refuge, but also on living up to the sustainability requirements. Therefore, buildings biggest challenge was to create a space that ensures the feeling of safety in those ever-changing weather conditions, provides wide-open views to the surrounding landscape and serves as an exemplary piece of sustainable architecture.

By referring to the local context, including fisherman's houses, wooden summer bungalows, coastal landscape and hallmark of Nørre Vorupør – colorful fishing boats resting on the wide beach - building became unified with surroundings. It's program provides visitors' with two open exhibition spaces – one permanent, telling the story about the National Park and the other – temporary, additionally paired with spacious auditorium, that together create a perfect space, which serves as a local business and communication platform. Visitors can also enjoy the restaurant with terrace and views to the sea, but also gift shop combined with tourist information and finally comfortable restrooms and showers serving all of the beach users, especially surfers.

Not only the Visitor Center has been developed as an adventure destination that provides a unique pathway on the roof all the way from the entrance to the top of the dune, which gradually reveals breathtaking views over the town, than to the plaza and finally to the North Sea, but also it fullfiled all of the technical requirements of low-energy architecture.

On one hand, building appears to be expressive, on the other it blends with the dune and draws the square to the inside, which creates a perfect fusion between city and nature, but foremost between visitors and local people.





04 PPROCESS

FUNCTIONS ARRANGEMENT

After the analysis of needs and goals stated by the Board of National Park, the primary program has been set and following various plan arrangements. First option was to place functions in an linear order, where the dining area becomes a center where both exhibition visitors and users of educational part could meet, but also where the office spaces where disconnected from the rest of the building due to its contrasting function.

Second option investigated the possibility of gathering all functions around the main exhibition area , while being grouped thematically. Some of the characteristics of this solution have been used in the final design, where exhibition is also centrally located, but with improved communication system.

Third option is based on an idea where the entire building becomes an exhibition space and other functions are placed within as „islands". Unfortunately, it may cause significant problems with providing daylight as well as unnecessary increase of the overall area of the building.

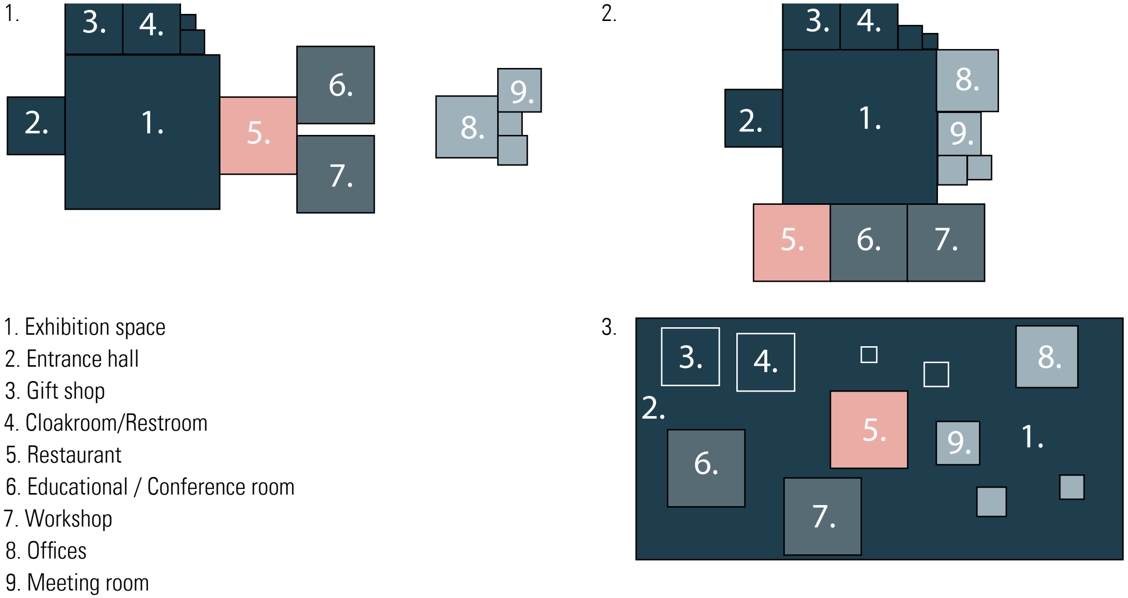


Fig. 103 Different plan arrangements

PRIMARY SKETCHING

Primary sketching is a very crucial stage of the design process, as it gives an initial driving force for the entire design. In this phase different solutions referring to the main three concepts where investigated, while taking into consideration possibilities of function arrangements. First group of sketches was following the concept path of traditional fisherman housing with its pitched roofs and modest appearance reinterpreted into the contemporary form.

On the contrary smooth, wavy shapes following the concept of building that mimics the dune, where investigated in a variety of ways. Finally, sketches that paved the path for further design were created following the concept of a building including a certain level of integration with the dune, without actual imitating its shape, but with strong connection to the local materiality.

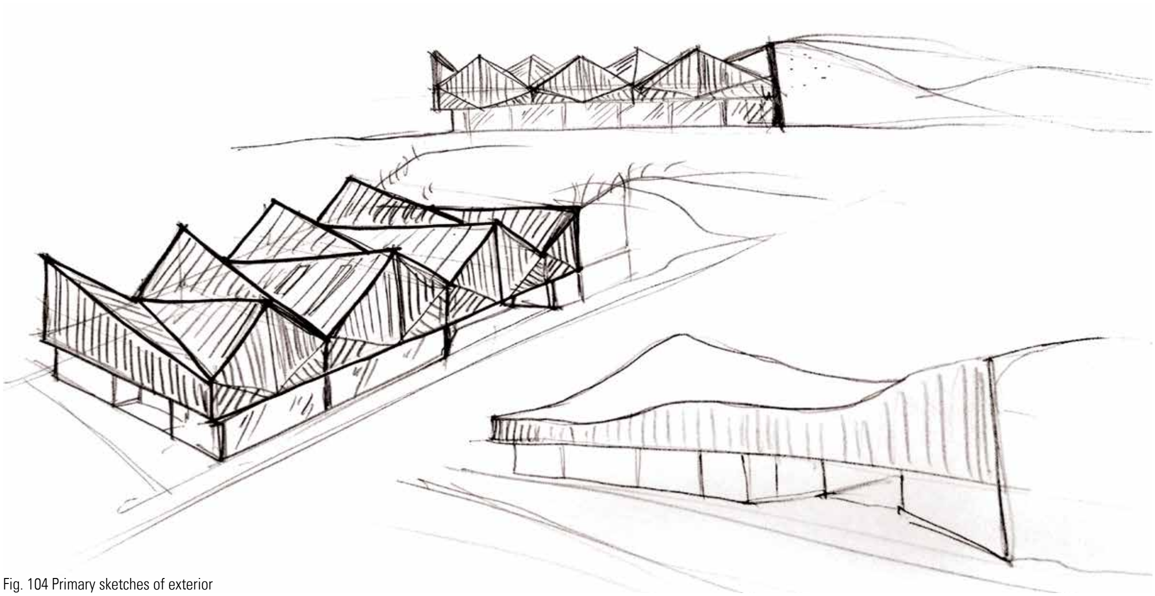


Fig. 104 Primary sketches of exterior

PRIMARY SKETCHING

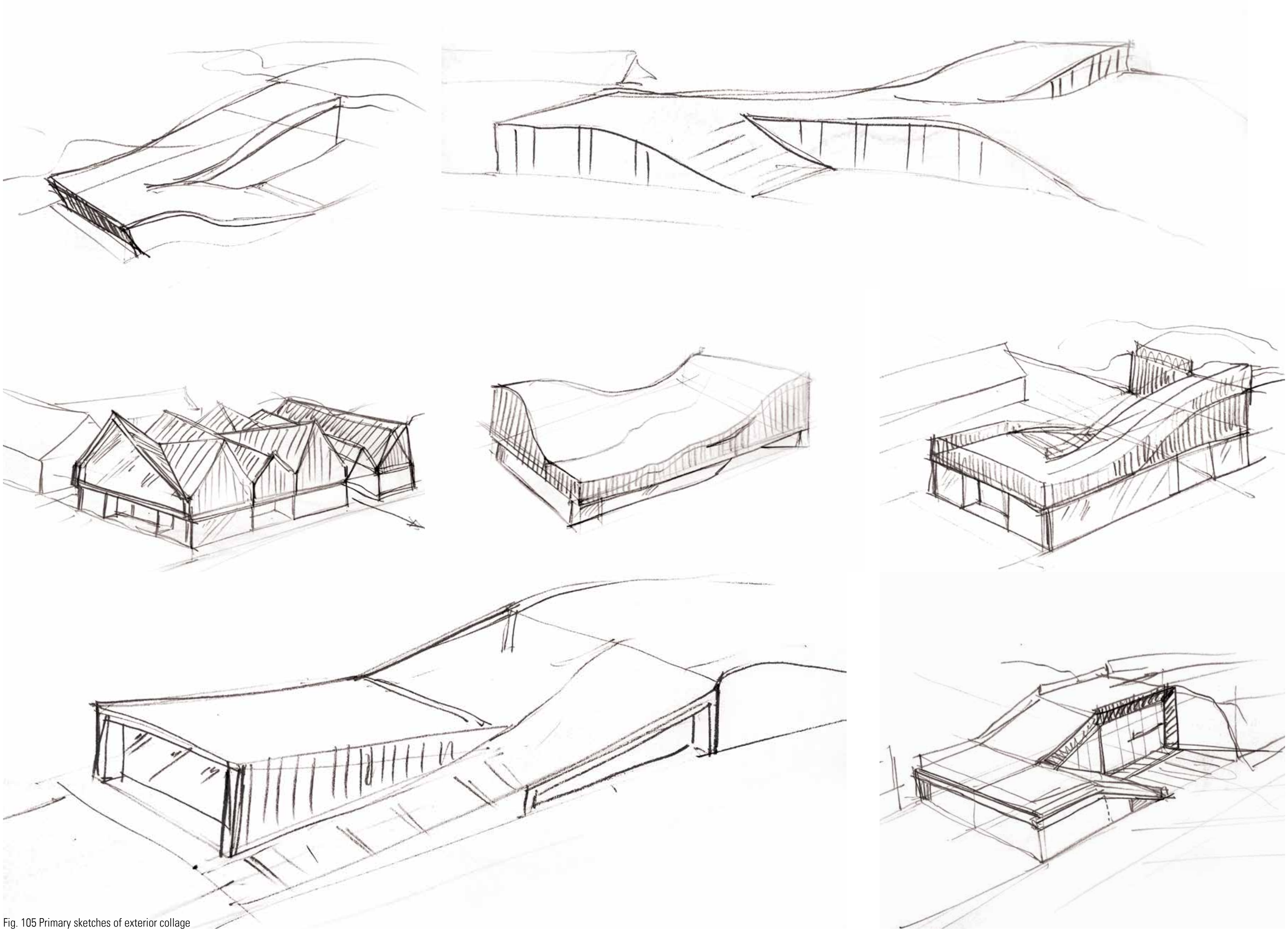


Fig. 105 Primary sketches of exterior collage

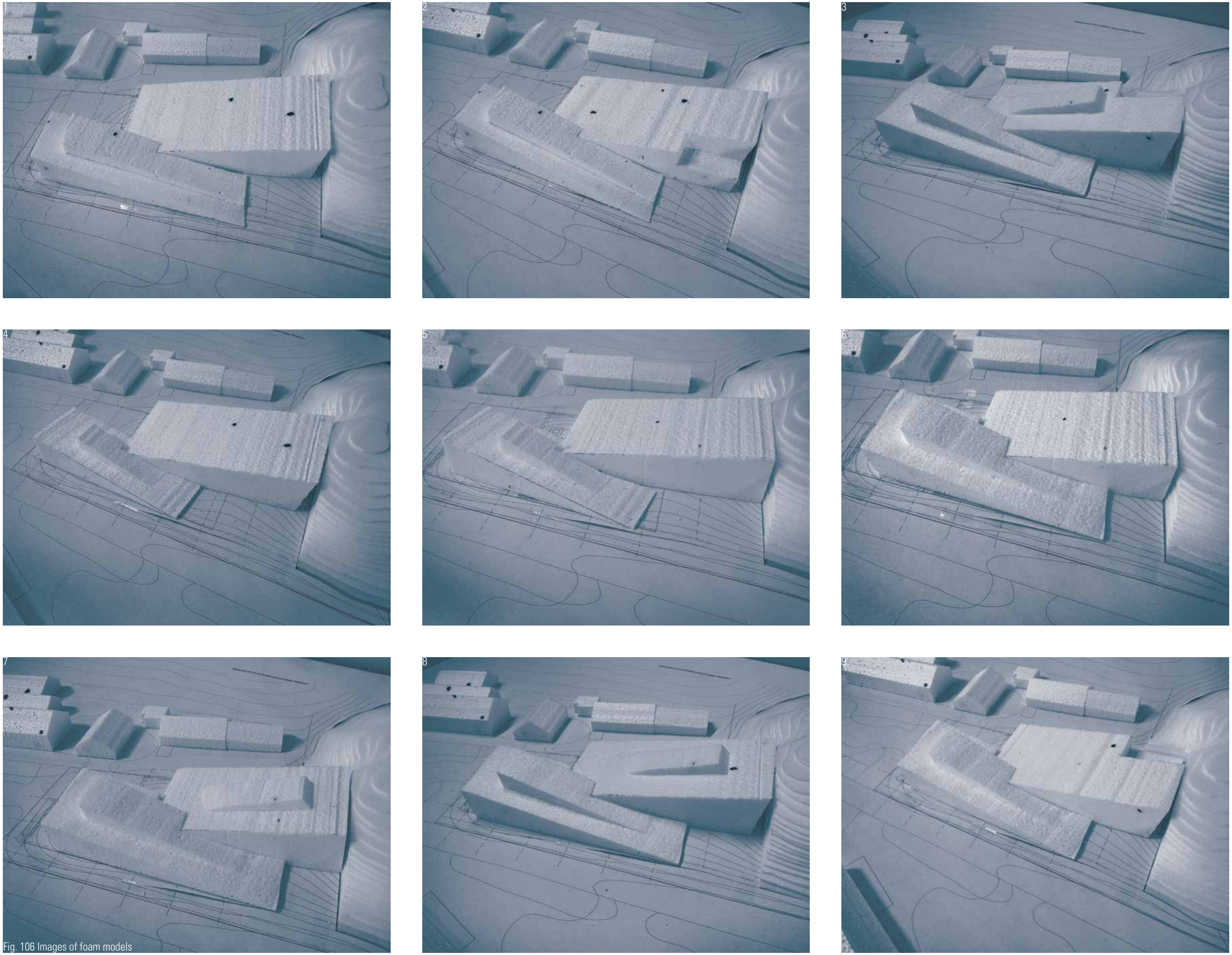


Fig. 106 Images of foam models

FORM STUDIES

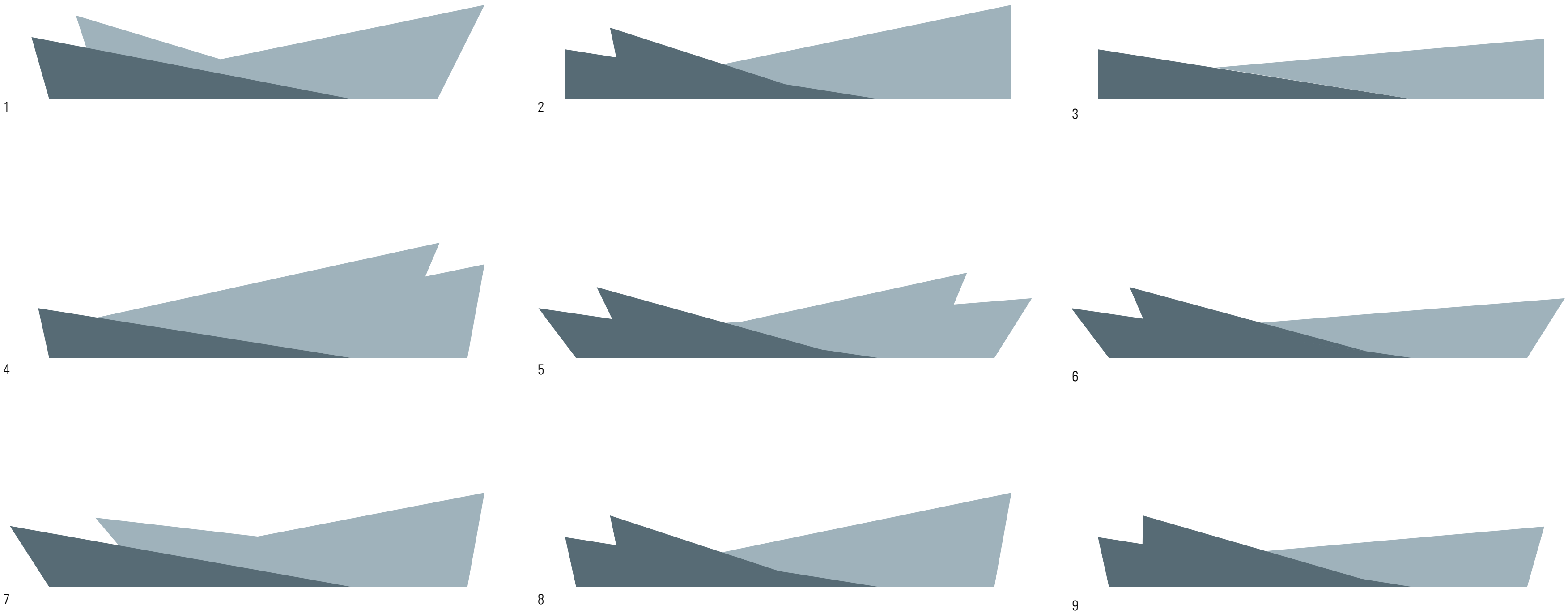


Fig. 107 Proportion studies

Numerous form studies have been carried out in an iterative process, simultaneously with sketching and searching for optimal functional solution of the building. Preparation of foam models allowed observing relations of building with surrounding in scale and form, but also finding important viewpoints and lines leading the sight. During form studies different proportions of two or more volumes were tested, including studies of height, depth and position of them in relation to each other and neighboring houses. Another important part of the studies both in foam and 2-dimensional drawings, included studies on various angles and slopes of the roof, as well as walls inclination and positioning of the skylights. Form studies led to finding the most optimal solution according to scale, inclination and overall impression of building dynamics. The slightly tilted shape with two main volumes and one skylight has been chosen as the most interesting and suitable on the site, therefore further studies on materials, indoor climate and energy performance were carried out on the basis of that shape. (Fig. 106 opt. 9; Fig. 107 opt. 9)

ELEVATIONS STUDIES

Fig. 108 Trollstiegen Visitor Center, Norway

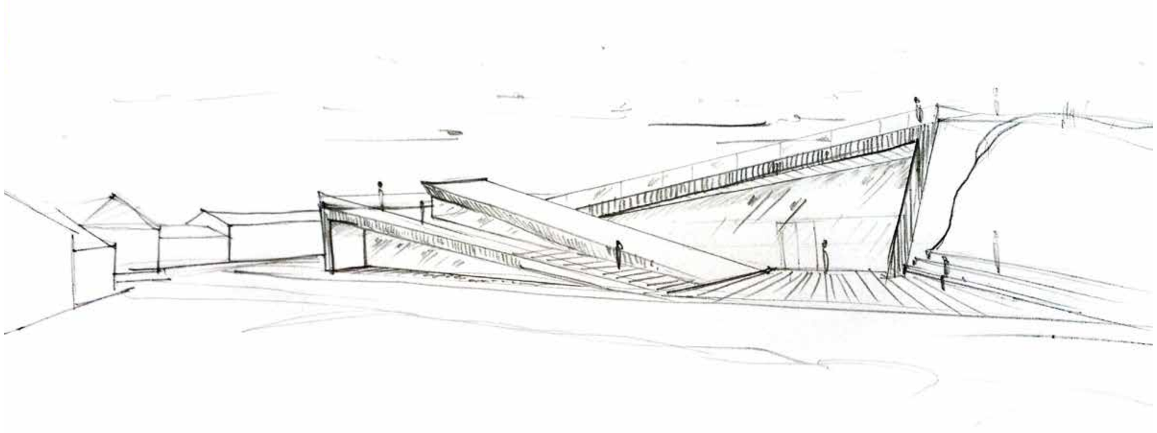


Fig. 109 Elevation option I - sketch

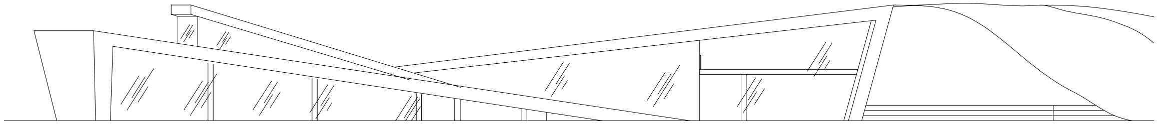


Fig. 110 Elevation option I

Studies of facades were mainly focused on southern elevation, as it is considered the most frontal and visible from distance. Simultaneously with tests of architectural expression primary studies of indoor climate were carried out, including calculations of 24-hour average temperatures in the temporary exhibition, which due to its southern exposure was perceived as the most critical.

First option was focused on providing the maximum of transparency through the building, exposing its interior to the outside, while being clearly framed. Nevertheless, that solution caused significant overheating during summer months, as well as temperature drops over night. Hence, it was clear that first option has to be rejected and suitable solutions of shading and other passive methods of cooling need to be implemented. (Appendix p. 96 fig. 142)

24h avarege temperatures in August t_u = 20,5 ^{0}C

If the ventilation air has the same temperature as outdoor air:
24 average: 27,7 ^{0}C
Temperature variation: 7,3 ^{0}C
Maximum: 31,3 ^{0}C

If the ventilation air has the same temperature as the outdoor 24-hour average temperature:
24 average: 27,7 ^{0}C
Temperature variation: 5,4 ^{0}C
Maximum: 30,4 ^{0}C

If the ventilation air has constant temperature 2 ^{0}C lower than 24-hour average temperature (18,5 ^{0}C):
24 average: 26,2 ^{0}C
Temperature variation: 5,4 ^{0}C
Maximum: 28,9 ^{0}C

Fig. 111 24-hour average temperatures spreadsheet results for option I

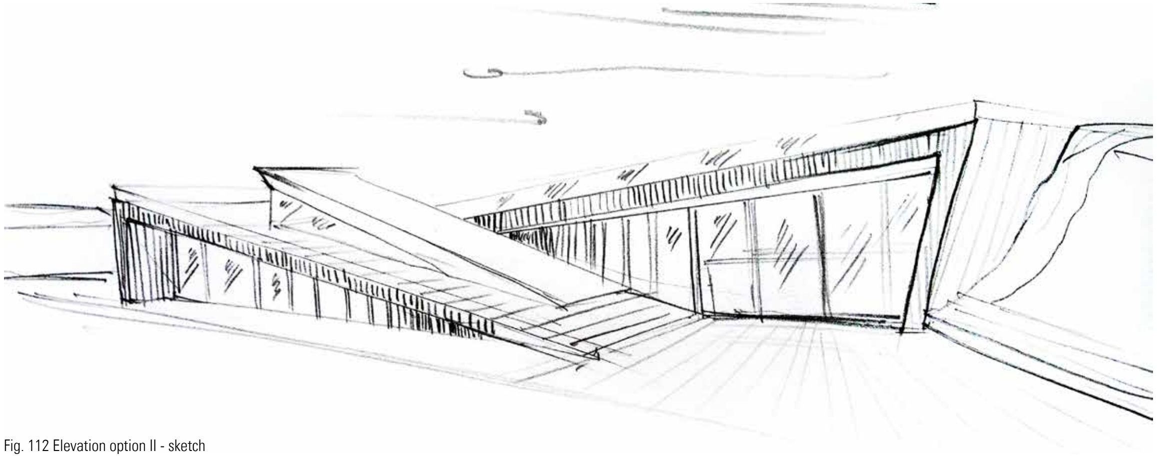


Fig. 112 Elevation option II - sketch

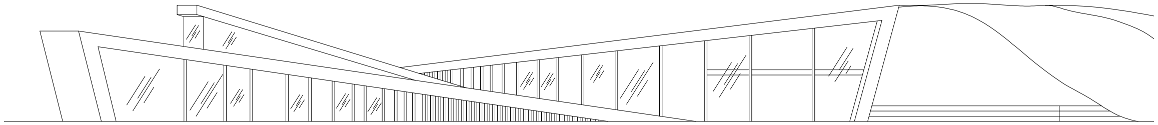


Fig. 113 Elevation option II

24h avarege temperatures in August t_u = 20,5 ^{0}C

If the ventilation air has the same temperature as outdoor air:
24 average: 26,1 ^{0}C
Temperature variation: 6,2^{0}C
Maximum: 29,2 ^{0}C

If the ventilation air has the same temperature as the outdoor 24-hour average temperature:
24 average: 26,1 ^{0}C
Temperature variation: 4,3 ^{0}C
Maximum: 28,2 ^{0}C

If the ventilation air has constant temperature 2 ^{0}C lower than 24-hour average temperature (18,5 ^{0}C):
24 average: 24,6 ^{0}C
Temperature variation: 4,3 ^{0}C
Maximum: 26,8 ^{0}C

Fig. 114 24-hour average temperatures spreadsheet for option II

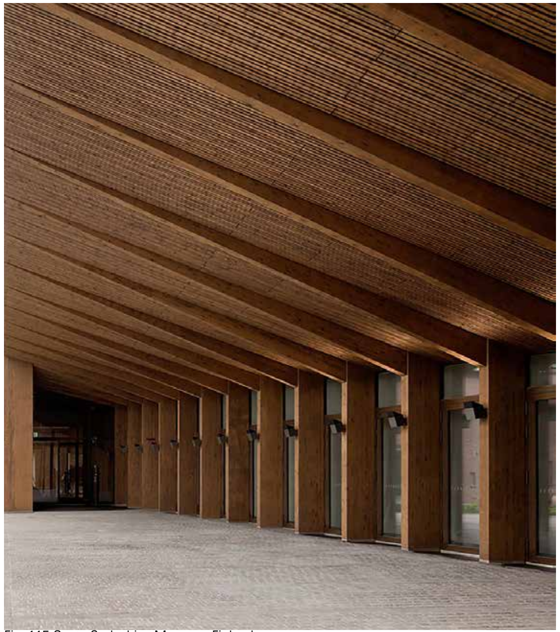


Fig. 115 Gosta Serlachius Museum, Finland

Second option of façade design was focused on providing vertical external shading. This solution was repeating the previous principle of giving the maximum of transparency, while implementing subtle vertical shading elements that were densest were the building was the lowest and were more and more scattered as the building was getting higher. Even though, this solution slightly improved 24-hour average temperatures results, the problem of overheating and significant temperature differences was not solved. Thus, the further studies were carried out.
(Appendix p. 96 fig. 143)

ELEVATIONS STUDIES

Fig. 116 Gosta Serlachius Museum, Finland

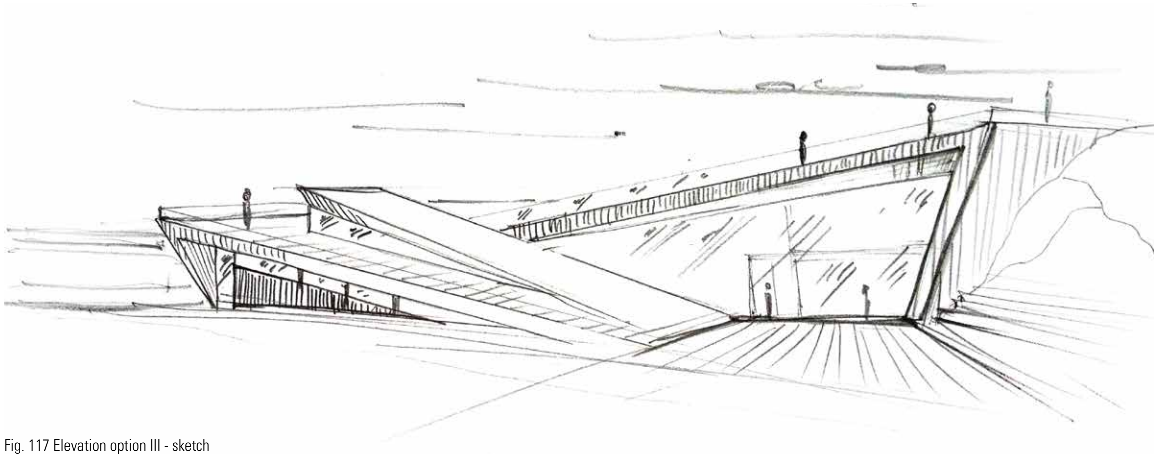


Fig. 117 Elevation option III - sketch

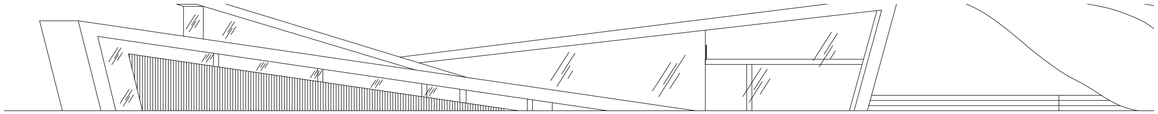


Fig. 118 Elevation option III

Third option included an idea of considerable reduction of glazed area, by implementing a self-standing wall, while only keeping the stripe of glazing on top and side of the façade. That design was meant to be fine solution for the exhibition area, as the topside light is considered to be the best natural lighting solution for museums, however the building lost its primary idea of openness and transparency. It also did not resolve completely the problem of overheating. Although, that option improved results, the amount of glass without shading was too large to completely prevent overheating.
(Appendix p. 96 fig. 144)

24h avarege temperatures in August t_u = 20,5 ^{0}C

If the ventilation air has the same temperature as outdoor air:
24 average: 25,0 ^{0}C
Temperature variation: 5,3^{0}C
Maximum: 27,7 ^{0}C

If the ventilation air has the same temperature as the outdoor 24-hour average temperature:
24 average: 25,0 ^{0}C
Temperature variation: 3,4 ^{0}C
Maximum: 26,7 ^{0}C

If the ventilation air has constant temperature 2 ^{0}C lower than 24-hour average temperature (18,5 ^{0}C):
24 average: 23,5 ^{0}C
Temperature variation: 3,4 ^{0}C
Maximum: 25,2 ^{0}C

Fig. 119 24-hour average temperatures spreadsheet for option III

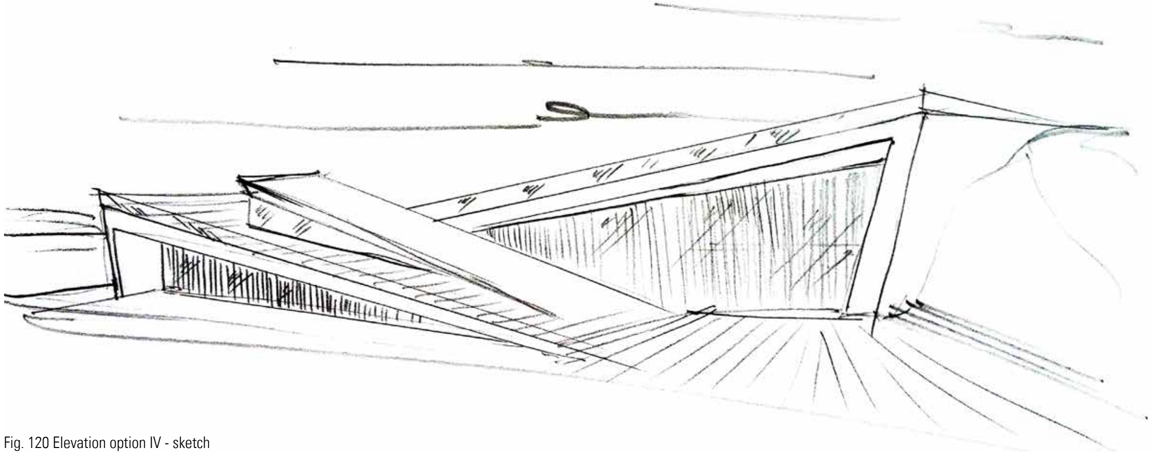


Fig. 120 Elevation option IV - sketch

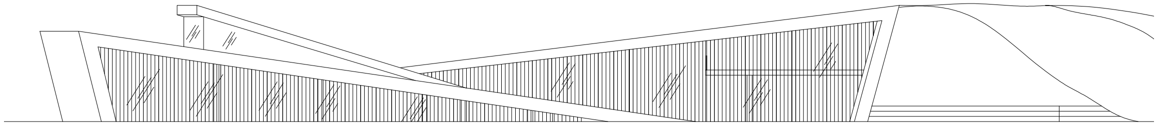


Fig. 121 Elevation option IV

24h avarege temperatures in August t_u = 20,5 ^{0}C

If the ventilation air has the same temperature as outdoor air:
24 average: 24,4 ^{0}C
Temperature variation: 4,6 ^{0}C
Maximum: 26,7^{0}C

If the ventilation air has the same temperature as the outdoor 24-hour average temperature:
24 average: 24,4 ^{0}C
Temperature variation: 2,7 ^{0}C
Maximum: 25,8 ^{0}C

If the ventilation air has constant temperature 2 ^{0}C lower than 24-hour average temperature (18,5 ^{0}C):
24 average: 22,9 ^{0}C
Temperature variation: 2,7 ^{0}C
Maximum: 24,3 ^{0}C

Fig. 122 24-hour average temperatures spreadsheet for option IV

Fig. 123 Lussy Sports Hall, Swizerland

Fourth solution including external shading made of very dense and thin elements, achieved the best results of all tested versions, however it was not satisfactory according to architectural expression. Nevertheless it gave a very useful guidelines on which solution is working best and how to proceed further with the design. Moreover, none of the options solved the problem of addressing western façade. As it is considered to be the second most important side of the building, further studies were needed. Nevertheless the principle of using very dense and thin elements was used in the final design and influenced all other elevations.
(Appendix p. 96 fig. 145)

MATERIALS EXTERIOR

Fig. 124 Exterior material tests

Use of materials was primarily determined by observations of local architecture, both fishermans' housing and summer bungalows, but also by understanding of Nordic tactility and sensitivity towards materials. Therefore, wood has been chosen as a staring point for tests, using for example dark painted wood on the outside and pale or white wood on the inside as commonly used in the surrounding buildings. However, dark colored wood is not able to survive the harsh weather conditions, thus natural hues of timber that can age gracefully were chosen.

Tests on interior materials were focused mainly on providing the most inviting and warm atmosphere, were visitors can feel safe and comfortable. As mentioned before, Jay Appleton described in his *Experience of Landscape*, that people seek safe places with open vistas, that is why interior design put focus on providing that sense of confidence with the beautiful views of the nature outside.

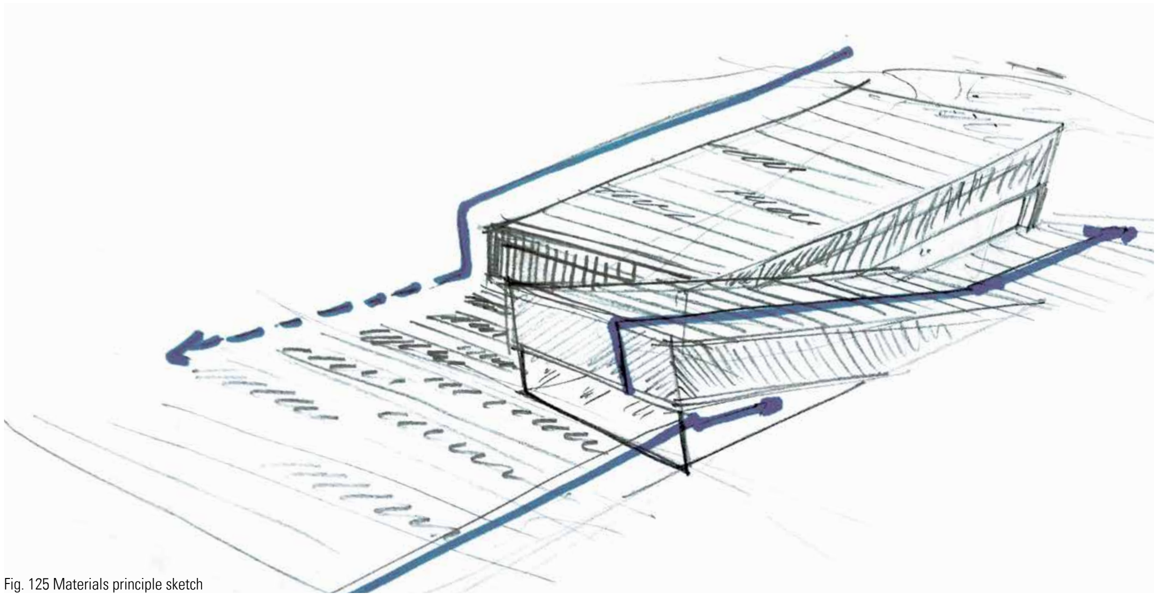


Fig. 125 Materials principle sketch

MATERIALS INTERIOR

Fig. 126 Interior material tests

Fig. 127 Materials combination tests

Fig. 128 Daylight factor diagram - workshop

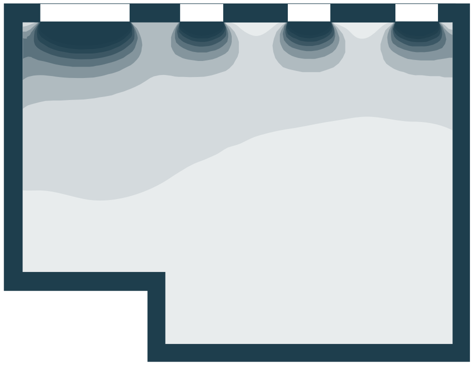


Fig. 129 Daylight factor diagram - offices, window height 2100 mm

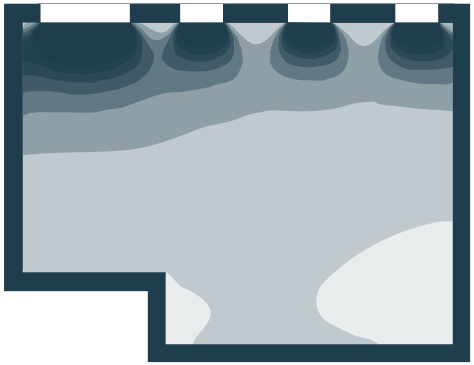


Fig. 130 Daylight factor diagram - offices, window height 2700 mm

Studies of daylight factor were carried out on the day of equinox and in conditions of overcast in two rooms considered to be the most critical. Firstly tested room was workshop that is dedicated for educational activities, thus requires proper natural lighting. Fortunately its southern exposure and large area of glazing ensured high daylight factor (Fig.128) Second area to study was office, where different heights of windows were tested. As the width of windows was determined by functional reasons, their height was the only variable. Hence, window heights of 2100 mm (Fig.129) , 2500 mm, 2700 mm (Fig.130) and 3000 mm were tested, what led to the conclusion that 2700mm height is the most suitable as it provides enough daylight for working conditions. (Full results in Appendix p. 97)
Moreover, the external shading element has been tested in order to find its optimal depth and length. Diagrams (Fig. 131)show path of sunrays on days of equinox, summer and winter solstice. As the most suitable has been chosen option 1. , which allows the infiltration of sunrays in the wintertime, while blocking them in the summer.

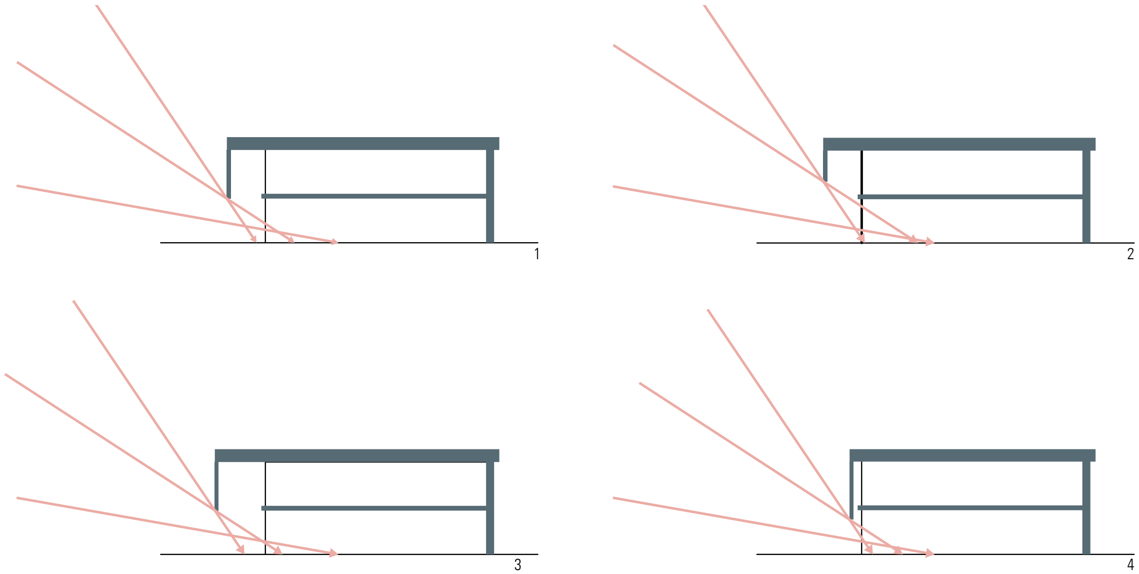


Fig. 131 External shading studies

BUILDING ENVELOPE

In order to achieve satisfying results of both indoor climate and low energy performance of the building, external envelope needs to be designed sensibly, by providing air tightness and low thermal transmittance of external walls. Therefore, all of the partitions have been designed using Rockwool U-value calculator until the very low U-value has been achieved. [Rockwool, 2015] Large areas of glazed curtain walls has been chosen among various producers to find product with self-cleaning system, low U-value and suitable g-value. Selected windows are Pilkington Insulight with triple glazing including argon that reach U-value of 0,6 Wm²K and g-value depending on the exposure - slightly lower on southern facades 0, 47 to prevent excessive solar transmittance and on northern facades 0,55. [Pilkington, 2015]

CURTAIN WALL	
Pilkington Insulight triple glazed aluminium	
U-value	0,6 W/m²K

INTERNALL WALL 1	
Interior finish plaster	20 mm
Light concrete	120 mm
Wooden cladding	30 mm
Total thickness	170 mm

INTERNALL WALL 2	
Interior finish plaster	20 mm
Gypsum wall	100 mm
Interior finish/ceramic tiles	20 mm
Total thickness	140 mm

WOODEN DECK ROOF	
Thermowood pine deck	20 mm
Pine substructure supporting steps	150 mm
Drainage gravel	100 mm
Filtering membrane	
Hard insulation	300 mm
Waterproofing membrane	
Reinforced concrete slab	300 mm
Installation space	680 mm
Suspended gypsum ceiling	20 mm
Total thickness	870 mm
U-value	0,12 W/m²K

GREEN ROOF	
Vegetative layer	> 200 mm
Filtering membrane	
Drainage gravel	100 mm
Filtering membrane	
Hard insulation	300 mm
Waterproofing membrane	
Reinforced concrete slab	300 mm
Installation space	630 mm
Suspended gypsum ceiling	20 mm
Total thickness	900 mm
U-value	0,10 W/m²K

RETAINING WALL	
Interior hygienic plaster	20 mm
Reinforced concrete retaining wall	300 mm
Waterproofing membrane	
Hard insulation	250 mm
Total thickness	570 mm
U-value	0,14 W/m²K

EXTERNAL WALL	
Interior plaster	15 mm
Reinforced concrete wall	250 mm
Hard insulation	400 mm
Vertical secondary structure in insulation layer	50 mm
Horizontal secondary structure	50 mm
Thermowood pine cladding	30 mm
Total thickness	870 mm
U-value	0,078 W/m²K

GROUND FLOOR	
White concrete tiles	20 mm
Lightweight concrete with floor heating	50 mm
Hard insulation	100 mm
Reinforced concrete foundation slab	300 mm
Waterproofing membrane	
Hard insulation	250 mm
Leveling lightweight concrete	100 mm
Total thickness	820 mm
U-value	0,085 W/m²K

FIRST FLOOR	
Thermowood pine flooring	20 mm
Lightweight concrete	50 mm
Reinforced concrete foundation slab	300 mm
Installation space	500 mm
Suspended gypsum ceiling	20 mm
Total thickness	370 mm

Reaching low energy requirements of the building took numerous studies on size and quality of external building envelope. After the primary calculations have been made, without applying any additional energy sources the total energy requirement reached 68,5 kWh/m²/year according to Energy Frame 2020. (Fig. 132) Therefore, it became clear that reaching nearly zero result would become a challenge without contribution from external energy supplies. Therefore, photovoltaic panels have been designed as considered to be the easiest and clearest natural energy source.

After implementing photovoltaic panels that supplemented the overall energy performance with approx. 55 kWh/m²/year, further studies focused on glazed areas. As windows are one of the major factors influencing the energy performance hence, different sizes of windows has been tested. First trail was made with curtain walls facing south and north in temporary exhibition of 150m² area and main exhibition of 200m², but results didn't reach the required energy frame (Fig. 133). Thus, further studies focused on downsizing glazed areas were carried out including sizes such as 120m² for temporary exhibition and 180m² for main exhibition (Fig. 134), consequently 120m² and 140m² (Fig. 135) and so on. Finally the decision was made that windows of area 75m² and 140m² will give the best energy performance, while still providing intended architectural expression.

Energy frame Buildings 2020

Without supplement	Supplement for special conditions	Total energy frame
25,0	0,0	25,0
Total energy requirement		68,5

Fig. 132 Tylko bez zachodniego

Energy frame Buildings 2020

Without supplement	Supplement for special conditions	Total energy frame
25,0	0,0	25,0
Total energy requirement		28,1

Fig. 133 Temporary exhibition window area of 150m² and main exhibition window area of 200m²

Energy frame Buildings 2020

Without supplement	Supplement for special conditions	Total energy frame
25,0	0,0	25,0
Total energy requirement		23,3

Fig. 134 Temporary exhibition window area of 120m² and main exhibition window area of 180m²

Energy frame Buildings 2020

Without supplement	Supplement for special conditions	Total energy frame
25,0	0,0	25,0
Total energy requirement		18,6

Fig. 135 Temporary exhibition window area of 120m² and main exhibition window area of 140m²

INDOOR CLIMATE

Designing a building with good indoor climate without compromising on architectural expression is an arduous and iterative process, which requires a lot of tests on various architectural solutions. As the common space of both exhibitions was taken as an exemplary room for calculations its major issue of overheating resulted from large amount of glazed area, therefore the biggest challenge was to find passive cooling solutions without decreasing the strength of building concept, but rather emphasizing its values.

Therefore, several solutions have been studied using BSim software. Firstly tested were two options without opening in the skylight and additional movable external shading devices (Fig. 136) as well as without skylight and movable shading on the southern wall. (Fig.137) Nevertheless, none of those options provided satisfactory indoor climate, as without movable shading and not allowing the additional natural ventilation by thermal buoyancy resulted in excessive overheating during summer months.

Afterwards, option without opening in the skylight, but with movable shading on both sides was tested. Unfortunately, it also didn't fulfill requirements. (Fig.138)

Finally, two options were tested including openings in the skylight, but without movable shading devices on southern wall in one case and without western in another case. However, none of the solutions allowed the required results. (Fig. 139; Fig. 140) Thus, the final solution was to keep openings in the skylight and movable external shading operating only in case of very hot summer days.

Co2(ppm)	381,4	361,3	361,4	361,4	361,3	365,4	442,3	430,7	441,0	368,5	361,5	361,2	361,3
PAQ(-)	0,4	0,6	0,7	0,6	0,5	0,4	0,2	0,1	0,2	0,2	0,4	0,5	0,6
Hours > 21	8138	744	672	744	720	744	491	551	544	720	744	720	744
Hours > 26	242	0	0	0	16	2	80	87	55	1	1	0	0
Hours > 27	100	0	0	0	0	1	31	42	25	1	0	0	0
Hours < 20	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 136 BSim resluts - no skylight, no movable shading

Co2(ppm)	364,9	361,3	361,4	361,4	361,3	365,4	377,2	367,2	372,6	367,5	361,5	361,2	361,3
PAQ(-)	0,4	0,6	0,7	0,6	0,5	0,4	0,2	0,2	0,2	0,2	0,4	0,5	0,6
Hours > 21	7934	744	672	744	720	744	418	491	473	720	744	720	744
Hours > 26	135	0	0	0	16	2	38	44	33	1	1	0	0
Hours > 27	44	0	0	0	0	1	11	8	23	1	0	0	0
Hours < 20	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 137 BSim resluts - no skylight, no southern movable shading

Co2(ppm)	363,8	361,3	361,4	361,4	361,3	365,4	371,7	364,0	368,2	367,4	361,5	361,2	361,3
PAQ(-)	0,4	0,6	0,7	0,6	0,5	0,4	0,2	0,1	0,2	0,2	0,4	0,5	0,6
Hours > 21	8006	744	672	744	720	744	440	516	498	720	744	720	744
Hours > 26	201	0	0	0	16	2	67	67	47	1	1	0	0
Hours > 27	96	0	0	0	0	1	31	37	26	1	0	0	0
Hours < 20	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 138 BSim resluts - no skylight

Co2(ppm)	366,3	361,3	361,4	361,4	361,3	370,0	380,8	368,3	375,2	371,8	361,5	361,2	361,3
PAQ(-)	0,4	0,6	0,7	0,6	0,5	0,4	0,2	0,2	0,2	0,3	0,4	0,5	0,6
Hours > 21	7900	744	672	744	720	742	417	481	461	711	744	720	744
Hours > 26	88	0	0	0	0	2	26	29	30	1	0	0	0
Hours > 27	39	0	0	0	0	0	8	7	23	1	0	0	0
Hours < 20	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 139 BSim resluts - no southern movable shading

Co2(ppm)	365,9	361,3	361,4	361,4	361,3	370,0	377,6	366,3	375,3	371,6	361,5	361,2	361,3
PAQ(-)	0,4	0,6	0,7	0,6	0,5	0,4	0,2	0,2	0,2	0,3	0,4	0,5	0,6
Hours > 21	7929	744	672	744	720	742	424	493	471	711	744	720	744
Hours > 26	115	0	0	0	0	2	33	48	31	1	0	0	0
Hours > 27	56	0	0	0	0	0	16	16	23	1	0	0	0
Hours < 20	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 140 TBSim resluts - no western movable shading

REFLECTION

Design of the Thy National Park Visitor Center was based upon the real demand of that kind of building, set by Board of National Park Thy and included in the *Nationalparkplan 2010-2016*. Moreover, the park authorities delineated all crucial aspects such as site location, preliminary program and most importantly motivation, goals and vision. Those introductory materials on one side facilitated the project development and have set frames for the design, on the other hand, reconciliation of all those demands together with technical requirements and low-energy class 2020 has become a true challenge.

In this project the focus was put on developing the sensible Nordic architecture, with the tectonic approach to the context and sustainable design foremost. Nevertheless, this is where the biggest difficulty was met – reaching low energy profile, without compromising on concept, aesthetical values or functionality.

Most of examples of sustainable architecture lack certain level of contextuality and regional aspects, being packed with advanced technologies they often loose humanistic approach. Therefore, this design concentrated on ensuring all mentioned values in one building. Despite the fact that results of energy performance could probably be much better, even reaching zero-energy standards, the project was directed to be well balanced and user friendly, instead of reaching for exaggerated demands.

Visitor Center being a single student project has been delimited from economic considerations that could have an indubitable impact on decision-making process. Moreover, some of the constructional issues could be addressed deeply, however most of them have been discussed and taken into consideration.

In the "process" chapter it was presented how new digital tools such as BSim, Be10, Velux Daylight Visualizer and spreadsheets were used in order to improve the design. Even on a very conceptual stage they enabled fast feedback loops on the technical performance as well as spatial ideas and selection of materials. Those new digital tools definitely facilitate the sensible design, decision-making and general technical awareness, however it is still the functionality and sensitive, proportional design that most of the users value first.

Fig. 141 View from the top of the dune

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Fig.8 SKAGEN TOURIST, (2015) *Skagen Odde Naturcenter* [Online image] Available from: http://www.skagen-tourist.dk/danmark/skagen-odde-naturcenter-gdk600087 [Accesed 21/02/2015]

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Fig.22-23 Own paintings

Fig.24-26 Own illustrations

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Fig.108 WALLPAPER (2012) *Trollstiegen Visitor Center* [Online image] Available from: http://www.wallpaper.com/architecture/trollstigen-visitor-centre-by-reiulf-ramstad-architects-norway/5890#65193 [Accesed 21/04/2015]

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Fig. 115 PEGENAUTE P. (2014) *N.N* [Online image] Availabre from: http://www.archdaily.com/580604/gosta-serlachius-museum-mx_si/ [Accesed 24/04/2015]

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Fig. 123 VIRDIS ARCHITECTURE (2014) *N.N.* [Online image] Available from: Availabre from: http://www.dezeen.com/2014/06/29/lussy-sports-hall-virdis-architecture-swizerland/ [Accesed 25/04/2015]

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Fig.127 Collage of 4 illustrations:
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Fig.128-162 Own illustrations

05 APPENDIX

Results

Project:
Visitor Center

Choosen month:	August	tu =	20,5	ϒC

If the ventlation air has same temperature as outdoor air

24-hour average	ti =	27,7	ϒC
Temperature variation	Δti =	7,3	ϒC
Max. Temperature	timax =	31,3	ϒC

Additional calculations

If the ventilation air has the same temperature as the outdoor 24-hour average temperature

24-hour average	ti =	27,7	ϒC
Temperature variation	Δti =	5,4	ϒC
Max. Temperature	timax =	30,4	ϒC

Calculation where the ventilation air has a constant inlet temperature which is Δt =	2

If the ventilation air has a constant temperature of 18,5 °C

24-hour average	ti =	26,2	ϒC
Temperature variation	Δti =	5,4	ϒC
Max. Temperature	timax =	28,9	ϒC

Fig. 142 24-hour average temperature spreadsheet - option I

Results

Project:
Visitor Center

Choosen month:	August	tu =	20,5	ϒC

If the ventlation air has same temperature as outdoor air

24-hour average	ti =	26,1	ϒC
Temperature variation	Δti =	6,2	ϒC
Max. Temperature	timax =	29,2	ϒC

Additional calculations

If the ventilation air has the same temperature as the outdoor 24-hour average temperature

24-hour average	ti =	26,1	ϒC
Temperature variation	Δti =	4,3	ϒC
Max. Temperature	timax =	28,2	ϒC

Calculation where the ventilation air has a constant inlet temperature which is Δt =	2

If the ventilation air has a constant temperature of 18,5 °C

24-hour average	ti =	24,6	ϒC
Temperature variation	Δti =	4,3	ϒC
Max. Temperature	timax =	26,8	ϒC

Fig. 143 24-hour average temperature spreadsheet - option II

Results

Project:
Visitor Center

Choosen month:	August	tu =	20,5	ϒC

If the ventlation air has same temperature as outdoor air

24-hour average	ti =	25,0	ϒC
Temperature variation	Δti =	5,3	ϒC
Max. Temperature	timax =	27,7	ϒC

Additional calculations

If the ventilation air has the same temperature as the outdoor 24-hour average temperature

24-hour average	ti =	25,0	ϒC
Temperature variation	Δti =	3,4	ϒC
Max. Temperature	timax =	26,7	ϒC

Calculation where the ventilation air has a constant inlet temperature which is Δt =	2

If the ventilation air has a constant temperature of 18,5 °C

24-hour average	ti =	23,5	ϒC
Temperature variation	Δti =	3,4	ϒC
Max. Temperature	timax =	25,2	ϒC

Fig. 144 24-hour average temperature spreadsheet - option III

Results

Project:
Visitor Center

Choosen month:	August	tu =	20,5	ϒC

If the ventlation air has same temperature as outdoor air

24-hour average	ti =	24,4	ϒC
Temperature variation	Δti =	4,6	ϒC
Max. Temperature	timax =	26,7	ϒC

Additional calculations

If the ventilation air has the same temperature as the outdoor 24-hour average temperature

24-hour average	ti =	24,4	ϒC
Temperature variation	Δti =	2,7	ϒC
Max. Temperature	timax =	25,8	ϒC

Calculation where the ventilation air has a constant inlet temperature which is Δt =	2

If the ventilation air has a constant temperature of 18,5 °C

24-hour average	ti =	22,9	ϒC
Temperature variation	Δti =	2,7	ϒC
Max. Temperature	timax =	24,3	ϒC

Fig. 145 24-hour average temperature spreadsheet - option IV

DAYLIGHT FACTOR

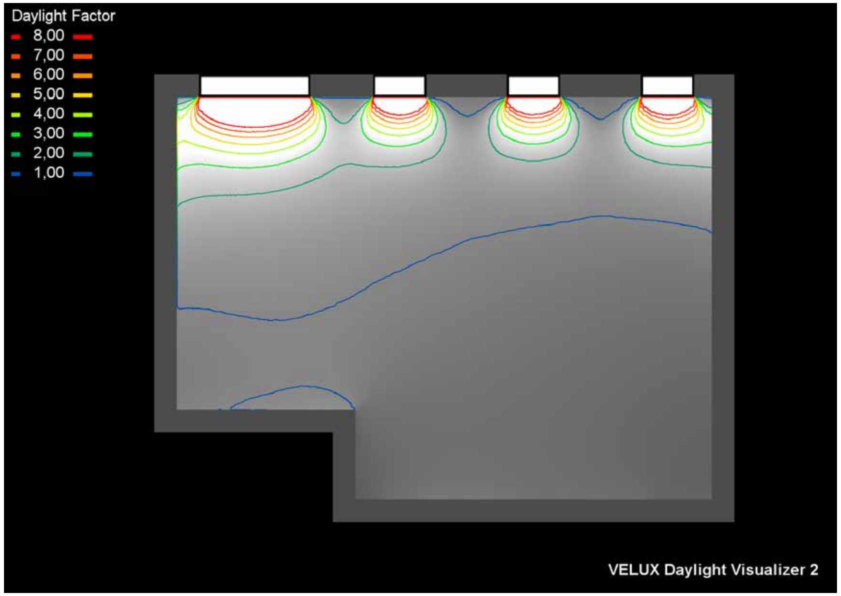


Fig. 146 Velux daylight visualizer - window height 2100mm

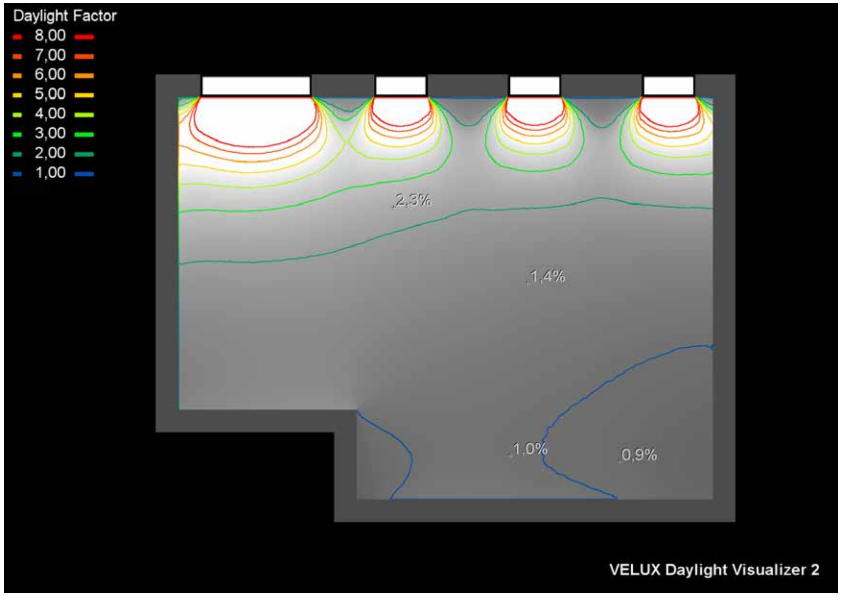


Fig. 148 Velux daylight visualizer - window height 2700mm

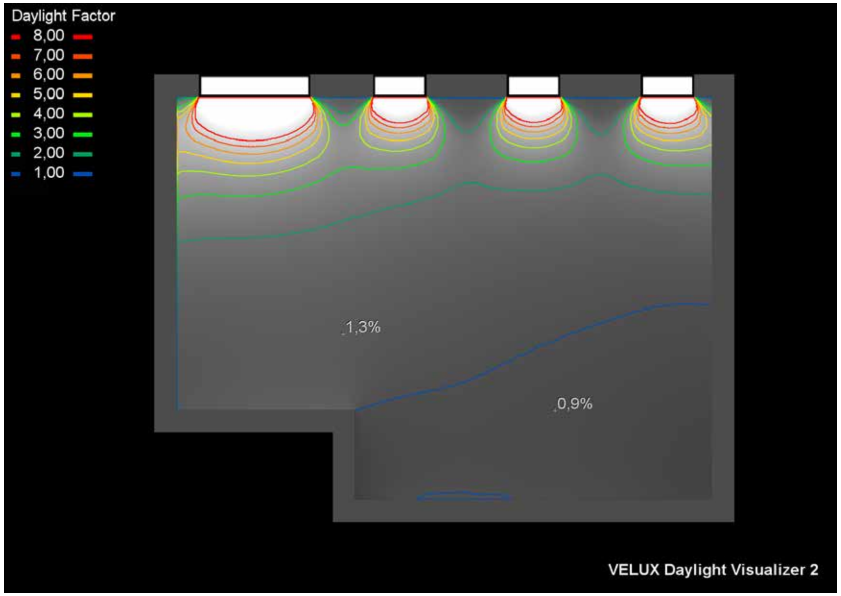


Fig. 147 Velux daylight visualizer - window height 2500mm

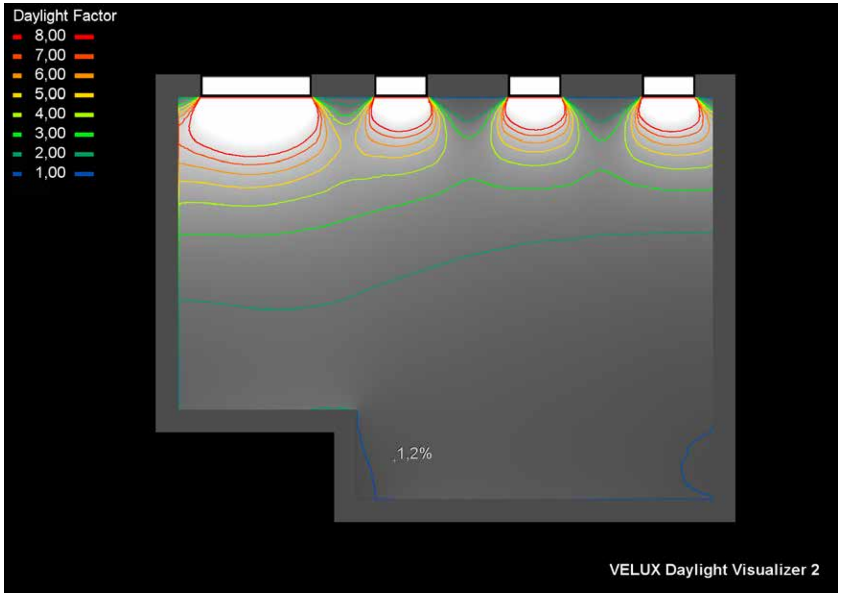


Fig. 149 Velux daylight visualizer - window height 3000mm

AIR CHANGE RATE

Indoor air quality
(Based on sensory calculation)

Air change rate on basis of experienced air poll

Pollution load:

Occupants (1person)	**1 olf**
Building	**0,2 olf per m^2**

Percentage of dissatisfied:
Maximum PD = 20% (Class ll (B))

$C=C_i + 10\ (q/V_L)$

c = experienced air quality [dp]
c_i= experienced air quality outdoor [dp]
q= Pollution load [olf]
V_L= necessary air flow supply [l/s]

c	**1,4 dp**
c_i	**0,1 dp**

q= occupants * persons + building * area

persons	30
area	307,0 m^2
q	**91,4 olf**

Necessary air flow supply

$C=C_i + 10\ (q/V_L)\ > V_L= (10*q)/(c-c_i)$

V_L	**703,1 l/s**

Air change rate

$n=(v_L*3600s)/(1000*V_{room})$

	V_{room}		
	area	*307 m^2*	
average	*height*	*5,2 m*	
	V_{room}		1596,4 m^3
	n		**1,59 h^{-1}**

Air change rate on basis of Co2 level

determined by the allowed CO2 concentration
Class ll in DS/EN 15251
CO2 load can max be 550ppm higher than the outdoor CO2 conc.
outdoor concentration in Denmark (in most location) 350
a person exhales 10l/min with a CO2 conc. On 4%

$c=(q/nV)+c_i$

Co2 concentration:
q=(4/100)*50pers.*((10l/min * 60min/h)/1000l/m3)

q	**0,096 m^3/h**

Air change rate:
$900ppm = 1000000*(q/(n*V_{room}))+350ppm$

$n=(1000000*q)/((900-350)*V_{room})$

n	**0,11 h^{-1}**

Source: GKB, Aalborg University

Fig. 148 Air change rate calculations - main exhibition

Indoor air quality
(Based on sensory calculation)

Air change rate on basis of experienced air pollution

Pollution load:

Occupants (1person)	**1 olf**
Building	**0,2 olf pe**

Percentage of dissatisfied:
Maximum PD = 20% (Class ll (B))

$C=C_i + 10\ (q/V_L)$

c = experienced air quality [dp]
c_i= experienced air quality outdoor [dp]
q= Pollution load [olf]
V_L= necessary air flow supply [l/s]

c	**1,4 dp**
c_i	**0,01 dp**

q= occupants * persons + building * area

persons	20
area	200,0 m^2
q	**60,0 olf**

Necessary air flow supply

$C=C_i + 10\ (q/V_L)\ > V_L= (10*q)/(c-c_i)$

V_L	**431,7 l/s**

Air change rate

$n=(v_L*3600s)/(1000*V_{room})$

V_{room}		
area	*200 m^2*	
height	*4,75 m*	
V_{room}		950,0 m^3
n		**1,64 h^{-1}**

Air change rate on basis of Co2 level

determined by the allowed CO2 concentration
Class ll in DS/EN 15251
CO2 load can max be 550ppm higher than the outdoor CO2 conc.
outdoor concentration in Denmark (in most location) 350
a person exhales 10l/min with a CO2 conc. On 4%

$c=(q/nV)+c_i$

Co2 concentration:
q=(4/100)*20pers.*((10l/min * 60min/h)/1000l/m3)

q	**0,48 m^3/h**

Air change rate:
$900ppm = 1000000*(q/(n*V_{room}))+350ppm$

$n=(1000000*q)/((900-350)*V_{room})$

n	**0,92 h^{-1}**

Source: GKB, Aalborg University

Fig. 149 Air change rate calculations - temporary exhibition

Indoor air quality
(Based on sensory calculation)

Air change rate on basis of experienced air pollution

Pollution load:

Occupants (1person)	**1 olf**
Building	**0,2 olf pe**

Percentage of dissatisfied:
Maximum PD = 20% (Class ll (B))

$C=C_i + 10\ (q/V_L)$

c = experienced air quality [dp]
c_i= experienced air quality outdoor [dp]
q= Pollution load [olf]
V_L= necessary air flow supply [l/s]

c	**1,4 dp**
c_i	**0,01 dp**

q= occupants * persons + building * area

persons	50
area	90,0 m^2
q	**68,0 olf**

Necessary air flow supply

$C=C_i + 10\ (q/V_L)\ > V_L= (10*q)/(c-c_i)$

V_L	**489,2 l/s**

Air change rate

$n=(v_L*3600s)/(1000*V_{room})$

V_{room}		
area	*90 m^2*	
height	*4 m*	
V_{room}		360,0 m^3
n		**4,89 h^{-1}**

Air change rate on basis of Co2 level

determined by the allowed CO2 concentration
Class ll in DS/EN 15251
CO2 load can max be 550ppm higher than the outdoor CO2 conc.
outdoor concentration in Denmark (in most location) 350
a person exhales 10l/min with a CO2 conc. On 4%

$c=(q/nV)+c_i$

Co2 concentration:
q=(4/100)*50pers.*((10l/min * 60min/h)/1000l/m3)

q	**1,2 m^3/h**

Air change rate:
$900ppm = 1000000*(q/(n*V_{room}))+350ppm$

$n=(1000000*q)/((900-350)*V_{room})$

n	**6,06 h^{-1}**

Source: GKB, Aalborg University

Fig. 150 Air change rate calculations - workshop

Indoor air quality

(Based on sensory calculation)

Air change rate on basis of experienced air poll

Pollution load:

Occupants (1person)	**1 olf**
Building	**0,2 olf per m^2**

Percentage of dissatisfied:

Maximum PD = 20% (Class ll (B))

$C=C_i + 10\ (q/V_L)$

c = experienced air quality [dp]
c_i= experienced air quality outdoor [dp]
q= Pollution load [olf]
V_L= necessary air flow supply [l/s]

c	**1,4 dp**
c_i	**0,1 dp**

q= occupants * persons + building * area

persons	10
area	85,0 m^2
q	**27,0 olf**

Necessary air flow supply

$C=C_i + 10\ (q/V_L)\ > V_L= (10*q)/(c-c_i)$

V_L	**207,7 l/s**

Air change rate

$n=(v_L*3600s)/(1000*V_{room})$

	V_{room}		
	area	*85 m^2*	
average	*height*	*5,2 m*	
	V_{room}		442,0 m^3
	n		**1,69 h^{-1}**

Air change rate on basis of Co2 level

determined by the allowed CO2 concentration
Class ll in DS/EN 15251
CO2 load can max be 550ppm higher than the outdoor CO2 conc.
outdoor concentration in Denmark (in most location) 350
a person exhales 10l/min with a CO2 conc. On 4%

$c=(q/nV)+c_i$

Co2 concentration:

q=(4/100)*50pers.*((10l/min * 60min/h)/1000l/m3)

q	**0,096 m^3/h**

Air change rate:

900ppm = 1000000*(q/(n*V_{room}))+350ppm

n=(1000000*q)/((900-350)*V_{room})

n	**0,39 h^{-1}**

Source: GKB, Aalborg University

Fig. 151 Air change rate calculations - offices

Indoor air quality

(Based on sensory calculation)

Air change rate on basis of experienced air poll

Pollution load:

Occupants (1person)	**1 olf**
Building	**0,2 olf per m^2**

Percentage of dissatisfied:

Maximum PD = 20% (Class ll (B))

$C=C_i + 10\ (q/V_L)$

c = experienced air quality [dp]
c_i= experienced air quality outdoor [dp]
q= Pollution load [olf]
V_L= necessary air flow supply [l/s]

c	**1,4 dp**
c_i	**0,1 dp**

q= occupants * persons + building * area

persons	70
area	150,0 m^2
q	**100,0 olf**

Necessary air flow supply

$C=C_i + 10\ (q/V_L)\ > V_L= (10*q)/(c-c_i)$

V_L	**769,2 l/s**

Air change rate

$n=(v_L*3600s)/(1000*V_{room})$

	V_{room}		
	area	*150 m^2*	
average	*height*	*3,2 m*	
	V_{room}		480,0 m^3
	n		**5,77 h^{-1}**

Air change rate on basis of Co2 level

determined by the allowed CO2 concentration
Class ll in DS/EN 15251
CO2 load can max be 550ppm higher than the outdoor CO2 conc.
outdoor concentration in Denmark (in most location) 350
a person exhales 10l/min with a CO2 conc. On 4%

$c=(q/nV)+c_i$

Co2 concentration:

q=(4/100)*70pers.*((10l/min * 60min/h)/1000l/m3)

q	**0,096 m^3/h**

Air change rate:

900ppm = 1000000*(q/(n*V_{room}))+350ppm

n=(1000000*q)/((900-350)*V_{room})

n	**0,36 h^{-1}**

Source: GKB, Aalborg University

Fig. 152 Air change rate calculations - restaurant

Indoor air quality

(Based on sensory calculation)

Air change rate on basis of experienced air poll

Pollution load:

Occupants (1person)	**1 olf**
Building	**0,2 olf per m^2**

Percentage of dissatisfied:

Maximum PD = 20% (Class ll (B))

$C=C_i + 10\ (q/V_L)$

c = experienced air quality [dp]
c_i= experienced air quality outdoor [dp]
q= Pollution load [olf]
V_L= necessary air flow supply [l/s]

c	**1,4 dp**
c_i	**0,1 dp**

q= occupants * persons + building * area

persons	40
area	89,0 m^2
q	**57,8 olf**

Necessary air flow supply

$C=C_i + 10\ (q/V_L)\ > V_L= (10*q)/(c-c_i)$

V_L	**444,6 l/s**

Air change rate

$n=(v_L*3600s)/(1000*V_{room})$

	V_{room}		
	area	*89 m^2*	
average	*height*	*6,3 m*	
	V_{room}		560,7 m^3
	n		**2,85 h^{-1}**

Air change rate on basis of Co2 level

determined by the allowed CO2 concentration
Class ll in DS/EN 15251
CO2 load can max be 550ppm higher than the outdoor CO2 conc.
outdoor concentration in Denmark (in most location) 350
a person exhales 10l/min with a CO2 conc. On 4%

$c=(q/nV)+c_i$

Co2 concentration:

q=(4/100)*8pers.*((10l/min * 60min/h)/1000l/m3)

q	**0,096 m^3/h**

Air change rate:

900ppm = 1000000*(q/(n*V_{room}))+350ppm

n=(1000000*q)/((900-350)*V_{room})

n	**0,31 h^{-1}**

Source: GKB, Aalborg University

Fig. 153 Air change rate calculations - auditorium

Indoor air quality
(Based on sensory calculation)

Air change rate on basis of experienced air poll

Pollution load:

Occupants (1person)	**1 olf**
Building	**0,2 olf per m²**

Percentage of dissatisfied:

Maximum PD = 20% (Class II (B))

$C = C_i + 10\,(q/V_L)$

c = experienced air quality [dp]
c_i= experienced air quality outdoor [dp]
q= Pollution load [olf]
V_L= necessary air flow supply [l/s]

c	**1,4 dp**
c_i	**0,1 dp**

q= occupants * persons + building * area

persons	8
area	63,0 m²
q	**20,6 olf**

Necessary air flow supply

$C = C_i + 10\,(q/V_L) > V_L = (10*q)/(c - c_i)$

V_L	**158,5 l/s**

Air change rate

$n = (v_L * 3600s)/(1000 * V_{room})$

V_{room}

	area	*63 m²*	
average	*height*	*4 m*	
	V_{room}		252,0 m³
	n		**2,26 h⁻¹**

Air change rate on basis of Co2 level

determined by the allowed CO2 concentration
Class II in DS/EN 15251
CO2 load can max be 550ppm higher than the outdoor CO2 conc.
outdoor concentration in Denmark (in most location) 350
a person exhales 10l/min with a CO2 conc. On 4%

$c = (q/nV) + c_i$

Co2 concentration:

q=(4/100)*8pers.*((10l/min * 60min/h)/1000l/m3)

q	**0,096 m³/h**

Air change rate:

$900ppm = 1000000*(q/(n*V_{room})) + 350ppm$

$n = (1000000*q)/((900-350)*V_{room})$

n	**0,69 h⁻¹**

Source: GKB, Aalborg University

Fig. 154 Air change rate calculations - gift shop

Be10 RESULTS

Key numbers, kWh/m² year

Energy frame in BR 2010

Without supplement	Supplement for special conditions	Total energy frame
72,8	0,0	72,8
Total energy requirement		103,8

Energy frame low energy buildings 2015

Without supplement	Supplement for special conditions	Total energy frame
41,9	0,0	41,9
Total energy requirement		93,4

Energy frame Buildings 2020

Without supplement	Supplement for special conditions	Total energy frame
25,0	0,0	25,0
Total energy requirement		68,5

Contribution to energy requirement		Net requirement	
Heat	52,0	Room heating	45,4
El. for operation of bulding	20,7	Domestic hot water	5,4
Excessive in rooms	0,0	Cooling	0,0

Selected electricity requirements		Heat loss from installations	
Lighting	15,4	Room heating	0,9
Heating of rooms	0,0	Domestic hot water	0,1
Heating of DHW	0,0		
		Output from special sources	
Heat pump	0,0		
Ventilators	5,0	Solar heat	0,0
Pumps	0,3	Heat pump	0,0
Cooling	0,0	Solar cells	0,0
Total el. consumption	37,8	Wind mills	0,0

Fig. 154 Be10 resluts without photovoltaic panels

Key numbers, kWh/m² year

Energy frame in BR 2010

Without supplement	Supplement for special conditions	Total energy frame
72,8	0,0	72,8
Total energy requirement		27,6

Energy frame low energy buildings 2015

Without supplement	Supplement for special conditions	Total energy frame
41,9	0,0	41,9
Total energy requirement		17,2

Energy frame Buildings 2020

Without supplement	Supplement for special conditions	Total energy frame
25,0	0,0	25,0
Total energy requirement		13,6

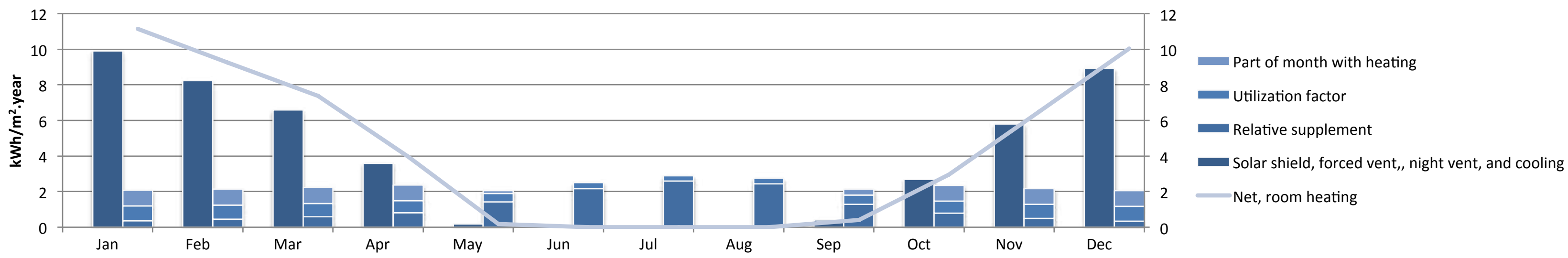
Contribution to energy requirement		Net requirement	
Heat	52,0	Room heating	45,4
El. for operation of bulding	20,7	Domestic hot water	5,4
Excessive in rooms	0,0	Cooling	0,0

Selected electricity requirements		Heat loss from installations	
Lighting	15,4	Room heating	0,9
Heating of rooms	0,0	Domestic hot water	0,1
Heating of DHW	0,0		
		Output from special sources	
Heat pump	0,0		
Ventilators	5,0	Solar heat	0,0
Pumps	0,3	Heat pump	0,0
Cooling	0,0	Solar cells	30,5
Total el. consumption	37,8	Wind mills	0,0

Fig. 155 Be10 resluts including photovoltaic panels

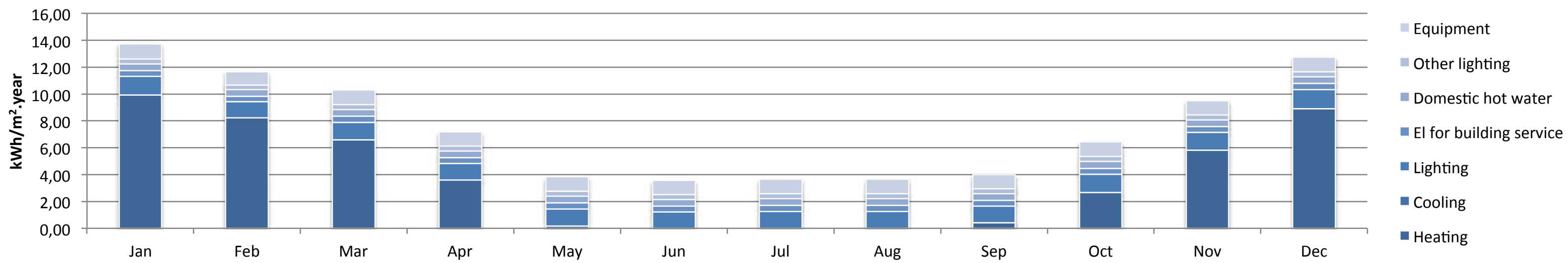
Be10 RESULTS

Heating requirement and heat gains



kWh/m² year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Solar shield, forced vent,, n	9,91	8,23	6,59	3,60	0,18	0,00	0,00	0,00	0,41	2,69	5,81	8,92	46,33
Relative supplement	0,35	0,44	0,58	0,82	1,43	2,16	2,60	2,44	1,29	0,80	0,49	0,35	0,00
Utilization factor	0,83	0,81	0,75	0,66	0,48	0,34	0,29	0,31	0,51	0,67	0,79	0,83	0,60
Part of month with heating	0,89	0,89	0,89	0,89	0,16	0,00	0,00	0,00	0,35	0,89	0,89	0,89	0,00
Net, room heating	11,15	9,25	7,38	3,98	0,18	0,00	0,00	0,00	0,41	2,95	6,51	10,04	51,86

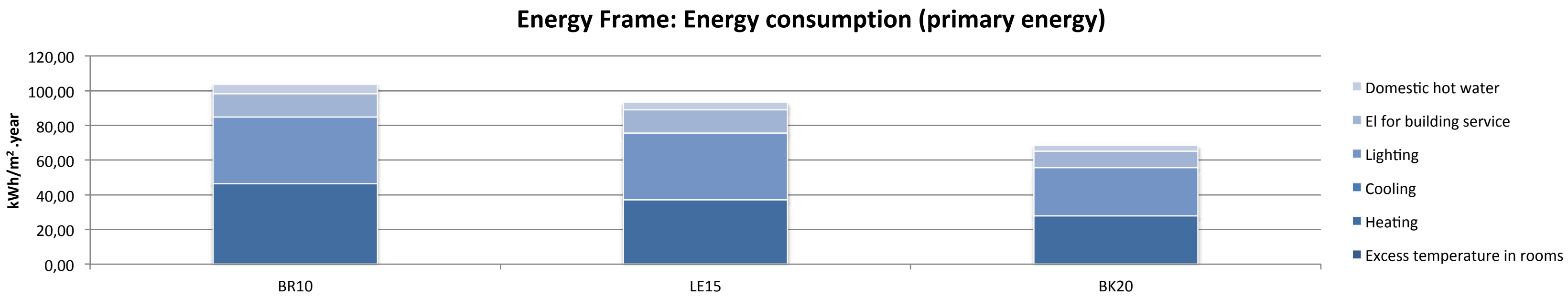
Energy consumption (final energy)



kWh/m² year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Excess temperature in roon	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Heating	9,91	8,23	6,59	3,60	0,18	0,00	0,00	0,00	0,41	2,69	5,81	8,92	46,33
Cooling	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Lighting	1,39	1,20	1,29	1,22	1,26	1,22	1,26	1,26	1,23	1,33	1,34	1,42	15,42
El for building service	0,45	0,41	0,45	0,44	0,45	0,44	0,45	0,45	0,44	0,45	0,44	0,45	5,32
Domestic hot water	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	5,4
Other lighting	0,37	0,34	0,37	0,36	0,37	0,36	0,37	0,37	0,36	0,37	0,36	0,37	4,38
Equipment	1,08	0,98	1,08	1,05	1,08	1,05	1,08	1,08	1,05	1,08	1,05	1,08	12,77

Fig. 157

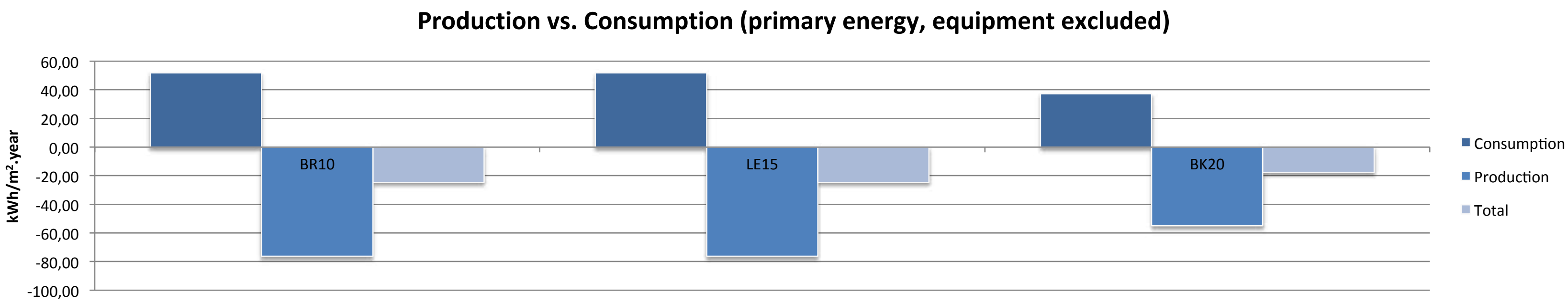
Be10 RESULTS



Energy consumption				
kWh/m² year	Final energy	BR10	LE15	BK20
Excess temperature in roon	0,00	0,00	0,00	0,00
Heating	46,33	46,33	37,06	27,80
Cooling	0,00	0,00	0,00	0,00
Lighting	15,42	38,54	38,54	27,75
El for building service	5,32	13,30	13,30	9,58
Domestic hot water	5,40	5,40	4,32	3,24
Total		103,58	93,23	68,37

Energy factors			
	BR10	LE15	BK20
Heating	1	0,8	0,6
El	2,5	2,5	1,8

Fig. 157



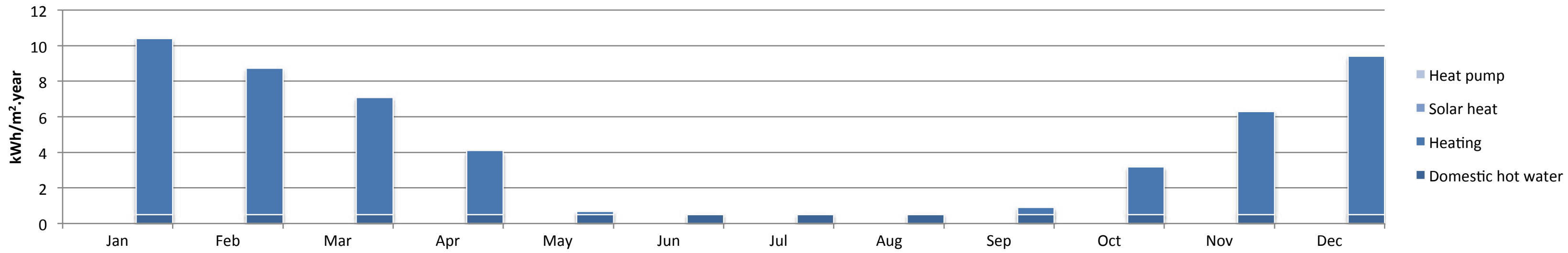
Energy consumption & production				
kWh/m² year	sumption/Product	BR10	LE15	BK20
Excess temperature in roon	0,00	0,00	0,00	0,00
Cooling	0,00	0,00	0,00	0,00
Lighting	15,42	38,54	38,54	27,75
El for building service	5,32	13,30	13,30	9,58
Other lighting	4,38	10,95	10,95	7,88
Equipment	12,77	31,92	31,92	22,99
Wind mills	0,00	0,00	0,00	0,00
Total performance	30,54	76,34	76,34	54,97
Solar heat	0,00	0,00	0,00	0,00
Heat pump	0,00	0,00	0,00	0,00

Energy factors			
	BR10	LE15	BK20
Heating	1	0,8	0,6
El	2,5	2,5	1,8

	Final energy	BR10	LE15	BK20
Consumption	37,89	51,85	51,85	37,33
Production	-30,54	-76,34	-76,34	-54,97
Total	7,35	-24,49	-24,49	-17,64

Fig. 158

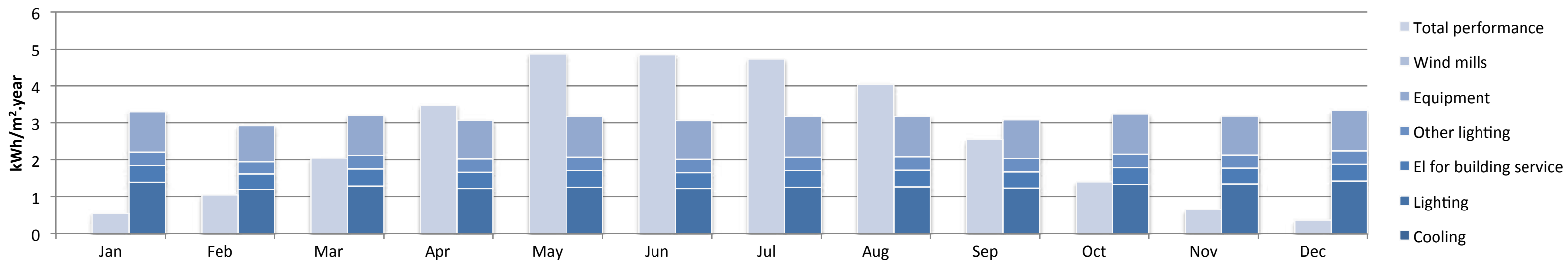
Heat production vs. consumption (final energy)



kWh/m² year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Domestic hot water	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	5,4
Heating	9,91	8,23	6,59	3,60	0,18	0,00	0,00	0,00	0,41	2,69	5,81	8,92	46,33
Solar heat	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Heat pump	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Fig. 159

Electricity production vs. consumption (final energy)



kWh/m² year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Excess temperature in roon	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Cooling	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Lighting	1,39	1,20	1,29	1,22	1,26	1,22	1,26	1,26	1,23	1,33	1,34	1,42	15,42
El for building service	0,45	0,41	0,45	0,44	0,45	0,44	0,45	0,45	0,44	0,45	0,44	0,45	5,32
Other lighting	0,37	0,34	0,37	0,36	0,37	0,36	0,37	0,37	0,36	0,37	0,36	0,37	4,38
Equipment	1,08	0,98	1,08	1,05	1,08	1,05	1,08	1,08	1,05	1,08	1,05	1,08	12,77
Wind mills	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Total performance	0,54	1,05	2,04	3,46	4,86	4,84	4,72	4,05	2,55	1,40	0,66	0,36	30,54

Fig. 160

NATURAL VENTILATION

Temporary exhibition

Solution Task 9

Pressure Coefficient				**Windfactor**	0,75			**Pwind**	0,4 pa	
Windward	0,06			**Vmeteo**	1 m/s			**Pmin**	-0,2 pa	
Leeward	-0,60			**Vref**	0,75 m/s			**Pmax**	0,0 pa	
Roof	-0,60									
Location of neutral plan, Ho		2,7 m				**Buildingvol.**		950,0 m3		
Outdoor temperature		12 C				**Volume**			m3/section/floor	
Zone temperature		22 C								
Discharge coefficient		0,7				**Internal pressure, P**	pa	-0,09		0,14
Air density		1,25 kg/m3								

	Area	Eff. Area	Height	Thermal Buoyancy	AFR (thermal)	Pres Coefficient	Wind pressure	AFR Wind)	Wind pressure	AFR total
	m2	m2	m	pa	m3/s		pa	m3/s	pa	m3/s
South top	5	3,5	7	-1,798	-5,94	0,06	0,107	1,446	-0,122	-6,134
South	8,00	5,600	1	0,699	5,92	0,06	0,107	2,313	-0,122	5,380
North	8	5,600	1	0,699	5,92	-0,6	-0,125	-2,509	-0,354	4,159
North top	5	3,500	7	-1,798	-5,94	-0,6	-0,125	-1,568	-0,354	-6,494
West	5	3,500	1	0,699	3,70	-0,5	-0,090	-1,330	-0,319	2,729
West top	5	3,500	6	-1,381	-5,20	-0,5	-0,090	-1,330082014	-0,319	-5,773
Roof										
				Massebalance	4,41		Massebalance	-4,42		0,00

Wind direction	ACR at 8m/s [h^{-1}]	ACR at 1 m/s [h^{-1}]
North	95,074	20,766
North east	83,266	20,024
East	19,023	17,329
South east	95,529	20,387
South	95,074	20,766
South west	58,093	19,099
West	63,587	15,878
North west	38,653	18,750

Sum	548,299	153,000
Average	68,537	19,125

Fig. 146 Natural ventilation spreadsheet

DUCT DIMENSIONING

Calculation of the air change rate (sensoric)				**MAIN EXH.**
Floors	1			
Heated floor area	307	m2		
Requiered extracted air				
=	856,9	l/s		
Air flow, V	(Extrated air *3600)/1000			
=	3084,84	m3/h		
Distribution duct	3084,84	m3/h		

Calculation of the air change rate (sensoric)				**SHOP**
Floors	1			
Heated floor area	63	m2		
Requiered extracted air				
=	158,5	l/s		
Air flow, V	(Extrated air *3600)/1000			
=	570,6	m3/h		
Distribution duct	570,6	m3/h		

Calculation of the air change rate (sensoric)				**AUDITORIUM**
Floors	1			
Heated floor area	89	m2		
Requiered extracted air				
=	444,6	l/s		
Air flow, V	(Extrated air *3600)/1000			
=	1600,56	m3/h		
Distribution duct	1600,56	m3/h		

Calculation of the air change rate (sensoric)				**OFFICES**
Floors	1			
Heated floor area	85	m2		
Requiered extracted air				
=	207,7	l/s		
Air flow, V	(Extrated air *3600)/1000			
=	747,72	m3/h		
Distribution duct	747,72	m3/h		

Calculation of the air change rate (sensoric)				**RESTAURANT**
Floors	1			
Heated floor area	150	m2		
Requiered extracted air				
=	769,2	l/s		
Air flow, V	(Extrated air *3600)/1000			
=	2769,12	m3/h		
Distribution duct	2769,12	m3/h		

Distribution duct sizes found by the "SBI nomogram 10"
http://www.ventilation-system.com/cat/456/

				diamteres:
Educational	ϕ	305	mm	31[illegible]
Exhibition 1	ϕ	310	mm	31[illegible]
Exhibition main	ϕ	415	mm	42[illegible]
Workshop	ϕ	350	mm	33[illegible]
Offices	ϕ	205	mm	21[illegible]
Restaurant	ϕ	415	mm	42[illegible]
Kitchen+wc	ϕ	90	mm	10[illegible]
External toilets	ϕ	125	mm	12[illegible]
Toilets	ϕ	90	mm	10[illegible]
Shop		170	mm	17[illegible]
Total	ϕ		mm	249[illegible]
Main supply duct	rectangle		mm	2400x120[illegible]
Main extract duct	rectangle		mm	2400x120[illegible]

Calculation of the air change rate (sensoric)				**WORKSHOP**
Floors	1			
Heated floor area	90	m2		
Requiered extracted air				
=	489,2	l/s		
Air flow, V	(Extrated air *3600)/1000			
=	1761,12	m3/h		
Distribution duct	1761,12	m3/h		

Calculation of the air change rate (sensoric)				**TEMP. EXH.**
Floors	1			
Heated floor area	200	m2		
Requiered extracted air				
=	431,7	l/s		
Air flow, V	(Extrated air *3600)/1000			
=	1554,12	m3/h		
Distribution duct	1554,12	m3/h		

Fig. 147 Calculations of ventilation duct sizes and results

DUCT DIMENSIONING

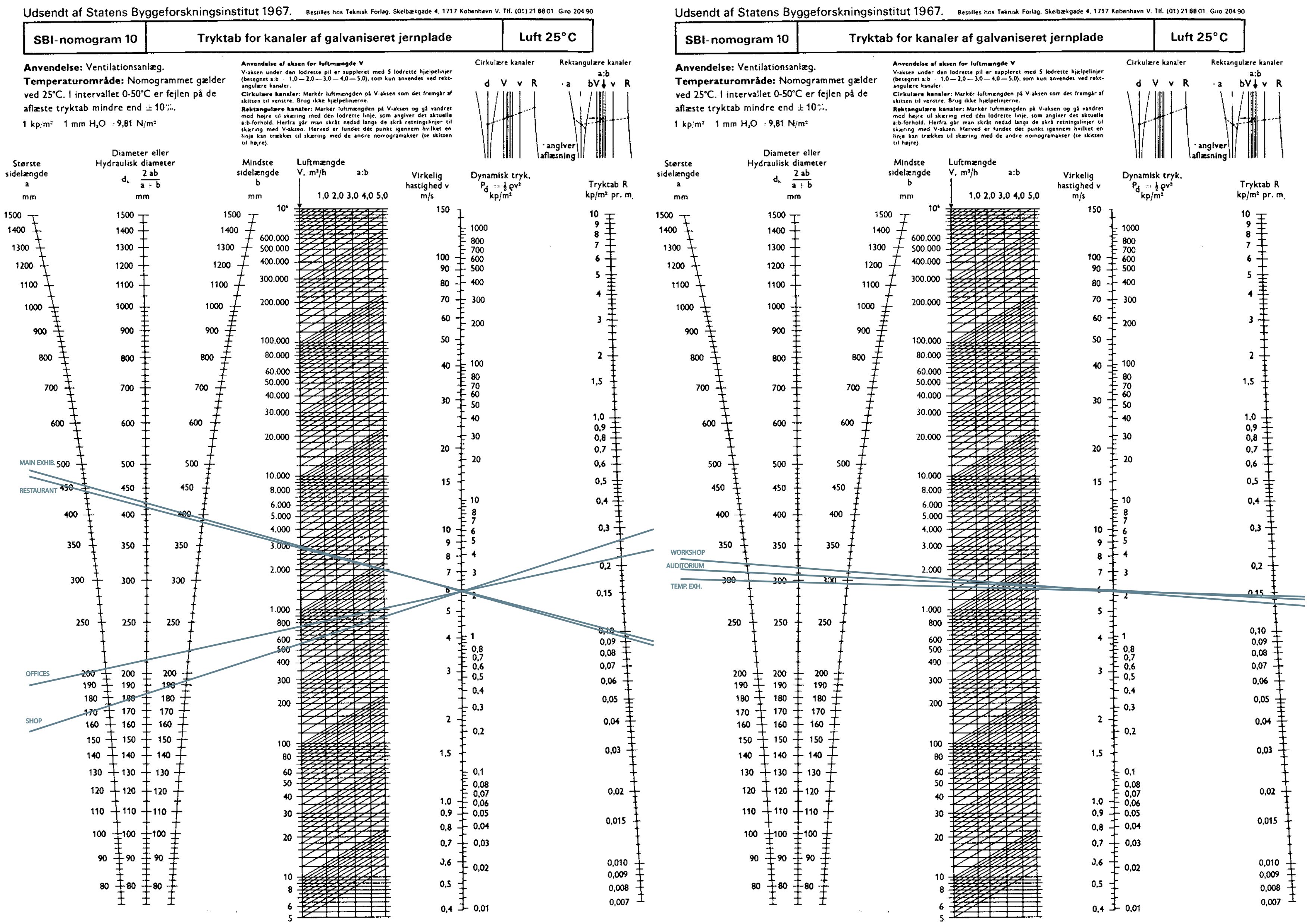


Fig. 163Ventilation ducts dimensioning

BSIM RESULTS

2002 | Month | Hours | ThermalZone114

ThermalZon	Sum/Mean	1 (31 days)	2 (28 days)	3 (31 days)	4 (30 days)	5 (31 days)	6 (30 days)	7 (31 days)	8 (31 days)	9 (30 days)	10 (31 days)	11 (30 days)	12 (31 days)
qHeating	4117,89	1259,99	843,95	327,69	56,93	0,00	0,00	0,00	0,00	0,62	10,22	444,72	1173,76
qCooling	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
qInfiltration	-9428,70	-1239,15	-1165,30	-1151,26	-909,46	-614,15	-382,37	-326,17	-330,94	-500,51	-774,02	-913,98	-1121,38
qVenting	-22196,81	0,00	0,00	0,00	-962,65	-3862,84	-4458,38	-4711,13	-4718,91	-3482,89	0,00	0,00	0,00
qSunRad	23568,45	818,92	1312,43	2013,86	2627,27	2955,60	2821,56	2854,80	2820,69	2290,15	1548,09	935,05	570,03
qPeople	1977,48	100,44	90,72	100,44	97,20	100,44	356,40	368,28	368,28	97,20	100,44	97,20	100,44
qEquipment	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
qLighting	29132,46	2582,70	2287,05	2489,55	2353,56	2371,03	2265,64	2355,56	2402,76	2385,96	2531,91	2493,90	2612,85
qTransmissi	-15428,88	-2029,68	-1910,30	-1851,99	-1413,33	-950,08	-602,84	-541,33	-541,87	-790,53	-1407,91	-1522,12	-1866,89
qMixing	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
qVentilation	-11741,88	-1493,21	-1458,55	-1928,29	-1849,53	0,00	0,00	0,00	0,00	0,00	-2008,72	-1534,77	-1468,82
Sum	-0,00	-0,00	-0,00	0,00	-0,00	-0,00	0,00	-0,00	0,00	-0,00	-0,00	0,00	-0,00
tOutdoor me	7,7	-0,5	-1,0	1,7	5,6	11,3	15,0	16,4	16,2	12,5	9,1	4,8	1,5
tOp mean(°C	21,9	21,2	21,3	21,8	22,1	22,3	22,1	22,3	22,2	21,7	22,8	21,6	21,2
AirChange(/	1,6	0,7	0,7	0,8	1,1	1,9	3,0	3,8	3,7	1,6	0,7	0,7	0,7
Rel. Moistur	35,8	22,8	20,6	22,7	26,9	37,9	51,0	55,5	53,2	49,8	34,7	31,1	23,3
Co2(ppm)	364,3	359,3	359,4	358,3	357,0	368,3	377,2	369,3	375,9	368,6	359,4	359,2	359,3
PAQ(-)	0,5	0,7	0,7	0,6	0,6	0,4	0,2	0,2	0,2	0,3	0,4	0,5	0,7
Hours > 21	7034	491	510	666	634	559	582	613	613	502	743	622	499
Hours > 26	84	0	0	0	0	8	23	28	25	0	0	0	0
Hours > 27	20	0	0	0	0	1	7	4	8	0	0	0	0
Hours < 20	0	0	0	0	0	0	0	0	0	0	0	0	0
FanPow	4038,19	575,44	519,75	627,75	607,50	0,00	0,00	0,00	0,00	0,00	575,44	556,88	575,44
HtRec	32258,10	6105,20	5587,05	5326,87	3591,69	0,00	0,00	0,00	0,00	0,00	2161,30	4015,61	5470,38
ClRec	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
HtCoil	100,76	47,84	32,73	0,09	0,02	0,00	0,00	0,00	0,00	0,00	0,00	1,17	18,90
ClCoil	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Humidif	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
FloorHeat	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
FloorCool	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CentHeatPu	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CentCooling	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CentHeatPu	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CentCooling	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

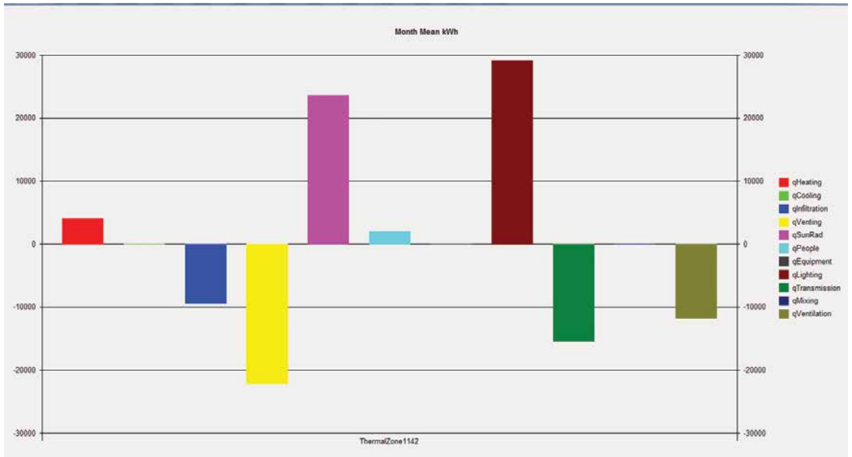


Fig. 161 Main exhibition

2002 | Month | Hours | ThermalZone121

ThermalZon	Sum/Mean	1 (31 days)	2 (28 days)	3 (31 days)	4 (30 days)	5 (31 days)	6 (30 days)	7 (31 days)	8 (31 days)	9 (30 days)	10 (31 days)	11 (30 days)	12 (31 days)
qHeating	12202,38	2745,28	2286,52	1734,90	714,30	0,00	0,00	0,00	0,00	10,20	621,09	1604,61	2485,48
qCooling	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
qInfiltration	-4837,47	-645,12	-604,78	-589,79	-473,69	-316,75	-184,45	-157,68	-160,17	-271,30	-378,90	-470,53	-584,31
qVenting	-10255,33	0,00	0,00	0,00	0,00	-2307,64	-1953,08	-2148,86	-1987,72	-1858,03	0,00	0,00	0,00
qSunRad	11101,81	509,50	813,18	1216,49	1730,53	2020,60	567,30	554,46	381,23	1444,69	976,50	550,50	336,82
qPeople	1977,48	100,44	90,72	100,44	97,20	100,44	356,40	368,28	368,28	97,20	100,44	97,20	100,44
qEquipment	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
qLighting	26091,71	2238,60	2012,30	2218,00	2133,33	2191,52	2119,61	2192,31	2203,84	2140,74	2228,04	2165,60	2247,80
qTransmissi	-26510,76	-3609,32	-3309,62	-3214,85	-2620,27	-1688,18	-905,79	-808,51	-805,47	-1563,50	-2063,39	-2651,87	-3269,99
qMixing	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
qVentilation	-9769,83	-1339,37	-1288,31	-1465,19	-1581,41	0,00	0,00	0,00	0,00	0,00	-1483,79	-1295,51	-1316,25
Sum	-0,00	-0,00	-0,00	0,00	0,00	0,00	-0,00	0,00	0,00	-0,00	0,00	0,00	-0,00
tOutdoor me	7,7	-0,5	-1,0	1,7	5,6	11,3	15,0	16,4	16,2	12,5	9,1	4,8	1,5
tOp mean(°C	22,1	21,9	22,1	22,1	22,7	22,5	21,7	22,0	21,9	22,4	22,4	22,0	21,9
AirChange(/	1,8	1,1	1,1	1,1	1,1	1,9	3,1	4,0	3,7	1,3	1,1	1,1	1,1
Rel. Moistur	35,4	21,8	19,7	22,2	26,0	37,1	51,9	56,1	54,1	47,6	35,5	30,5	22,4
Co2(ppm)	367,8	361,3	361,4	361,4	361,3	370,0	386,4	371,9	384,5	371,8	361,5	361,2	361,3
PAQ(-)	0,4	0,6	0,7	0,6	0,5	0,4	0,2	0,2	0,2	0,3	0,4	0,5	0,6
Hours > 21	7852	744	672	744	720	742	409	461	442	710	744	720	744
Hours > 26	59	0	0	0	0	2	14	18	24	1	0	0	0
Hours > 27	20	0	0	0	0	0	6	4	9	1	0	0	0
Hours < 20	0	0	0	0	0	0	0	0	0	0	0	0	0
FanPow	2108,52	308,32	278,48	308,32	298,37	0,00	0,00	0,00	0,00	0,00	308,32	298,37	308,32
HtRec	24849,45	4823,67	4409,36	3797,26	2578,81	0,00	0,00	0,00	0,00	0,00	1737,79	3178,83	4323,74
ClRec	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
HtCoil	32,53	18,74	9,83	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,30	3,67
ClCoil	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Humidif	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
FloorHeat	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
FloorCool	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CentHeatPu	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CentCooling	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CentHeatPu	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CentCooling	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

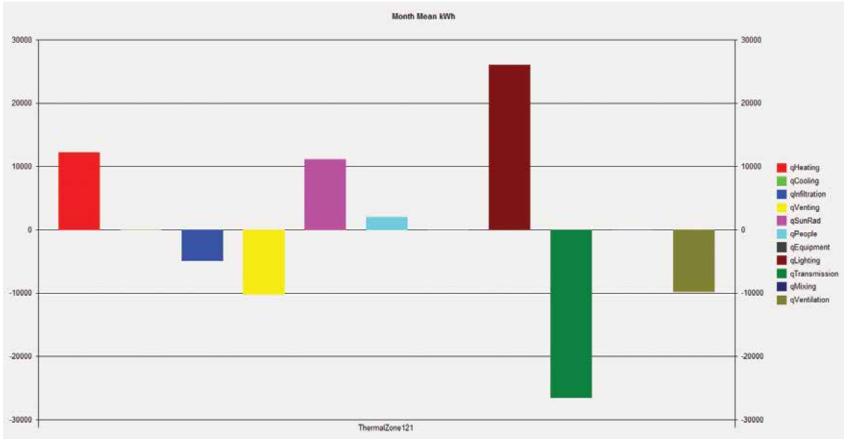


Fig. 162 Temporary exhibition