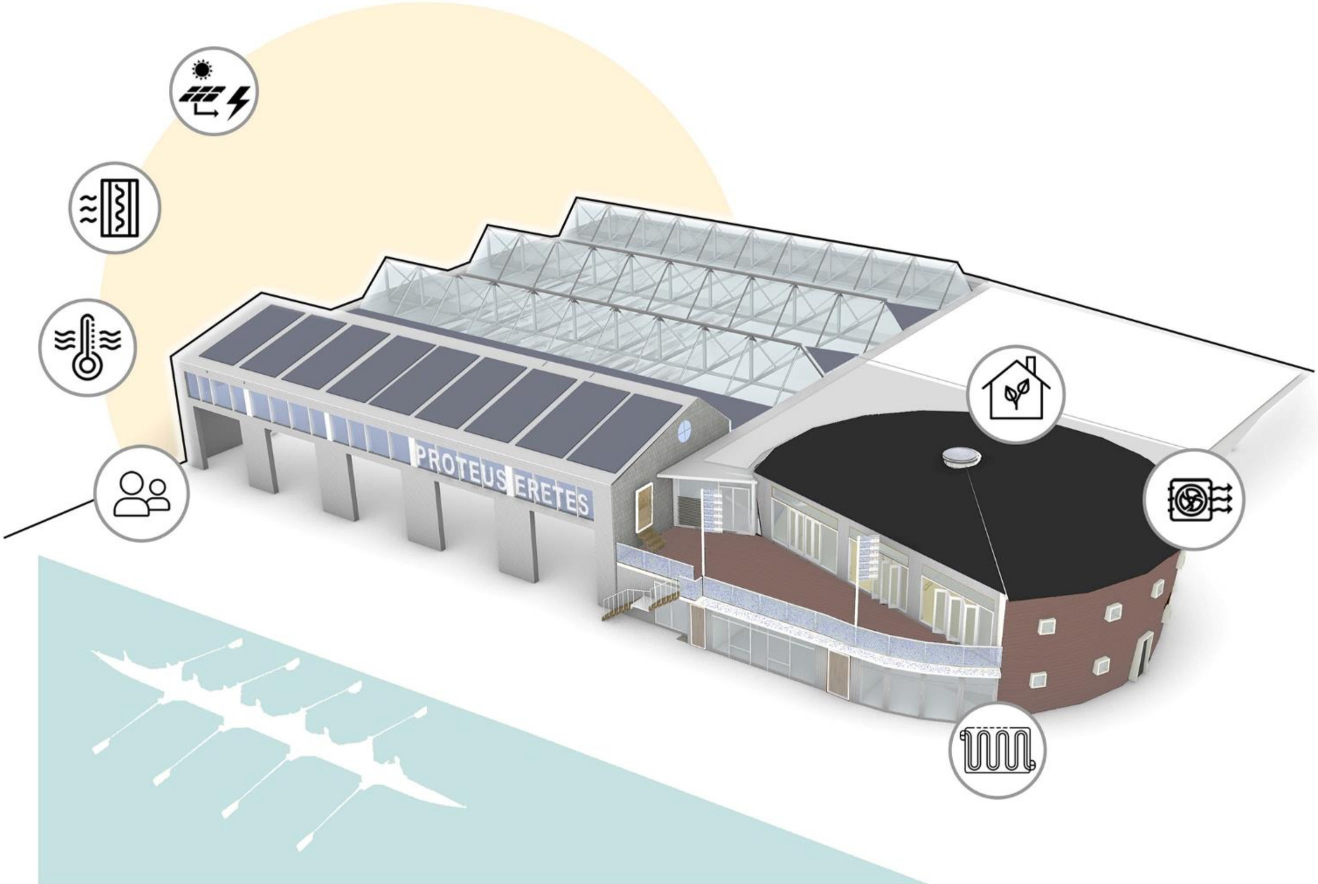
RENOVATION OF PROTEUS ERETES



a nearly Zero Energy Building with High Indoor Comfort

Master Thesis Report

Irum Faisal
5277310

Delft University of Technology

Climate Design Graduation Studio

Department of Architectural Engineering + Technology

Master Track: Building Technology

Name - Irum Faisal

Student number - 5277310

First Mentor - Prof.dr.ir. A.A.J.F van den Dobblesteen (Climate)

Second Mentor - Prof.dr.ir. AC Boerstra (Building Services)

External - Building Committee, D.S.R. Proteus Eretes

Delegate Examiner - Ir. MH Meijs

Acknowledgement

''If the vision is clear, the process is simple''

The journey of my entire master's course at TU Delft has been a wonderful experience. Indeed, it was a great learning in the field of building technology, climate, sustainability, and architecture. Looking back to the beginning of master's and finally graduating now, the journey has been immensely exciting, fruitful, and full of surprises. Each step taken to learn through courses of building technology in a diverse cultural environment has shaped my interest in a very symbiotic manner. Not only do I see improvement in my professional path but also an overall improvement in my architectural intellect.

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Abstract

One of the major risks to our planet today is climate change, which is a problem that worries people all over the world. There is rise in global temperature level and greenhouse gas emissions. Building industry has a huge share in this aspect. The current built environment accounts for almost 40% of energy consumption and 36% CO_2 emissions in the Netherlands. Therefore, to meet national energy efficiency and greenhouse gas emission targets, the energy performance of existing buildings is critical. In existing buildings, the challenge is threefold when it comes to refurbishment. Occupant behaviour towards indoor environment and energy usage behaviour. Secondly, the labour required for technical changes and lastly the financial limitations. Therefore, it is important to design or redesign building with the aim to provide good indoor quality using energy efficient building elements which are simple, adaptable, sustainable, and affordable. The study explored in this graduation focuses on renovation of Proteus Eretes rowing accommodation using integrated climate design strategies. The report highlights the need of occupants and their interaction with indoor environment. The proposal is a combination of key solutions that can make huge impact on energy savings and comfort conditions in the rowing facility. This research by design methodology aims to bridge the gap between energy neutrality and occupant comfort in buildings.

Keywords: nearly zero energy, indoor environmental quality, occupant comfort, energy efficiency, thermal comfort, indoor air quality, energy performance, daylight

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1. INTRODUCTION

1.1 Problem Statement

Buildings, which account for almost half of all annual energy and greenhouse gas emissions, are the most critical focus for any climate change strategy. To reach Europe's 2030 climate goals, the construction sector must reduce emissions by 60%. That means annual renovations must increase by an order of magnitude; they are currently creeping along at 1% each year. Worse, ordinary renovations save very little energy, only 9% in residences and 16% in commercial structures. It’s the deep renovations that cut energy by 60% or more, but that’s only happening to under 0.3% of the stock (Wind, 2021). The existing building stock is therefore coming into highlight to meet higher level renovation activity, as well as more research into the long-term viability of building renovation.

The important characteristic that distinguishes the process of building renovation to new building construction is that there is an existing building and existing user. Incorporating green technologies in refurbishment projects, specially of older buildings, presents many technical, financial, and social challenges. The starting point of such a subject would be the pre-evaluation of the building condition and the experience of using it that provides a baseline for post-evaluation. The operational energy and indoor environment quality are the main indicators to explain the past and present condition of the building. It is affected by climate of region, building configuration, building material characteristics and occupancy characteristics (Praseeda & Mani, 2017).

Following the above problem, the renowned rowing facility of Delft, DSR Proteus Eretes which was built in 1997 calls for attention to sustainable renovation. Proteus Eretes was an association with 350 members in the past which have tolled up to more than 850 as of today. The building was initially designed for limited number of occupants however the membership continues to grow. As a result, the space that the building offers is no longer sufficient to accommodate or to provide a comfortable indoor environment. Therefore, the renovation/extension of Proteus came into planning. The main reasons that lead to introduction of this topic are increasing occupancy, high energy consumption and uncomfortable indoor environment in the current building. The underperforming building envelope with outdated mechanical systems cause poor indoor environment which affects occupant’s experience and results in high energy consumption overall. This research aims at transition of Proteus-Eretes building into a nearly zero energy complex which provides high indoor quality to the users.

The focus in most research works has so far been on comprehensive renovation projects, concentrating mainly on building envelope and technical installations, which among other things involve a major improvement in energy performance. Such renovations are being encouraged in European energy policies and are also called “deep renovations”—for instance, in the EU’s Horizon 2020 programme for research and innovation (European Commission Decision & European Commission, 2015). While keeping in mind the well being of occupants during deep renovation, the building should be able to achieve resilience through integrated climate design in a way that has huge potential to reduce operational energy and enhance indoor quality. Therefore, climate responsive strategies can be very promising that are able accommodate passive and active solutions for the rowing facility.

1.2 Research Objectives

The research offers a beginning point for understanding the difficulties in existing sports facilities with respect to indoor environment quality and energy consumption. It reflects the occupant's behaviour towards the building performance and their participation and adaptability to sustainable changes. The decisions for renovation of building skin, material, natural illumination is addressed as energy related aspects. They determine what type of building retrofits for heating, cooling, artificial lighting ad ventilation are needed. Moreover, the building's energy demand is affected and assessment of natural energy supply.

Aiming to achieve pragmatic solution to this problem, the following objectives aim:

i. To focus on energy performance and energy loads that is affected by indoor environment, building services, and building fabric.

ii. To investigate climate design strategies for building renovation to enhance the thermal performance, indoor air quality, occupant comfort and installation of renewable energy sources in a holistic manner.

iii. To combine passive strategies and active renewable technologies aiming to make the building nearly zero energy.

iv. To develop various design scenarios and compare them with the baseline (existing) scenario. By using simulation tools, the performance of each design scenario will be verified and validated for thermal performance, energy efficiency, daylight and occupant comfort aiming to achieve the most suitable solution.

Additionally, there are some boundaries set in this research which are mentioned below:

i. NOT focus on embodied energy of materials, rather on operational energy emissions from existing systems

ii. NOT focus on financial drawbacks Proteus Eretes is facing. However, to some extent the low-cost solutions and factors will be highlighted with respect to market research.

iii. NOT focus on Life cycle assessment or Life cycle costing of the building.

iv. NOT focus on 'building extension plan' as required by the association to accommodate increasing functions and occupants. However, improvements in existing design will be tackled to improve indoor comfort for occupants.

1.3 Research Question

Main Question:

What are the sustainable strategies that can be used in renovation projects to reach nearly zero energy (NZE) and high indoor environmental quality (IEQ) for user comfort?

Sub questions that will answer the main question with the case of Proteus Eretes:

1. How to evaluate the relationship between a building's energy performance and the occupants' acceptance of the indoor environment?
2. What type of climate integrated design solutions are suitable for such renovation projects? How to combine passive and active solutions to reduce the heating, cooling, lighting and ventilation demand?
3. What building factors contribute to thermal performance and thermal comfort? How to easily incorporate thermal mass system in the rowing facility to enhance the indoor climate?
4. What are the factors affecting indoor air quality? How can the indoor air quality be improved?
5. What are the ways to optimize the use of available natural sources and increase the rate of usable renewable energy source?
6. What are the technical challenges in retrofitting climate responsive solution in the current Proteus Eretes building? How to overcome these challenges in a conscious manner?
7. How to measure the effectivity and adaptability of the integrated climate design in the renovation of Proteus Eretes?

1.4 Research Methodology

The methodology is divided into three parts which would be adopted for the graduation. This is followed by methodology flow chart with phase-wise objectives and graduation timeline.

a. Literature research and building visit–

The beginning of this research focuses on establishing an understanding of the themes that would facilitate sustainable renovation of the rowing facility. To identify issue in the building, site visits and user survey will be performed to accumulate information regarding occupant's perception of the current indoor environment. This step is followed by data collection by association that explains the requirement list, vision for sustainability and Koninklijke Nederlandsche Roeibond standards. Simultaneously, an intensive study will be done on performance indicators for the energy transition; nZEB and indoor environmental quality. Moreover, in-depth study is crucial for renovation strategies that take in account operational energy, methods to include energy efficient technology, requirements stated under Building Decree (2012) and guidelines for nZEB, passive and active solutions for improving thermal performance, ventilation, and lighting and how these can affect user comfort inside the building. The goal is to acknowledge information and define important criteria for the sustainable design of sports facilities, especially rowing accommodations. This literature review shall guide in sorting out the main parameters that are relevant for the renovation of Proteus Eretes.

b. Assessment methods, strategies, and design set-up–

Subsequently, building analysis for rowing facility would be performed to assess building envelope, thermal performance, glazing efficiency, heating and ventilation system, energy consumption and overall building physics. This will further help to identify the key locations in the building for improvement. Parallel to this, exploratory research will be a continuation of literature compilation to design strategies for climate responsive elements. Passive and active solutions would be explored to incorporate thermal mass system, energy efficient glazing, heat recovery ventilation and renewable energy system for building retrofit. These will be quantified based on calculations and simulation methods that will be developed to achieve adaptability and user flexibility of the system. This phase of graduation is very important for the following comparative analysis and performance validation for the long-term viability of rowing club building.

c. Comparative analysis and performance validation –

To validate the design solutions, a comparative analysis technique will be used. Design scenarios with different climate solutions will be developed and compared to the existing baseline scenario on these aspects: energy savings, thermal comfort, daylight autonomy, indoor air quality, predicted mean vote for occupant in summers and winters. By using computation tools for energy and comfort analysis like Design builder and Grasshopper plug-ins honeybee and ladybug, the scenarios will be verified, and modifications would be made to overcome design challenges and reach the energy criteria defined for nZEB and thermal comfort. The final design shall then be selected, and renovation details will be developed.

Conclusion

The outcome shall result in formulating case-specific conclusions, guidelines, and limitations for integrating climate design solutions for the renovation of rowing facilities. Through this thesis, inputs regarding nZEB and IEQ for rowing accommodations shall be proposed for the edition of the KNRB handbook.

Figure 1 Graduation Plan

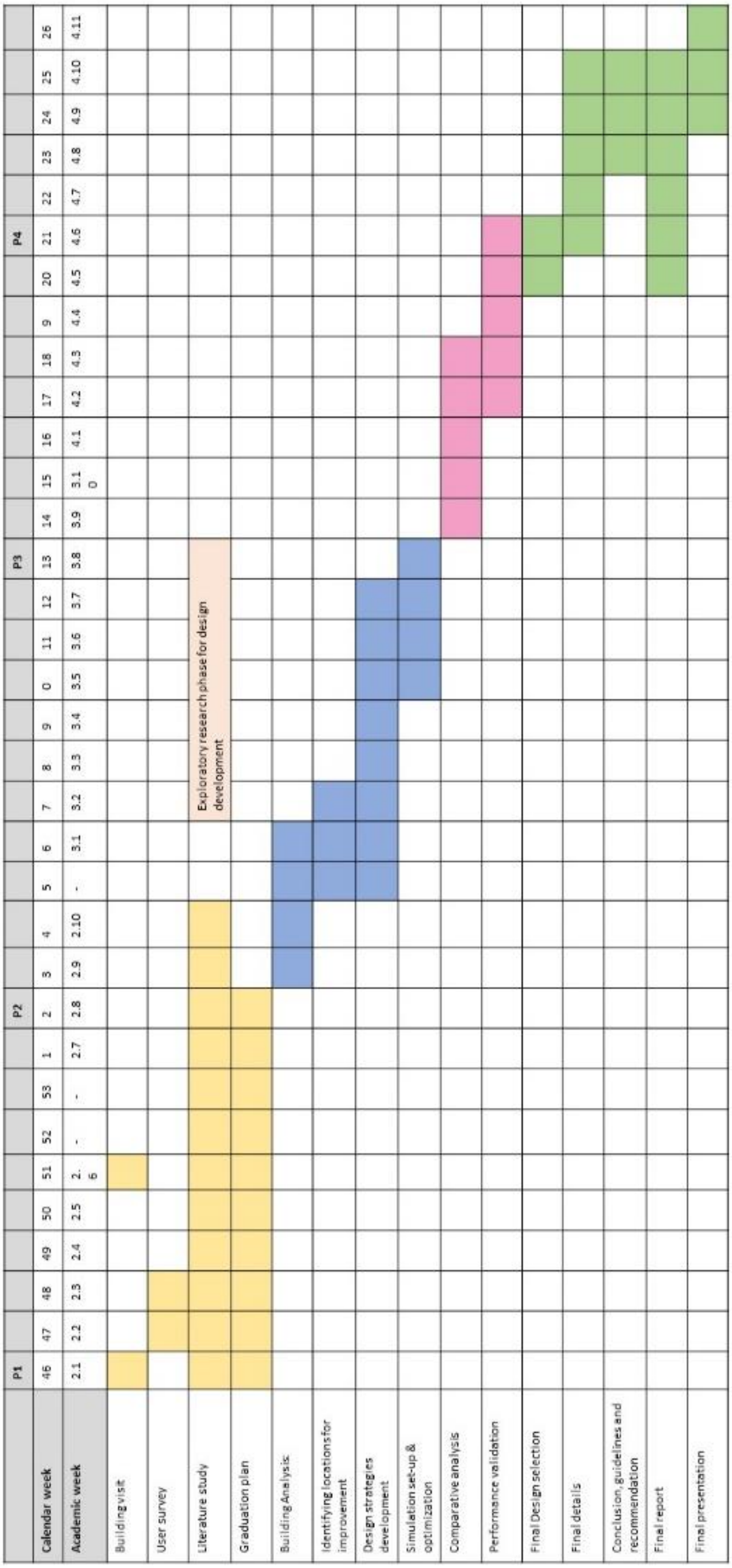
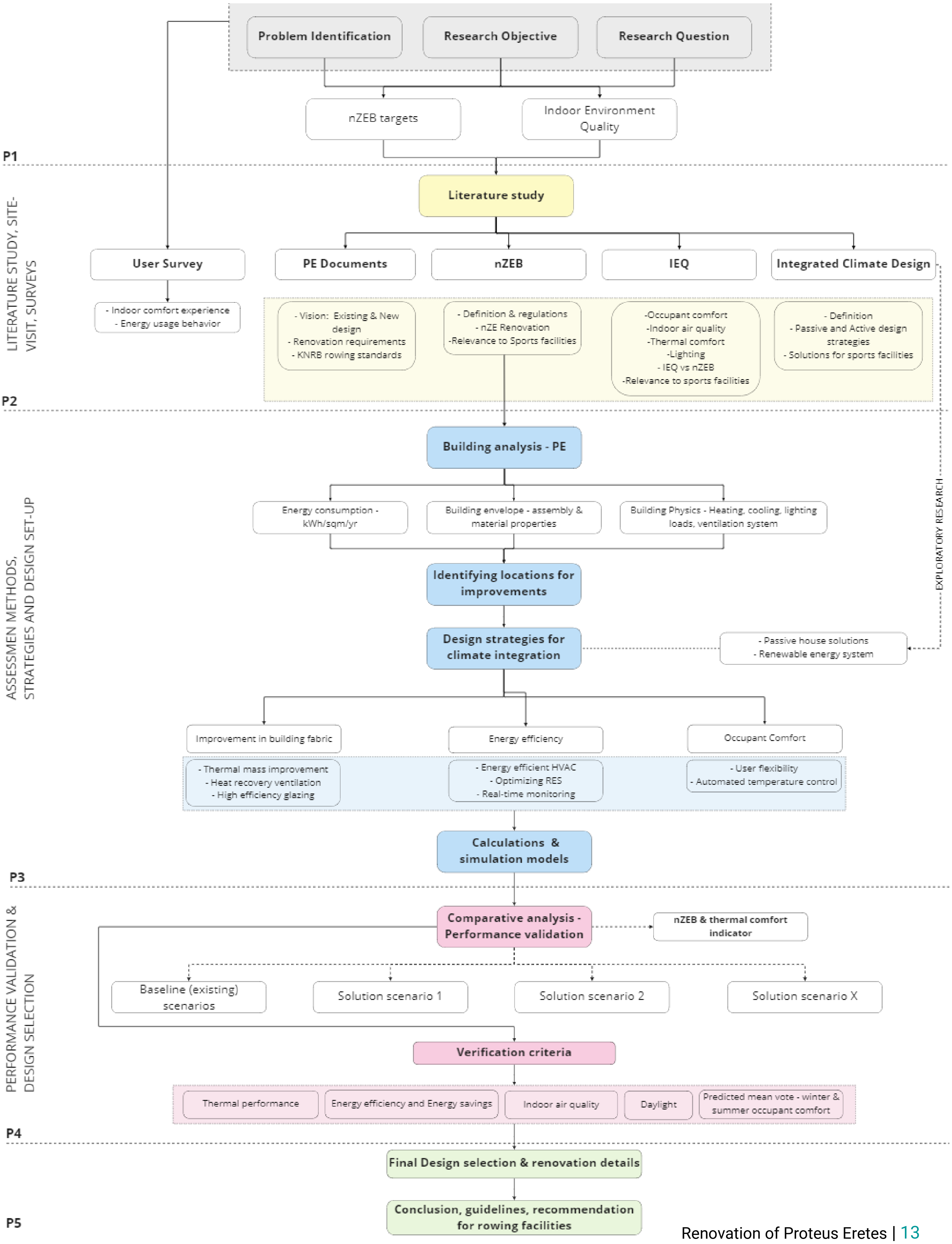


Figure 2 Methodology Flowchart with phase wise objectives



1.5 Societal relevance

The proposal for this real-life design problem should be able to represent itself as a strong business case serving a larger audience - a transition plan for the Dutch renovation industry that visions of sustainability and energy neutrality, especially sports facilities.

A large portion of society is becoming aware of high energy consumption and energy demands, including the energy of their buildings. This calls for attention to societal involvement in the transition of existing building stock towards nearly zero energy building. Not only energy is the issue, but human comfort and health are an integral part associated with the quality of building. This project includes interaction with individuals associated with the rowing club and other stakeholders that concern the building design. Therefore, the approach to propose design solutions for smooth energy transition of Proteus Eretes involves agreement and acceptability from the concerned individuals towards sustainable and healthy change.

1.6 Scientific relevance

At the core of this project lies intervention for better energy performance and indoor comfort that affects user flexibility. By exploring and applying scientifically verified climate design solutions that respond to energy neutrality and indoor quality, the proposal aims at bridging the gap between building's quality, use of energy and health of occupants. The emphasis is specially made on the energy-efficient design of sports accommodation which has not been thoroughly researched in the past. Therefore, the methodology that will be followed in this thesis delves deep into problem analysis from different perspectives focusing on nearly zero energy renovation and indoor quality in small scale sports buildings. The literature not only highlights theories for integrating climate design, but also technical complexity and reasoning. The main idea is to influence architects and building engineers to strategize solutions and follow such a design process for building renovation that is acceptable by the existing users and results in the long-term viability of the building.

2. LITERATURE REVIEW

2.1 Nearly Zero Energy Buildings (nZEB)

Scaling up and accelerating the decarbonisation of buildings is an urgent issue, not only because building emissions remain high despite current policies, but also because many buildings in the EU are of low quality, resulting in low living quality and high fuel costs. In EU's climate agreement 2019, the Netherlands determined to make a substantial contribution by emitting 49% less greenhouse gases (GHGs) in 2030 than in 1990, and 95% less by 2050 (Netherlands Enterprise Agency, 2020).

There is no single definition for nearly zero energy building, different organizations and policy makers define it in their own terms. However, the commonality in most definitions speaks of a high-performance building which has low energy demand and produces it's own energy. One of the main enablers of nZEBs is that it makes the building cost-effective, healthy and energy efficient. The Energy performance building directive describes requirements to which nZEBs should comply for both residential and non-residential sectors. In the Netherlands, building performance is measured by the Energy Performance Coefficient (EPC). Insulation levels (roof/walls/floor and window including frame) and installations (heating, cooling, hot water, ventilation, and lighting) are considered when calculating the EPC. Table 3 summarizes the EPC standards for both residential and non-residential buildings in the Netherlands. The EPC demand for residential structures has tightened over time, from 1.4 at the start in 1995 to 0.6 since January 2011. This requirement for the non-residential sector was expected to be reduced by 50% by 2017, when compared to the EPC criteria of 2007 (Gvozdenovic et al., 2015).

Table 1 EPC requirement for Dutch buildings developed before 2015, Source: (Gvozdenovic et al., 2015)

	EPC-demands			
	Current policy	Future policy		
		2015	2017 (1)(2)	2020
Residential buildings	0.6	0.4 (1)		≈ 0 (1) all buildings *"nearly Zero Energy Buildings"* Governmental buildings have to be nZEB in 2018
Offices	1.1		0.8 (1)	
Health, clinical	2.6		1.8 (1)	
Health, non-clinical	1.0		0.9 (1)	
Educational	1.3		0.7 (1)	
Retail	2.6		1.7 (1)	
Sports	1.8		0.9 (1)	

(1) According to the National Plan to promote nearly Zero Energy Buildings in the Netherlands
*(2) 50% decrease*d primary energy consumption compared to 2007 for governmental buildings

2.1.1 Nealy zero energy Renovation

Renovation of existing building renovations play an important role in obtaining an energy-neutral building stock. The annual replacement of existing stock is just 1–2%, which is why improving the energy performance of existing buildings is critical to meeting national energy efficiency and greenhouse gas emission targets (Kalamees et al., 2017).

The Long-Term Renovation Strategy explains how the Netherlands is putting climate change in the built environment into action. This strategy complies with the Energy Performance of Building Directives (EPBD) standards. It paints a clear picture of the wide range of policies and initiatives that the Netherlands is pursuing in order to attain a low-CO_2 built environment by 2050 (Netherlands Enterprise Agency, 2020).

If a renovation affects 25% or more of the surface area of the building envelope, it is considered substantial. Energy performance requirements then apply at the level of components of the envelope. Minimum Rc values of 6.0 m2K/W (roof), 4.5 m2K/W (façade), or 3.5 m2K/W (floor) are required, with a maximum U-value of 1.65 W/m2K for façade openings (Netherlands Enterprise Agency, 2020). A full restoration of an old structure using modern zero-energy building technology can achieve energy consumption ratings of 15 to 35 kWh/m2. If zero-energy building components or passive house components are used, the heating energy consumption can be decreased by 75% to 95% (Schulze Darup et al., 2015).

Table 2 Minimum requirements for building components for new buildings and major renovations, Source: (Korving & Wisman, 2021)

Minimum requirements for the thermal quality of the building envelope by 1 January 2015 for new buildings and major renovation (> 25% envelope).	
Roofs	R-value ≥ 6 m^2.K/W
Floors	R-value ≥ 3.5 m^2.K/W
Façades	R-value ≥ 4.5 m^2.K/W
Transparent façade sections	U-value < 65 W/m^2.K
Individual structure	U-value < 2.2 W/m^2.K

2.1.2 Requirements for Nearly zero energy building

The Netherlands follows the Trias Energetic strategy which describes that by minimizing building energy demands, the building should become minimal energy consumers. A more decentralized iteration is adapted to the Trias Energetica. Two steps are added which includes measure to improve local energy exchange and storage systems (smart grids), which are becoming increasingly critical for nZEB due to the intermittent nature of most renewable energy sources (Gvozdenovic et al., 2015).

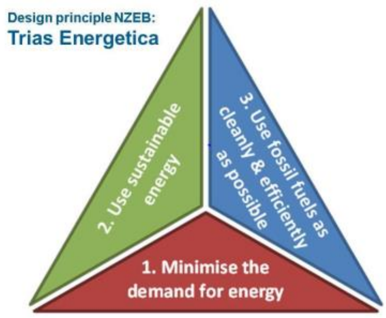


Figure 2. Trias Energetica.

Figure 3 Trias Energetica, Source: (Gvozdenovic et al., 2015)

1. Reduce energy demand by implementing energy-saving measures.
2. Use sustainable sources of energy.
3. *Take measures that improve (local) energy exchange.*
4. *Storage of renewable energy.*
5. Use fossil energy as efficient as possible

The nearly zero energy requirement followed in Netherlands are referred as the BENG guidelines (Almost Energy Neutral Buildings) formulated in 2012, which states the energy performance for residential or non-residential building is determined based on 3 criteria (RVO, 2020):

- BENG 1- Maximum energy needed (kWh/m2 per year)
- BENG 2- Maximum primary energy use (kWh/m2 per year)
- BENG 3- Minimum share of renewable energy (%)

BENG 1 – This takes in account heating and cooling demand of the building. This stage is achieved by ensuring airtight envelope, insulation level and high efficiency glazing, amount of window to wall ratio. These aspects must be dealt for both summer and winter performance of the building.

BENG 2 – Technical installation for indoor climate is considered in this criterion for most energy efficient installation for heating, cooling, ventilation, and hot water. In case, PV is used in the building, then energy generated is subtracted from the primary consumption. Use of gas boiler for heating is completely phased out to comply with BENG.

BENG 3 – The building design should take in account the amount of surface that can be used for installation of PV for solar energy generation. Other renewable energy sources like water powered heat pump, heat-cold storage (Aquifer thermal energy storage), solar boiler should also be explored (RVO, 2020).

2.1.3 Sports facilities towards nZEB

Across the Europe, energy actors have definite policy framework for renovation of existing housing or commercial buildings, however they still lack in providing adequate framework for sports facilities to become nearly zero energy (Weeth et al., 2015). The Netherlands has rich sports tradition accounting for 5.7 million sqm of sports buildings. Research performed by Nuon in 2014, collected data on energy consumption and financial situation of sports associations. It was noticed that due to high energy bills the financial position of sports organizations deteriorated. This energy is mainly affected due to ventilation and heating loads inside the sports buildings. According to this research, 12000 sports facilities consume annual consumption 228 million m^3 natural gas and 1 billion kWh electricity. The average energy consumption of a sports club is approx. 19,000 m^3 of natural gas and approximately 80,000 kWh of electricity. The annual energy bill is between € 10,000 and € 20,000 and constitutes 15-20% of the budget. Therefore, sports accommodation shows a good potential to reduce their energy consumption and target to become energy neutral. In recent years, more policy and budget incentives are being carried to make sports accommodations sustainable by improving their heating system, installing heat recovery ventilation and retrofitting envelope with efficient insultation values and glazing (Nederland Sportland, 2015).

2.2 Indoor environmental quality (IEQ)

The indoor environment plays an important role in occupant comfort and energy usage behaviour. This comfort is mainly dependent on four factors Indoor air quality, thermal comfort, daylight, and acoustics. In the context of building design, comfort is defined as a mental state that mirrors the physiological human condition of an experienced environment. Human comfort is subjective and based on the evolutionarily developed ability of humans to adapt themselves to changing environments and to adapt these environments to their needs (Looman, 2017). The occupant's acceptability of indoor environment directly affects the energy utilization inside the building. Hence, designing building for indoor environmental quality for occupants is very important.

Figure 4 Factors affecting indoor environmental quality, (Image: Own work)

2.2.1 Factors affecting IEQ

a. ***Indoor air quality*** is determined by the pollution or pollutants occupants are exposed to over time. Pollutants come from the outside air (the air that enters the building), are caused by the building itself and the heating and ventilation systems (if they are present), and are emitted by the occupants and their activities such as cooking, showering, cleaning, workout sweat, etc (Philomena M. Bluyssen, 2013). Inadequate ventilation can raise indoor pollutant levels by failing to bring in enough outside air to dilute emissions from interior sources and failing to transport indoor air pollutants out of the region. High temperatures and humidity levels can also raise pollution concentrations. The air contaminants are usually comprised of gaseous pollutants such as CO2, volatile organic compounds VOCs, odours and particulates. Bad indoor air can cause dizziness, irritation or even long-term respiratory and heart problems (Clancy, 2011).

Generally, building codes express requirements for IAQ in terms of minimum fresh air flow through a building in various ways (Rijksoverheid.nl, 2022):

- Air change per hour (ac/h)
- Air flow per unit of floor area (dm3/s-m2 or m3/h-m2)
- Air flow per person (dm3/s per person or m3/h-person)

For non-residential like office spaces or sports building, the minimum ventilation requirements differ because of occupancy schedule and functional usage. The following table highlights minimum ventilation requirement for spaces usually accommodated in sports building like rowing facility or a gym as per the Dutch Building Decree (2012). The minimum ventilation requirements for utility space such as kitchen is 21 dm3/s, toilet 7 dm3/s and shower with changing rooms is 14 dm3/s (Rijksoverheid.nl, 2022).

Table 3 Values for minimum ventilation requirement as mentioned in Building Decree 2012. (Table: Own work)

Space	Rp, Minimum Air flow per person (dm3/s per person)	Ra, Minimum Air flow per unit floor area (dm3/s-m2)
Fitness hall/ ergometer room	7	1.5
Restaurant/bars	4	0.9
Office spaces	2.5	0.3
Storage	-	0.6
Circulation	2.5	0.3

There are three methods to calculate the ventilation requirement:

- ASHRAE's equation for minimum outdoor airflow rate for breathing zone that takes in account minimum air flow per person and minimum airflow per unit floor area,

- $V_{bz} = R_p$ x people + R_a x Floor Area
- V_{bz} = outdoor air rate for Breathing Zone
- R_p = Air rate per person
- R_a = Air rate per square foot (or meter squared)

- Air change per hour method using volume of room and air change per hour, Quantity of airflow (m3/hr) = ACH * Volume
- Occupant activity level method that includes the metabolic rate of occupants performing an activity, number of occupants and outdoor CO2 concentration in parts per million.

The first method usually provides the least ventilation required to meet the base requirement, however the ventilation amount for good indoor air quality should consider activity level and occupancy hours.

a. Occupants frequently rank ***thermal comfort*** as one of the most critical requirements for any building. In assessments of building user satisfaction, it was discovered that having the "correct temperature" was one of the most essential factors. Additionally, air freshness is also considered as an important requirement. Even the subjective sensation of air freshness was discovered to be influenced by air temperature. As a result, temperature is intimately linked to two essential requirements of user comfort with the indoor environment (Al-Husinawi, 2017). Radiation, convection, and evaporation are three ways in which human body loses heat. An unpleasant sensation can distract individual from activity.

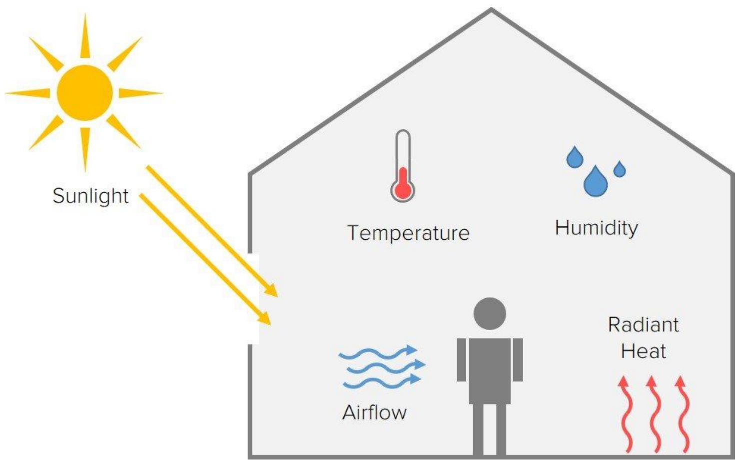


Figure 5 Factors affecting thermal comfort, Source: gruenecodesign.com

There are six factors affecting thermal comfort:

- Air temperature: by passive and mechanical heating -cooling, air temperature can be influenced.
- Mean radiant temperature: a room's weighted average temperature of all exposed surfaces The Relative Air Velocity increases as the temperature differential between the air and the exposed surfaces grows.
- Relative air velocity: the temperature felt due to wind on skin is air velocity.

- Humidity: the moisture content in air; if humidity is below 30% or above 70%, it may cause discomfort
- Activity levels: as per the type of activity, intense or not intense, the heating demand may differ
- Thermal resistance: this is affected by clothing or blankets used to feel warm and reduce the need of heating.

Thermal comfort is a significant factor affecting indoor air quality. This is also affected by the quality of construction. If there is air leakage around doors, windows, improper sealings, and the air can pass invariably if there is no insulation of ceiling, the movement of warm air upwards and heat losses; all disrupt the minimum requirement of thermal comfort factors.

There are certain methods used for evaluation of thermal comfort for a building:

i. **Fanger's model or static model**: Thermal comfort model according to Fanger's evaluates the climate of room based on Percentage of persons dissatisfied PPD and predicted mean vote PMV. Fanger's equation for PMV is based on heat balance of human being in his environment. PMV takes in account metabolic rate, clothing index, radiant temperature, relative humidity, air velocity and air temperature. The range of PMV lies between-3 (too cold) to +3 (too hot), with 0 representing neutral comfort condition experienced by the occupant (Schaudienst & Vogdt, 2017).

ii. **Adaptive comfort method:** This method considers naturally ventilated buildings unlike the Fanger's model. The outdoor running temperature which takes mean amount from previous along with natural ventilation affect the acceptability of occupants for comfortable thermal sensation. This method also includes the freedom to adjust clothing to maintain body temperature level.

iii. **ATG method:** The Dutch thermal comfort guideline follows the adaptive temperature limits ATG method. This is the third successful guideline after the Weighted temperature exceeding hours GTO method and Temperature Exceeding Hours TO method. In the Netherlands, most buildings combine operable windows with HVAC systems, passive façade ventilation systems, therefore correct comfort limits were hard to assign (Raue et al., 2006).

The GTO method was based on analytical model of PMV, which was widely accepted for years in the Netherlands after the TO. In the TO method, temperature of 25^{o}C may not be exceeded beyond 100hrs a year and temperature of 28^{o}C may not exceed beyond 10-20hrs a year. Since the TO method didn't account for the effect of thermal mass of the building, percentage dissatisfaction might not be correct, and therefore it was replaced by the GTO method. The hours in which the estimated or actual PMV exceeds the PMV-limit of +0.5 are weighted proportionally to the PPD. However, the GTO model only allows for 150 weighted hours for indoor comfort. Due to which ATG method was adopted in 2004, that has higher temperature range which communicates more clearly the relationship between indoor comfort and outdoor climate. More details of ATG are mentioned in ISSO 74 (Raue et al., 2006).

To determine comfort limits for operative temperatures based on different building types and distinct climates, two classifications are made Alpha and Beta, as shown in the flowchart. The Alpa/Beta type are based on the conditions of sealed building/operable windows, clothing adjustment, mechanical cool/no cooling, and temperature control.

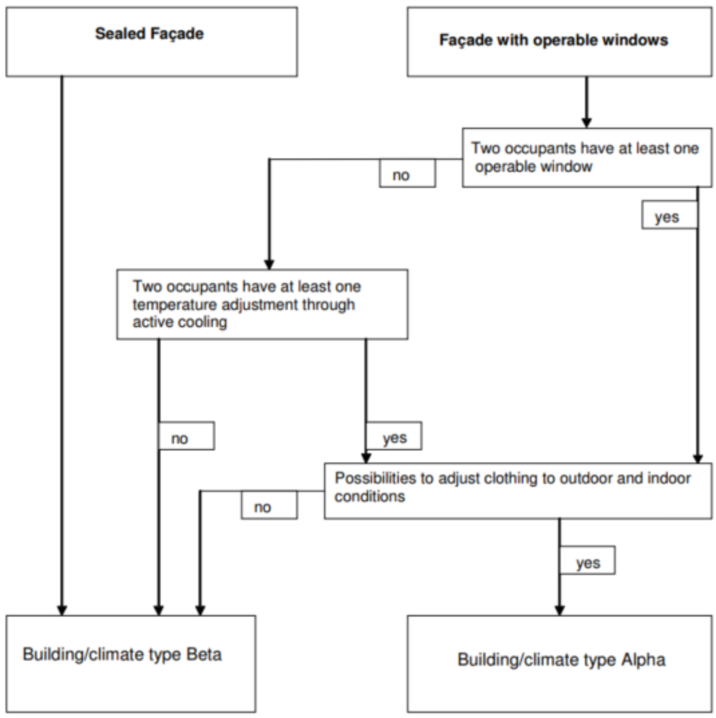


Figure 6 Diagram for determining type of building/climate Alpha or Beta. Source:(Raue et al., 2006)

Further included in ATG is the A/B/C/D classification that is currently used in the Netherlands for all new and renovation projects. This again is the measure for the expectation of thermal comfort in an old building, renovation or new built. In the Netherlands, class B is the most common thermal comfort level for renovation projects (Raue et al., 2006). The adaptive temperature limits for each classification are shown in the table below.

Table 4 Description of four classification levels. Source: (ISSO 74)

Class (bandwidth)	Requirements indoor operative temperature (°C)				Percentage Dissatisfied (%)	PMV analogy (bandwidth)
	Setpoint limit	Winter	In-between-seasons	Summer		
General	Setpoint line	21		24.5		
A	Upper limit	Same as class B (requires options available for occupant control with ± 2 K)			Max. 5%	-
	Lower limit	Same as class B (requires options available for occupant control with ± 2 K)				
B	Upper limit	24	18.8+0.33*T_{out}+1	Type β:26 Type α: 18.8+0.33*Tout+1	Max. 10%	-0.5 < PMV < +0.5
	Lower limit	20	20+0.2*(T_{out}-10)			
C	Upper limit	25	18.8+0.33*Tout+2	Type β:27 Type α: 18.8+0.33*Tout+2	Max.15%	-0.7 < PMV < +0.7
	Lower limit	19	19+0.2*(T_{out}-10)			
D	Upper limit	26	18.8+0.33*Tout+3	Type β:28 Type α: 18.8+0.33*Tout+3	Max. 25%	-1.0 < PMV < +1.0
	Lower limit	18	18+0.2*(T_{out}-10)			

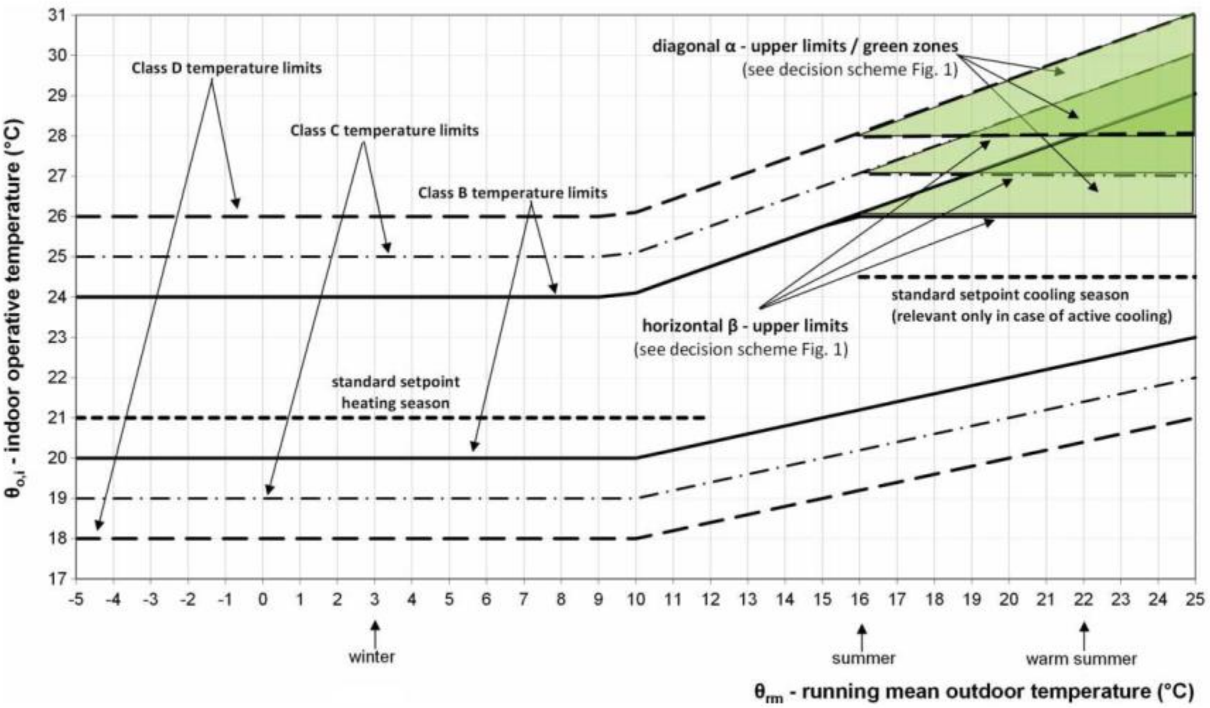


Figure 7 Adaptive Temperature Limits (ATG) chart. Source: (Raue et al., 2006)

b. In addition to thermal comfort and indoor air quality, ***daylight*** needs to be considered as well for psychological and visual comfort. Enough amount of natural light has a positive effect on individual performance and satisfaction. Using enough natural light during the day ensures reduction of lighting load which might occur if a space is dull or dark making the users to switch on artificial light in their space of work. To improve daylight in a building, it is important to consider visual light transmittance of glazing and the sizing (Bluyssen, 2009).

c. Indoor environment quality also includes ***acoustics*** as one of the parameters to assess occupant comfort. Building acoustics are affected by use of machinery, building services like HVAC system or occupant activities. Therefore, in order to keep controlled noise, the quality of building materials play a role in proper absorption of unwanted sound (Bluyssen, 2009).

2.2.2 Indoor comfort in Sports buildings

Indoor environmental quality has a special meaning in workplaces specially because it affects human health and comfort. Spaces associated with sports also need to be carefully design and installed with heating and ventilation system to maintain comfortable temperature and fresh air supply. The book on sports facilities and technologies written by Peter Culley and John Pascoe (2019), covers a range of discussion on the design, built environment and management of sports facilities including rowing clubs. The goal of sports facilities is to provide not just comfortable conditions for sportsmen, but also conditions that improve performance of athletes.

The variables of IEQ, are of special relevance in sports facilities, not only because physical activity challenges microclimate perception, but also because athletes have higher expectations for a healthy environment in which to practice their sport. As explained in the classification for thermal comfort, it is the measure of operative temperature experience by the occupants in a space to feel comfortable or not. Operative temperature is the average of mean radiant and ambient air temperature. Two other factors that affect thermal comfort are human's metabolic rate and clothing condition. Metabolic rate is the amount of heat produced by human body during an activity performed. And, clothing level of an individual is affected by on indoor climate, weather condition and type of activity performed. To understand this relationship, CBE Thermal comfort tool can be used for a set operative temperature required in a room for summers and winters conditions to classify thermal comfort category (complying with EN-16798).

Recreational room: For summer condition, the metabolic rate is set to 1.2 and clothing value of 0.5, the operative temperature is 28°C, with air speed 0.5m/s in case natural ventilation is present. The PPD is 11% which comes under Class C category of thermal comfort, an acceptable condition. While in winters, the clothing value increases to 1.2 considering people would wear sweaters or higher insulating clothing, operative temperature of 19°C, air speed provided no natural ventilation is 0.1m/s. This results in PPD of only 8%, hence a category of Class B.

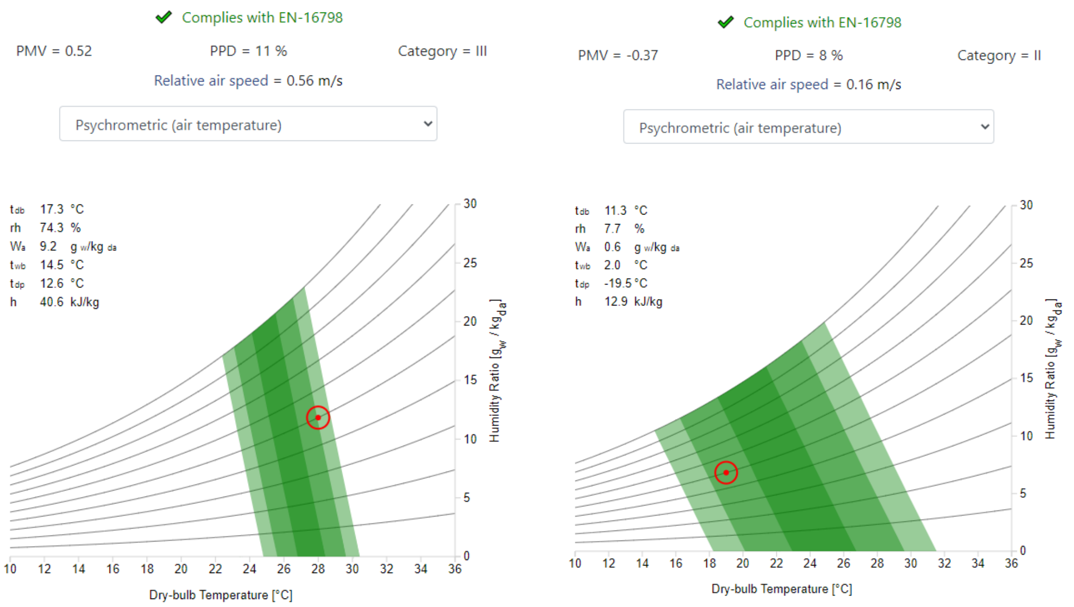


Figure 8 Thermal comfort in summer and winter for recreational room. Source: (Berkeley, n.d.)

In ideal situation for fitness rooms, the metabolic rate is 4 (heavy physical work) and clothing level 0.36 (light shorts and short sleeves) in summers with the operative temperature setting to 18°C and air speed to 0.3 m/s (allowing natural ventilation). The PPD results in 9% which is acceptable. Whereas for winters, the clothing level may increase to 0.74 (sweatpants, long-sleeve t-shirts), operative temperature of 13.5 °C, without any natural ventilation. This results to a comfortable condition with PPD of only 10% .

The renovation design goal should be achieved by predefine comfort temperature limits of a space and further optimization on temperature control points, heating, and cooling setbacks.

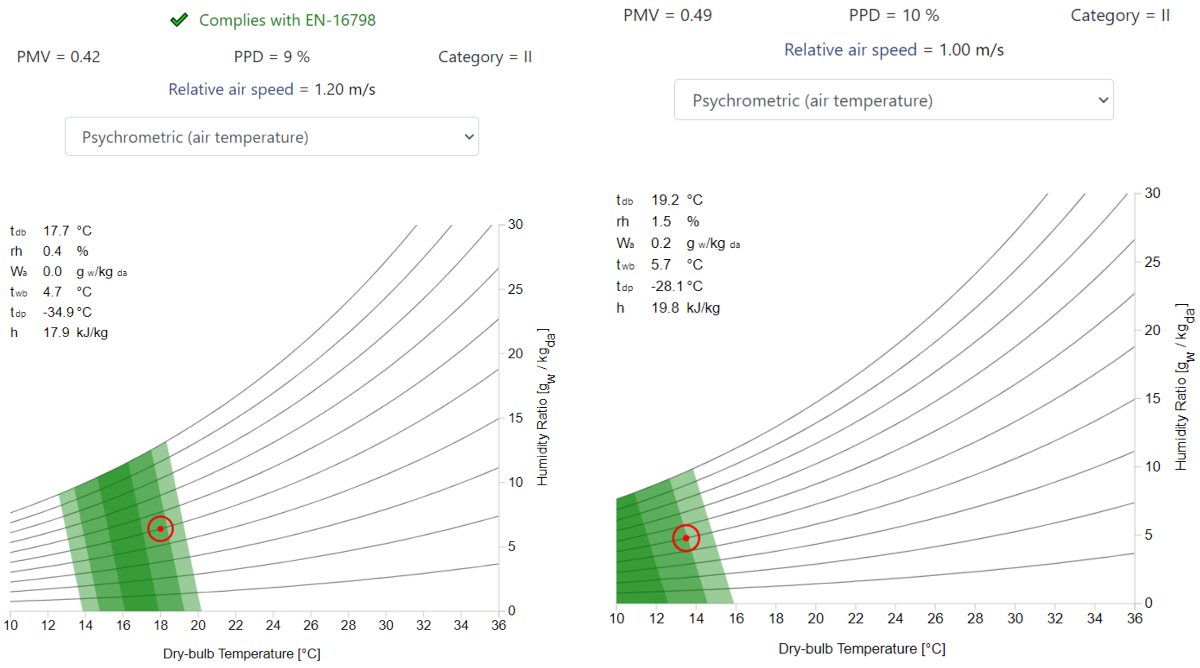


Figure 9 Thermal comfort for summer (left) and winter (right) in fitness room. Source: (Berkeley, n.d.)

2.3 Relation between nZEB and IEQ

Heat gains or losses through various structural elements such as walls, windows, and floors, internal heat loads, and rate of ventilation are the key factors defining a building's thermal performance. In turn the thermal response determines the quantity of energy required for heating and cooling to maintain optimal thermal comfort conditions for inhabitants. The interaction of numerous connected energy systems that continuously adjust to changing climatic circumstances and occupant comfort requirements can be seen as the way a building uses energy in general. These basic energy systems should be determined during building design as they have a direct impact on a building's energy efficiency (Aye et al., 2005).

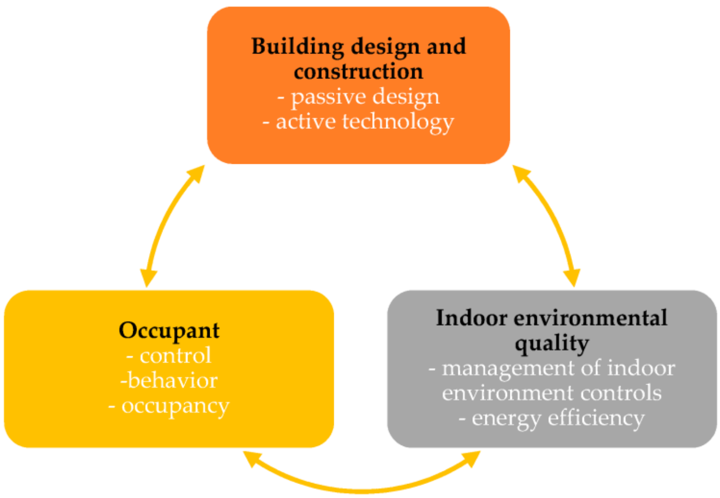


Figure 10 Relation between Building design, IEQ and occupants. Source: mdpi

A poor indoor environmental quality results in sick building syndrome i.e. a building that consumes lot of energy to provide comfortable environment to the users. Hence, designing for nearly zero energy building takes mark from setting goals for indoor environmental quality and occupant comfort.

2.4 Integrated climate design strategies

A green building is one that "uses a careful integrated design strategy that minimises energy use, maximises daylight, has a high degree of indoor air quality and thermal comfort, conserves water, reuses materials and uses materials with recycled content, minimises site disruptions, and generally provides a high degree of occupant comfort" (Miller & Buys, 2008).

The issue of creating comfortable and healthy interior environments while also reducing building energy demand necessitates innovative solutions that draws on existing knowledge and best practices (Looman, 2017). Today many new technologies for heating system, ventilation have developed and new techniques, materials are always under way to control indoor climate while reducing energy consumption.

The idea behind integrated climate systems in building is their relative simplicity and adaptability, and therefore possibility to create sustainable environment, especially in situations of existing buildings where centralized system have not been built, and there is shortage of space to integrate, where new building parts or high comfort related flows (ventilation, warmth, cold, electricity, etc) are desired (Van Timmeren, 2009). Therefore, the key to suffice the issues related to energy and comfort in a single potential design solution is by integrating climate responsive building elements with passive energy strategies and active sustainable building systems to control indoor climate (Looman, 2007).

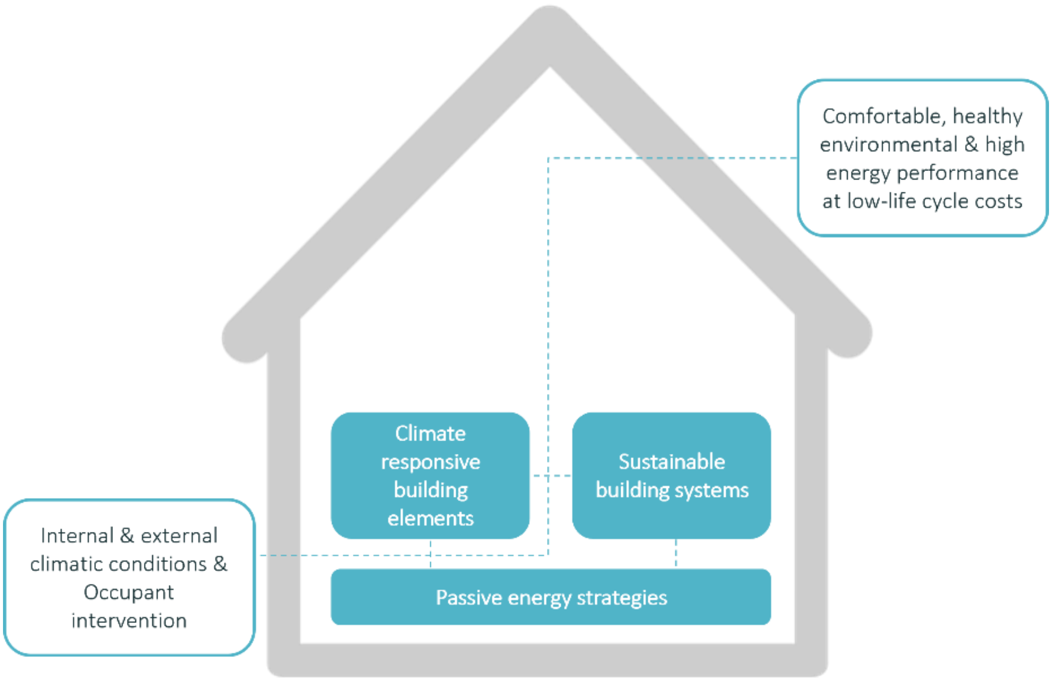


Figure 11 Integrated climate design concept, Source: (Looman, 2007)

For a building to reach net zero energy consumption over the course of a year, the total renewable energy generation of the building must either exceed, or at least be comparable to the total final energy of the facility. To reduce heating and cooling energy, low-energy buildings often use high levels of insulation, energy-efficient windows, low levels of air infiltration, and heat recovery ventilation. They may also use active solar technologies or passive building design strategies (Kang et al., 2015).

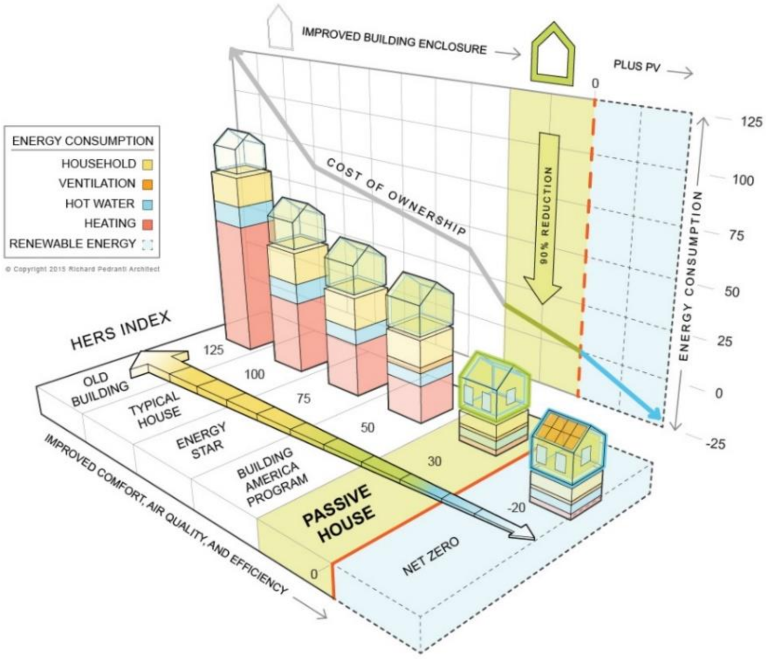


Figure 12 Passive house graph for NZEB & IEQ, Source: Richard Pedranti Architect, PC

While passive design measures include building orientation, air sealing, continuous insulation, windows, and daylighting, and designing a building to take advantage of nature, active technologies involve heating, cooling, and energy generation systems (Kang et al., 2015).

2.4.1 Passive Strategies

Passive building design considers building geometry, orientation, natural lighting and ventilation in the beginning of construction in order to improve 20% energy efficiency, 25% heating, and 10-30% cooling load reduction (Oh & Hong, 2017). However, in renovation projects changing building geometry or orientation is not possible every time, rather refurbishment of building envelope, thermal mass for heat storage and lighting improvement are feasible to increase energy savings and comfort.

a. Façade strategy

Façade thermal performance can be improved in many ways. Typology of façade assembly and insulation strategies can impact heat loss or heat fain. Transmission heat loss through the building envelope (heat conduction through building components) and ventilation heat loss are the two types of heat loss from the building (heat convection through openings and leaks in the building envelope). By adding insulation or reducing thermal bridges, transmission heat loss can be overcome which other wise account for 60-80% heat loss in an old construction.

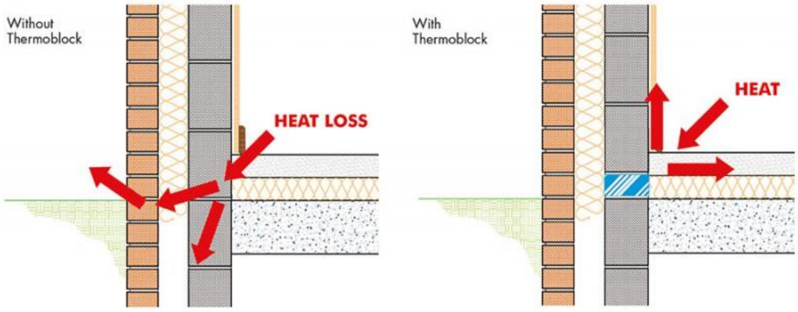


Figure 13 Thermal bridge. Source: (Marmox, n.d.)

A solar wall or ventilated double skin façade is efficient in summers and winters to reduce energy loads and allow desirable comfort level for indoors. This is a combination of single glazing outer unit and double-glazing inner unit with air cavity. There are air inlets provided in the outer skin which allows natural air to travel within the cavity due to stack effect. In summers, this removes solar gains and during winters the air temperature inside the cavity is raised to avoid heat loss. Additionally, blinds within the cavity can further improve the energy balance and comfort levels for both climatic conditions. It is important to consider the cavity gap to design such a system to work efficiently (Kilaire & Stacey, 2017).

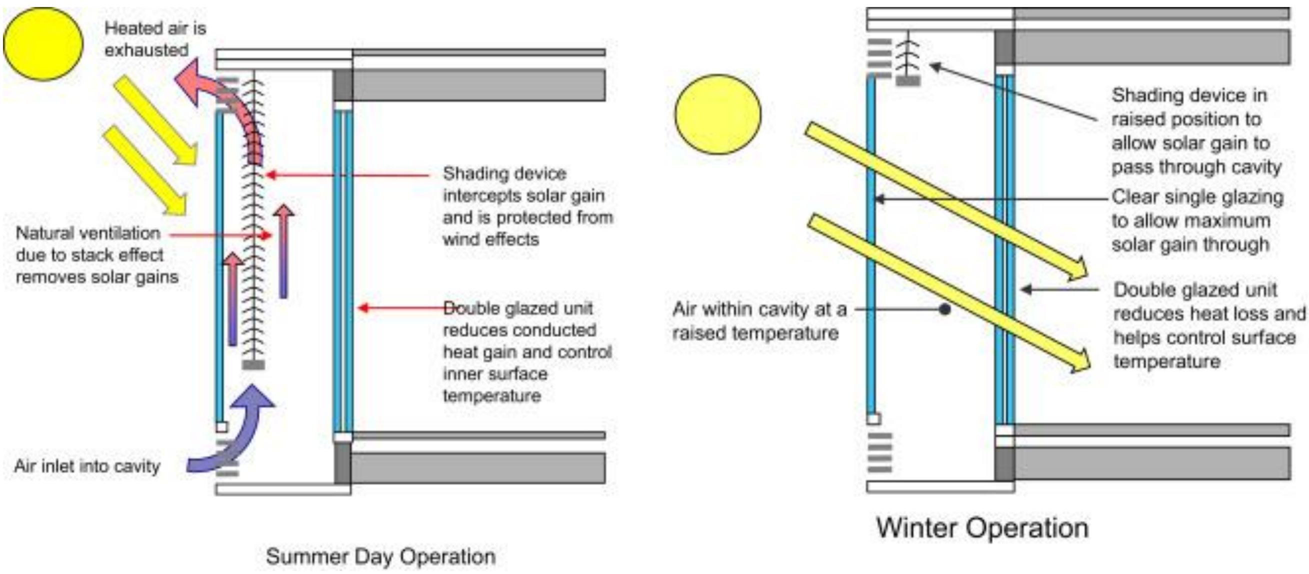


Figure 14 Ventilation double skin facade. Source: (Kilaire & Stacey, 2017)

Adding internal or external insulation layers to improve thermal performance is quite frequently used in renovation projects. However, it is advantageous to replace the façade for the most energy-efficient performance. Although this tactic takes a significant initial expenditure, it pays off in the long run. The cost estimate and impact to inhabitant can guides in choosing the best method (Konstantinou, 2014).

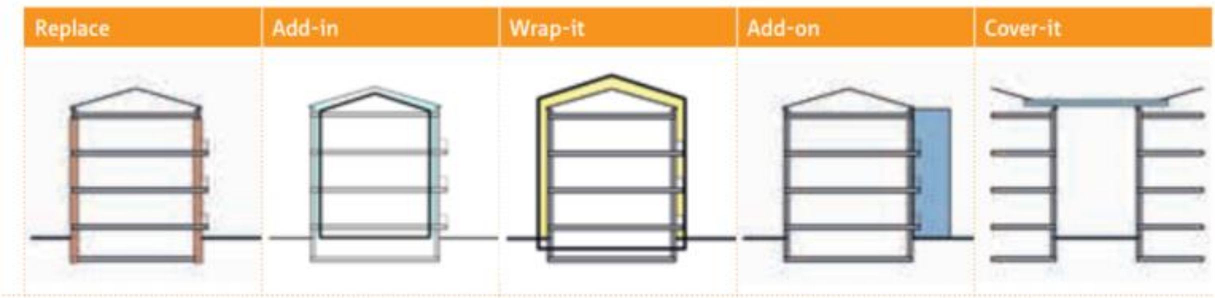


Figure 15 Various type of interventions for facade refurbishment. Source: (Konstantinou, 2014)

b. Window Glazing

Windows let in as much light as possible without generating glare, while heat gain should be kept to a minimum in the summer and maximized in the winter. To balance the flows of heat and natural light, proper dimensions, orientation, and glazing are required. These grading systems necessitate high-quality design to provide improved sunshine, vistas, comfort, ventilation, and energy efficiency, all of which are closely tied to fenestration systems.

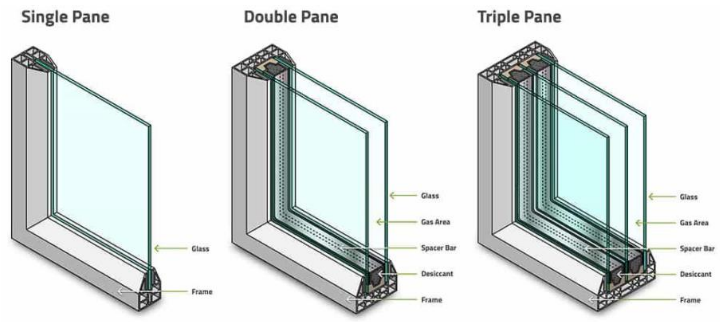


Figure 16 Multi-paned window. Source: (Brennancorp, n.d.)

The U value, solar energy transmittance (g-value), and light transmittance (LT) value of windows influence a building's energy consumption. Single glazing has a U value of 5.8 W/(m²K). In such a case more heat is lost through the window compared with solar gain: the overall balance is a clear loss of energy. Use of ordinary double glazing with a U value of 2.8 W/(m²K) improves the balance by reducing the amount of heating needed. Changing the glazing panes from higher U value to lower U value reduces the green house gas emissions (CO_2) during the product manufacturing. Further, using low-e coated double glazing, the balance is positive as seen in figure. Higher insulation can be achieved with triple glazing panes with U value almost 0.7 W/m2K (AGC, n.d.).

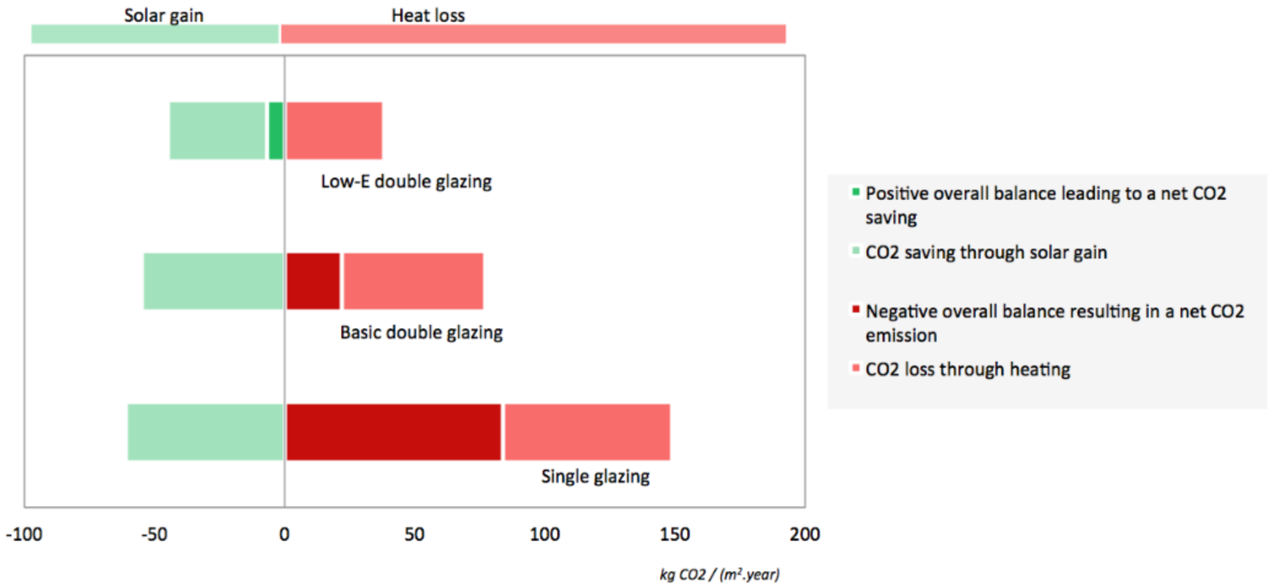


Figure 17 CO2 balance comparison between single glazing (lower bar), basic double glazing (middle bar), and low-e double glazing (upper bar). Source: (AGC, n.d.)

c. Natural ventilation

Openings are essential for natural ventilation. Refurbishment of building envelope must consider possible changes in position of openable windows or ventilation grills. The orientation and position of an opening can allow natural cross ventilation, keeping a pleasant environment for occupants. Specially, convective air movement or stack ventilation is a solution where because of air temperature difference, the warm air being more buoyant rises to escape through higher opening position, drawing in cooler air from lower openings.

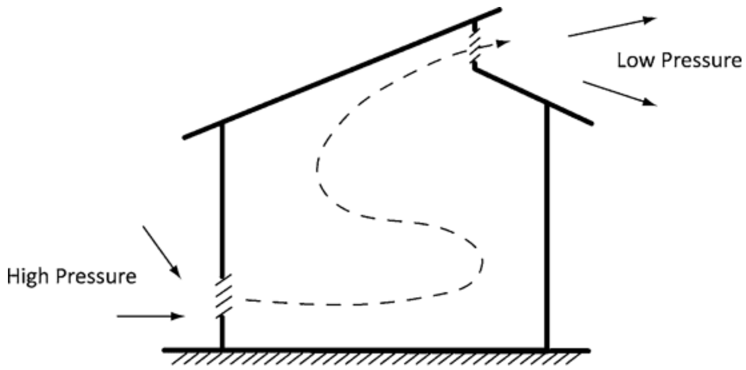


Figure 18 Stack Ventilation. Source:(Civilconstrcutiontips.com, 2017)

2.4.2 Active strategies:

Active strategies usually consist of heating, cooling, and ventilations systems and technologies to accommodate energy requirements. Solar electric and solar thermal panels, wind turbines, and geothermal energy exchangers are also examples of active techniques that generate energy.

a. Heating systems

The Netherlands is an extensive user of natural gas for heating. Out of overall energy consumption in the Netherlands, 38% goes to space heating and domestic hot water supply. Around 89% of Dutch houses use central heating system using gas-fired boiler. In response to the recent climate act to reduce CO2 emissions by 95% over 30 years, gas network should be replaced by electric network. Not only the CO2 emissions are high due to gas but also the rising cost (Van den Ende, 2017).

Efficient alternative to gas boiler is electric heat pumps that are environmentally friendly and use renewable energy from air, water or ground by changing the temperature of the natural heat flow from a lower to a higher usable temperature. In fact, extra energy from processes or exhaust air from buildings can also be a source for heat pump. As reported by the European Heat Pump Association in 2018, installation of heat pumps across Europe has generated 116 Terra-Watt-hour of energy while lowering the carbon emissions by 29.8 Million tonnes (Nowak, 2018).

The thermodynamic cycle for heat pump functioning includes an evaporator (liquid to gas heat exchanger), compressor, condenser (gas to liquid heat exchanger), expansion valve and a transfer fluid. The figure shows the vapour compression cycle providing heating and cooling at the same time.

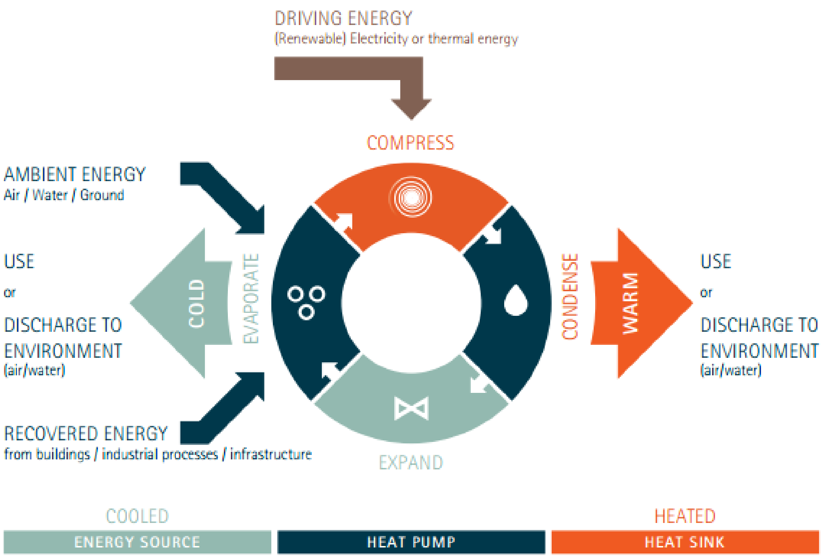


Figure 19 Vapour compression cycle of heat pump. Source:(Nowak, 2018)

Depending on the source of heat pump and favourable temperature levels, the coefficient of performance also differs. It is ideal to aim for low temperature heating and high temperature cooling such as underfloor heating system or low temperature radiators for best performance of heat pumps (Dobbelsteen et al., 2021).

Low temperature radiators work very well in sufficiently insulated buildings using 30% less energy than traditional radiators. Low-temperature radiators are typically equipped with a copper battery that heats the air that circulates around them. It also blows hot air out of the grills on the tops of these devices. Convection accounts for 80% of heat transfer in traditional radiators, whereas radiation accounts for 20%. Low-temperature radiators, on the other hand, rely entirely on convection to generate heat. They use temperature between 30-55ºC for water heating much less compared to regular radiators. A healthier indoor climate is achieved with low temperature radiators because of even distribution of heat in the space and less powerful air flows (Arceclima, 2017).

b. Cooling system

In Netherlands, it is not a requirement to install air conditioning system or air handling units in residential building or small-scale buildings. However, during summers in recent years with global rising temperature, the cooling demand has also increased in Dutch buildings. To achieve cooling in compact buildings without the expense of air conditioning units, the ideal way is to improve the natural ventilation via passive cooling strategies in building envelope. The major requirement is wind flow, buoyancy, appropriate air inlets and outlets. Natural ventilation adds to enhanced thermal comfort, having direct cooling effect on human body. Eventually, reducing the active cooling demand (Nicol et al., 2012).

c. Ventilation system

In Netherlands, the air supply of residential buildings is a hybrid system of natural supply with mechanical extract ventilation (MEV) for toilets, bathrooms, and kitchen. While for non-residential, usually balanced systems with mechanical exhaust and supply are installed. These balanced systems can be made more energy efficient with addition of heat recovery unit (Dobbelsteen et al., 2021).

Ventilation heat loss can be reduced by 90% with means of heat recovery. Ventilation heat loss ranges from 40 to more than 50 kWh/m2 (calculated values) and can be reduced to around 5 kWh/m2 with heat recovery ventilation systems (Schulze Darup et al., 2015). HRVs (heat recovery ventilators) and ERV (energy recovery ventilator) systems transfer heat or coolness from stale exhaust air to new intake air. The system continuously extracts moist, stale air from wet rooms (kitchens, baths, and utility rooms) and replaces it with fresh, filtered air in habitable spaces (bedrooms, living rooms, and dining rooms). HRV takes in account larger temperature difference between indoors and outdoor. In summers, it precools the outdoor air reducing the cooling demand while in winters it preheats the outdoor air reducing the space heating load.

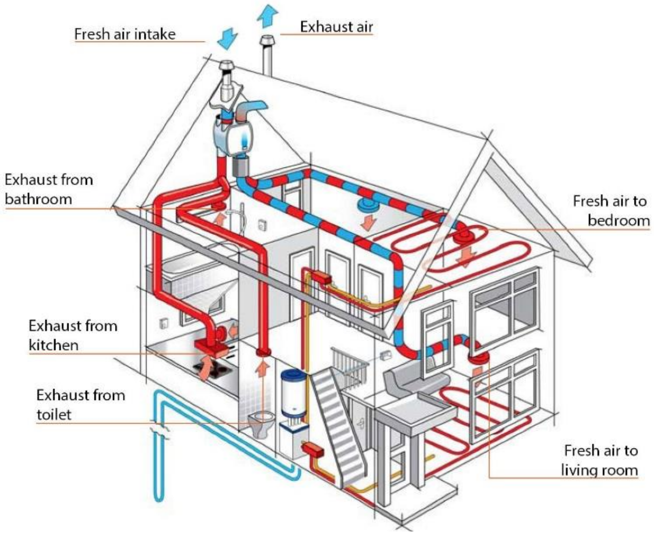


Figure 20 Ventilation with heat recovery in a dwelling, Source: (Customradiant.com, n.d.)

Two types of ventilation system can be installed in building as per space and requirements. ***Decentralised systems*** are small units with heat recovery that can be installed in rooms without ducts. These are quite ideal for renovation or retrofit as it can be installed through wall or ceiling cavity. It solves immediate climate issues in room specific problems such as mould or condensation in bathroom or kitchen. The heat recovery efficiency up to 92% and it is also cost-effective.

On the other hand, ***centralised ventilation system*** has ducting connected to single heat recovery unit. These are efficient for large volume with more heat recovery and better ventilation capacity. The heat recovery efficiency is up to 98%.

Figure 21 Decentralized heat recovery unit (left) and Centralised heat recovery unit (right). Source: (Ventiland, n.d.)

Ventilation airflow and energy savings in building can be improved by ***demand control system*** added to heat recovery ventilation. In demand control ventilation, the airflow is adjusted according to number of occupants with the aim of reducing fan energy consumption. The sensors respond to air pollutants inside a room thus increasing or decreasing the outdoor air flow rate. HRV enhances the energy saving of demand control when airflow is reduced. On the other hand, it helps compensate the extra ventilation cost when airflow is increased. As a result, optimal airflow rates and energy efficiency are ensured (AdvancedControlSolution, n.d.).

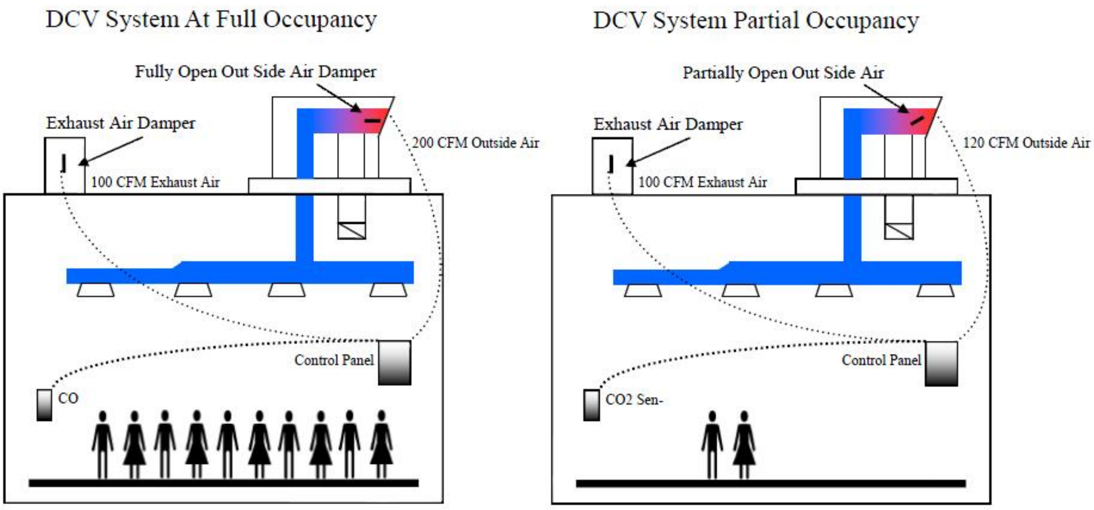


Figure 22 Demand Control Ventilation. Source: (AdvancedControlSolution, n.d.)

d. Photovoltaic panels as renewable energy source

The energy consumption in a building can further be reduced nearly to 100% if in-house generation of energy is made possible. The energy can be obtained from renewable resources like sunlight, geothermal, and wind. PV solar energy is non-polluting, has no moving parts that could fail, requires no maintenance and no supervision, and has a 20-30-year life cycle with low operating expenses. It is vital to prioritize supply over energy requirements when utilizing solar energy in sports halls and sports facilities. Even though the installed system has a certain quantity of energy to give, it should not be used to specify the amount of energy that the system will deliver. After installation, various factors such as shade, the location of the building, the tilt of the system, and how much sun it receives during the year can all affect the system's energy production (Hegger, 2008).

e. Source of heat pump also acting as renewable energy:

Addition to solar panel as renewable source, on site energy, there are more ways to approach for nearly zero energy refurbishment. The source for heat pump system as mentioned earlier, is renewable energy from air, water or ground.

- *Air source heat pumps (ASHP)* uses outside, indoor or exhaust air which is compressed in the pump and released at high temperature inside the building.
- *Ground source heat pump (GSHP)* uses transfer fluid (brine or water) which is extracted from ground via a closed loop horizontal or vertical collector. This heat of fluid is absorbed, compressed, and released at high temperature inside the building.
- *Water source heat pump (WSHP)* use water directly in open loop. Aquifers, rivers, lakes, and the sea, as well as wastewater, cooling water from industrial systems, and a district heating system, can all be used to power WSHP (Nowak, 2018).

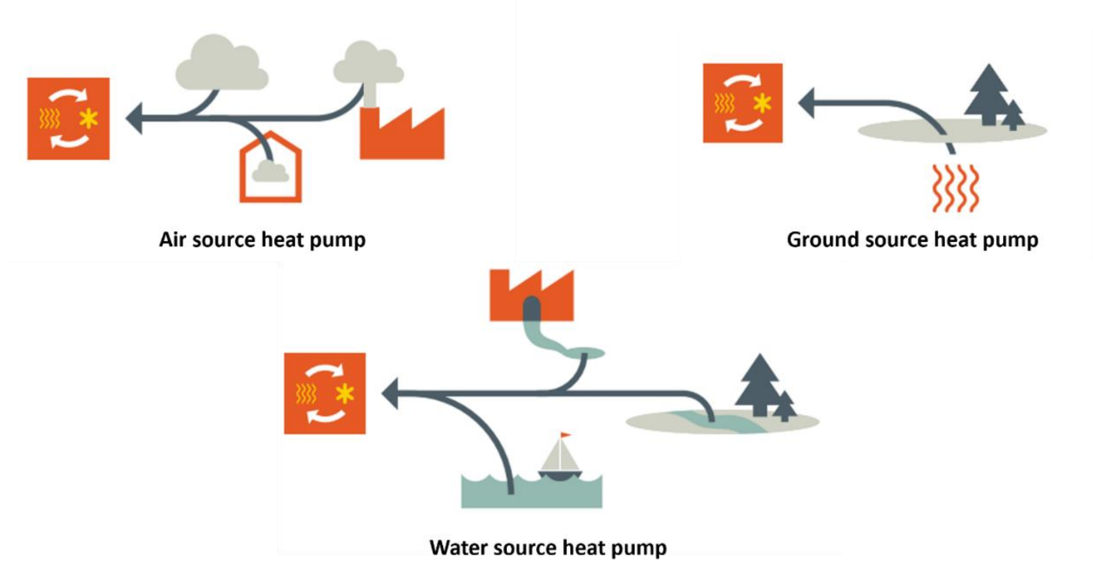


Figure 23 Source of heat pump. Source: (Nowak, 2018)

f. Automated control systems:

Another one of active strategies used in new buildings mostly, building automation systems. The computer networking of electrical devices meant to monitor and operate the HVAC, indoor air quality, temperature, fire & safety, lighting, humidity, and audio-visual control systems within a building is referred to as building automation. These smart technologies that can inspect indoor environment based on real time that can be helpful to understand building energy consumption.

2.4.3 Summary

An integrate climate design system focusses on the active and passive strategies. In many sports facilities, energy and comfort issues are not seen together making the energy consumption high to meet optimal comfort requirements. Hence, excellent heat protection, excellent airtightness, and extremely effective heat recovery from waste air are all essential properties that can be used in retrofit of existing buildings including sports complexes of lower scale. Without compromising indoor environment, combination of thermal mass improvement and energy generating technologies show large potential to reduce building's energy use, efficiency, and reduced CO_2 emissions.

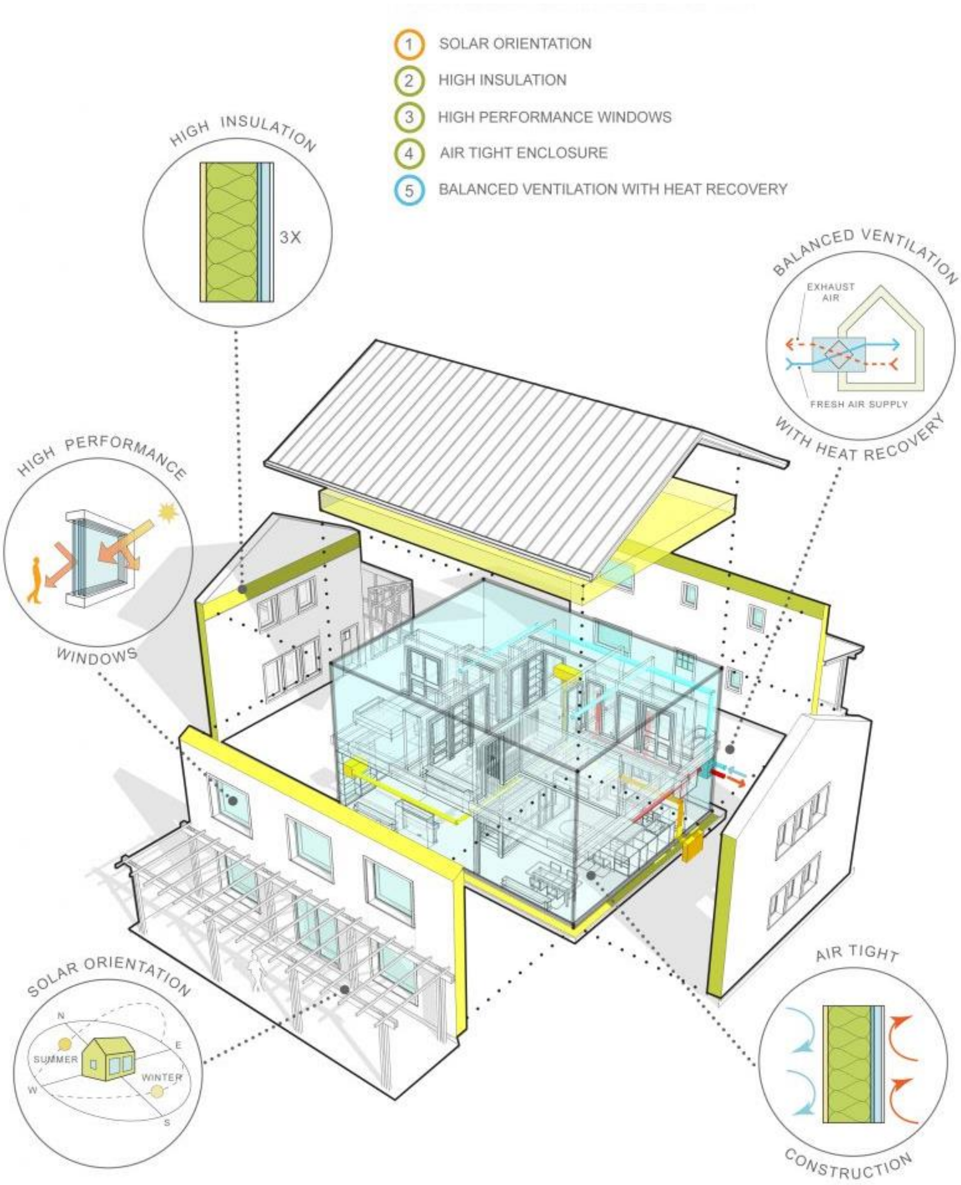


Figure 24 Passive house principles, Source: (Fieldgreendesign.com, n.d.)

2.5 Energy transition of Rowing facilities

With all the water surroundings in the Netherlands, the love for rowing is no wonder. The Dutch are pretty good rowers, following this sport as their speciality or as a recreational activity. There are about 121 rowing facilities in the country, while this number is ever increasing. The Koninklijke Nederlandsche Roeibond (KNRB) handbook describes practical and technical standards to be followed for the construction or renovation of rowing facility in congruence with the factors affecting sustainability. According to the handbook, sustainable design of a rowing accommodation points at five recurring themes: Energy, Environment, Health, Quality of use, Future value. Energy savings and lowering CO_2 emissions are an integral part of the architecture which can be simply achieved by proper sustainable planning, installations, insulation, and in-house energy generation. The KNRB manual also pours light on the 'Trias Energetica' concept as adopted all over the Netherlands for the energy transition map.

The KNRB manual has laid down guidelines as per the functionality of required spaces for rowing accommodations in Netherlands which comply with Building Decree (2012). Minimum room specifications, materials, furniture, electrical installations, lighting, ventilation, and heating requirements are mentioned. The following table mentions minimum requirement for indoor environment of spaces in rowing club.

Table 5 Minimum requirement for certain factors of indoor climate as per KNRB

	Office	**Ergometer/fitness**	**Changing-shower**
Temperature	20-23 ^{O}C	17-20 ^{O}C	
Lighting	At least 150 lux	At least 150 lux	At least 150 lux
Ventilation (ac/h)	Min. 2 ac/h	Min. 4 ac/h	Min. 10 ac/h
Airflow rate (m3/hr)	Based on requirement	Based on requirement	Min. 25 m3/h
Airspeed	Max 0.1 m/s	Max 0.2 m/s	Max 0.2 m/s

With energy consumption of more than 38000 kWh and gas consumption of 5010 m^3 during the latest pandemic year when the association remained mostly closed, it was realised to plan renovation of Proteus Eretes. Therefore, sustainability and building resilience of the rowing facility as renown DSR Proteus Eretes became of important value.

3. CASE ANALYSIS – D.S.R PROTEUS ERETES

3.1 History

DSR Proteus Eretes is the largest student rowing association in the Netherlands which was established in 1970. The fleet of 100 boats and the members count that is beyond 850, the association is ever growing and glowing with its achievements. Proteus-Eretes has about 60 race rowers who train to reach world-class levels of rowing and compete at a high level right away. Five members competed in the 2012 Summer Olympics, with two of them taking bronze in the women's eight team. The remaining members are more recreational rowers who can compete in a competitive setting. Almost every weekend during the season, they can participate in competitions.

3.2 Architectural context

In 1997, the Rowing Association opened its doors in the new "De Beuk" association building. A structure that was constructed following significant investigation about the association's wishes. The big warehouse, which had previously been owned by Praxis, as well as the large property on Rotterdamseweg, close to the Kruithuisbrug, presented a perfect location for the construction of a new association building. The architect Gunnar Daan was commissioned to design the building that incorporated the requirements of that time into the current structure: "De Beuk" (the beech, named on a tree).

Figure 25 De Beuk under construction, November 1996. Source: (ProteusEretes, n.d.)

There were approximately 350 members when the construction of de Beuk took place. The idea was to design the building for growth. After 18 years now, the shed and the raft still offer the space required by Proteus-Eretes however, the association number are going to cross 1000 as of 2021, which is leading to insufficient facilities that the building has to offer (Hadriani, 2021). Moreover, the building situation is very outdated in comparison to current architectural and energy regulations. The energy consumption is also high because the building envelope and present systems are unable to keep control of indoor climate.

Figure 26 Proteus Eretes Event, Source: (ProteusEretes, n.d.)

Because of the increasing association, professionalization, and changing climate study, it is necessary to inventory the association's wishes and evaluate the possibility of a renovation. The vision laid down by the Proteus-Eretes, thus, includes good workspace, inclusion of innovative rowing features, and addressing themes of sustainability as it reflects paramount importance (Hadriani, 2021).

The requirements planned out by the building committee includes not only the renovation of existing space, but also an extension which has extra committee rooms, changing rooms, ergo room and indoor rowing wagon. The most up to date plan collected from the building committee, points out that Proteus is facing financial set-back to carry out extension plan. However, the primary importance is still given to the extension/renovation plan that will help the building become future-proof and facilitate current size of association.

This thesis focuses on the renovation of existing space to improve the indoor environmental quality and make the building energy neutral. The next chapters draw attention to solving the age-old problems causing deterioration in indoor comfort and leading to high energy consumption by redesign layout, refurbishment, and retrofits. Building data collected, impression of site analysis, architecture, user surveys, building services and energy consumption were analysed in initial stages to propose renovation design strategies.

3.3 Site analysis

Location: The building is located on Rotterdamseweg next to the Kruithuisbrug facing the canal, also in close proximity to the main campus area of TU Delft and other institutional buildings. The site area is approximately 6300sqm. The total building footprint is 1500 sqm including both building blocks.

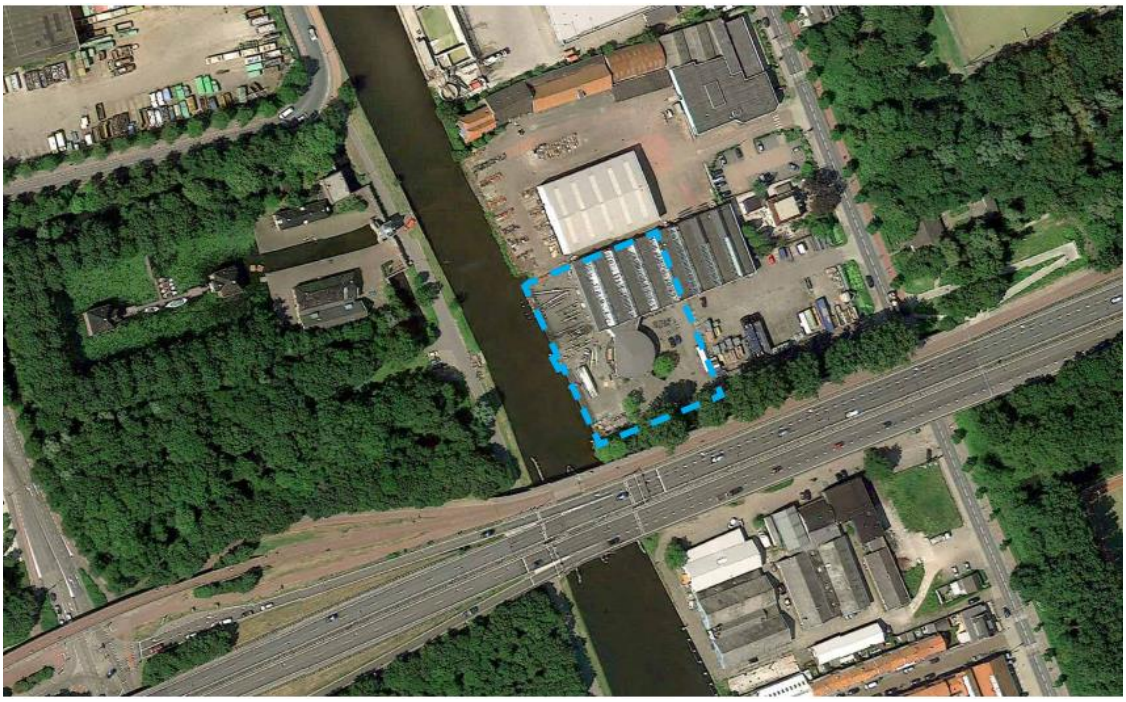


Figure 27 Site map, Source:(PE Building committee, n.d.)

Climate: Delft, has a typical weather like rest of the Netherlands. Being a small town surrounded by openness and green fields, the experience of any weather is felt more; the winter winds are higher and chilly. And in summers, there is clearer sky with sunny days felt more. Some important graphs about climate are shown that affect the design of buildings in general, also affecting the perspective on building's indoor comfort. Figure 19 shows Average temperature range during a year between 2 to 20^{O}C, figure 20, Average daily sky cover range during a year between 38%-65% and figure 21, Average relative Humidity range during a year between 75%-89%.

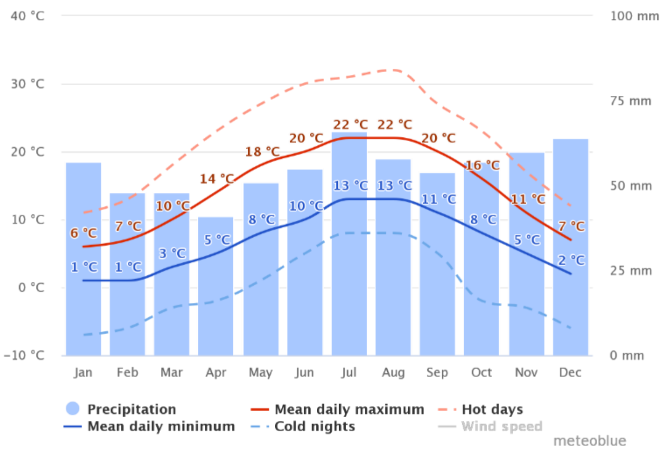


Figure 28 Temperature and precipitation range, Source: Meteoblue

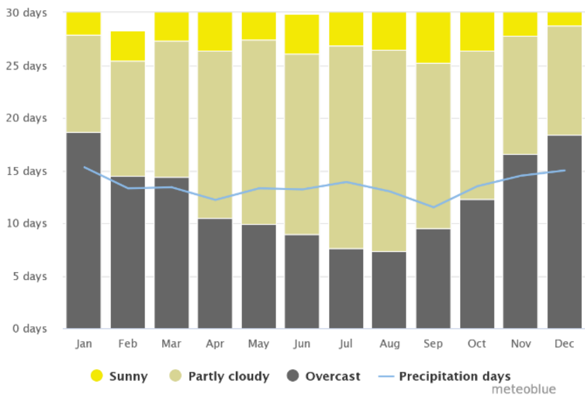


Figure 29 Sky cover range, Source: Meteoblue

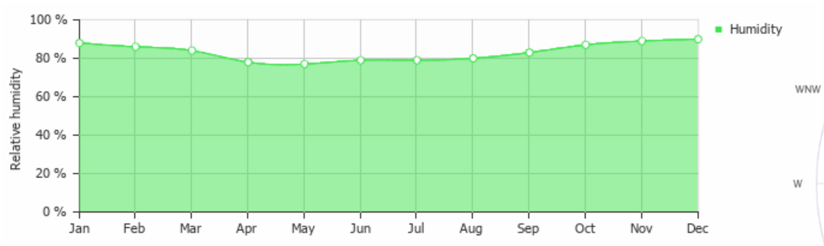


Figure 30 Average relative humidity, Source: weather & climate

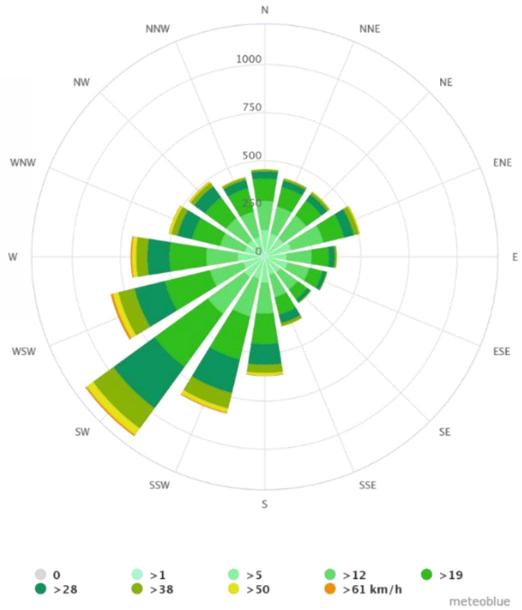


Figure 31 Wind rose diagram, Source:

Solar Analysis: Local shading by the surroundings and incident solar radiation on the building is investigated. The direct normal irradiance (DNI) levels Wh/m2 for delft gives the amount of solar radiation that would be received by that surface of the building which is struck by perpendicular rays from sun. Average hourly profiles for DNI (Wh/m2) is shown in figure 31. This is useful information to determine the potential of PV output.

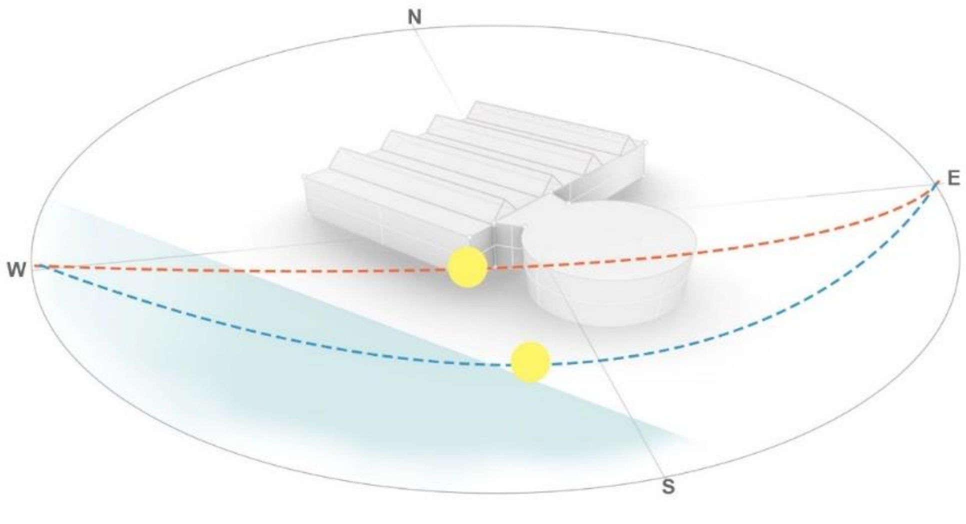


Figure 32 Sun path Proteus Eretes, Delft. Source: (own work)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5					34	82	33					
5 - 6				45	166	173	149	95				
6 - 7			23	198	239	224	213	191	125	1		
7 - 8		22	184	273	292	270	266	242	219	139	13	
8 - 9	68	178	237	320	343	306	306	279	265	206	111	55
9 - 10	155	218	260	344	367	334	330	299	271	220	159	121
10 - 11	188	243	290	370	383	344	336	314	276	242	184	157
11 - 12	207	263	320	377	389	358	350	325	281	259	194	171
12 - 13	199	268	330	376	392	364	352	323	273	244	179	164
13 - 14	177	238	289	360	383	365	346	317	256	217	155	137
14 - 15	132	204	258	335	368	365	347	298	244	191	116	88
15 - 16	30	162	232	303	344	339	335	287	230	135	23	4
16 - 17		38	171	253	290	298	297	251	174	15		
17 - 18			32	142	218	242	233	178	38			
18 - 19				10	96	158	147	43				
19 - 20						37	20					
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	1156	1835	2626	3704	4301	4259	4061	3444	2653	1870	1136	897

Figure 33 Average hourly profiles for Direct Normal irradiation Wh/m2. Source: (Globalsolaratlas.info, n.d.)

Annual radiation level for Proteus Eretes building in its urban context is studied in Grasshopper Ladybug using Amsterdam weather file of year 2020. Since the surrounding context height is comparable to building. There is more direct sunlight on building rooftop which means high prospects for roof installation with PV panels.

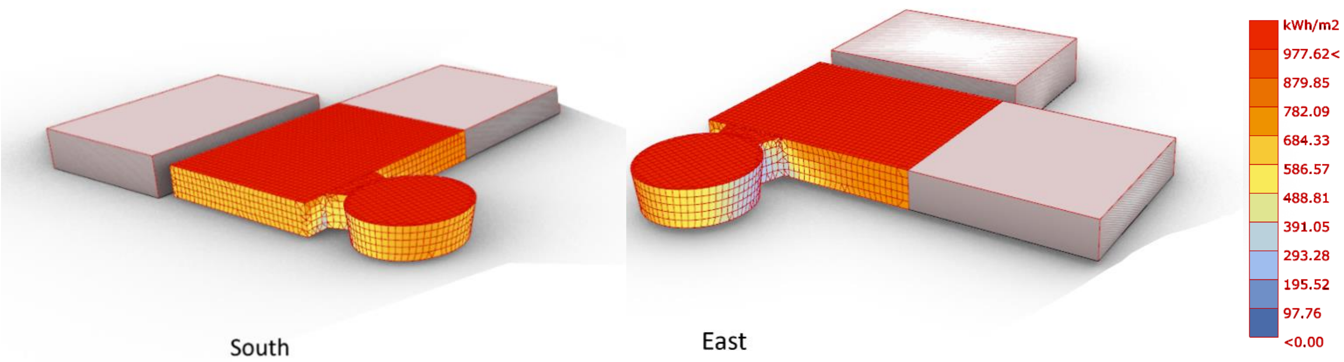


Figure 34 Radiation analysis Proteus Eretes. Source: (Own work)

3.4 Building First Impression

The site was visited early in the graduation phase to understand how rowing facilities function and the spatial configuration of Proteus Eretes. The occupancy, utility of space and general requirements were analysed as per the documents developed by the building committee. The whole accommodation is a combination of two built masses with different activities. De Beuk is the association building that serves the administration, committee offices, changing rooms on ground floor and a large bar attic with balcony, kitchen and board room on first floor. Attached to this building, is a large shed for storage of boats called Botenloods which also consists of ergometer room for rowers, workshop, and storerooms. Figures show some pictures taken on site visit of different spaces located in De Beuk and Boat Storage.

Figure 35 Spaces & function in the building

3.5 Indoor climate survey

To understand the indoor environmental quality and energy usage, a survey form containing thirteen questions was sent online to the members of Rowing club. The questionnaire aimed to record occupants' perception of indoor comfort and opinion on environment control strategy inside the building. They were able to provide information about their space of work, uncomfortable spaces, thermally underperforming areas, and other energy related knowledge.

Table 6 Survey questions on indoor comfort experience.

	No. of respondents	*25*	*December 2021*
1	*Which are the spaces in the rowing club building you find most comfortable to be in, to sit, work and relax? And why?*		
2	*Do you think your 'comfortable space of work' is well ventilated and provides thermal comfort?*		
3	*Which areas become uncomfortable during peak occupancy hours?*		
4	*What do you think causes indoor discomfort in the rowing club building?*		
5	*Any specific remarks about the indoor environment in mid winters and mid summers?*		
6	*When you are uncomfortable, what do you do? Are there specific actions you take to restore comfort?*		
7	*Are you satisfied with the natural light in your space of work?*		
8	*How do you assess the thermal environment/sound quality/air quality/quality of indoor environment at the moment? Rate on scale of -1 to 1.*		
9	*Do you have any ideas to improve the current indoor environment situation?*		
10	*Would you prefer low-tech or high-tech solution? Can you give an example if any?*		
11	*How do you wish to control indoor environment?*		
12	*Are there other problems you would like to mention regarding indoor environmental quality?*		
13	*Do you think you would profit from being given advice on your behaviour in relation to heating, ventilating and lighting?*		

Most respondents have common opinion for comfort level in certain rooms. The occupants usually prefer to sit in the committee rooms because of adequate furniture but complain about sensation of being too cold in winters. Bar Attic is a space for relaxation, specially in summers sitting at the balcony with beautiful view of canal. However, respondents face thermal discomfort because of inadequate ventilation.

At peak occupancy hours in summers, almost all rooms but specially bar attic, dressing rooms, ergometer room in boat storage become uncomfortable because of stuffy air, low fresh air supply and humidity. Due to old construction, internal partitions are not very sound proof which leads to noise pollution. Occupants voted almost all factors concerning the indoor environment, specially for poor heating and poor ventilation.

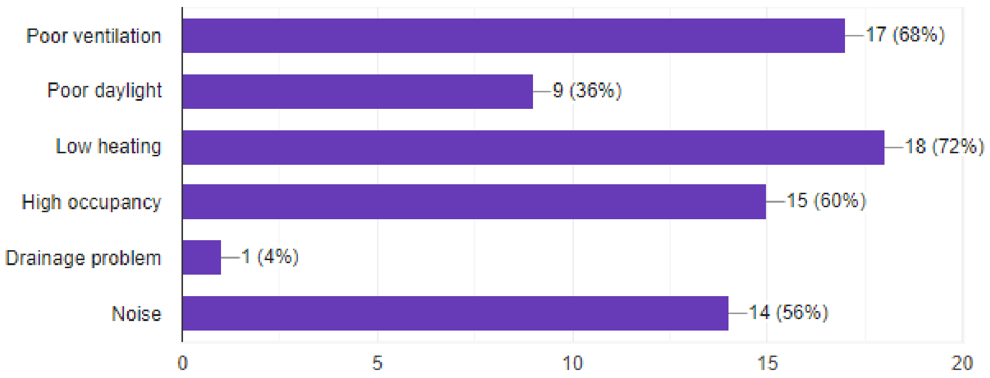


Figure 36 Factors voted for indoor discomfort at Proteus Eretes building

All temperature extremes are felt due to which the heating and cooling demand in winters and summers, respectively, increases. Occupants try to use mechanical system to comfort their indoor environment, dress accordingly or move outside the building to feel comfortable. Natural light and ventilation also help them to feel better. However, 70% of respondents complain about less natural light in the building. Most people have voted negatively on factors affecting indoor environment. From the figure 37, on a range of -1 to 1).

Some people commented that the spaces are so closely connected because of which the heat escapes a lot causing thermal discomfort. Other comments are made on the poor air quality. The toilets remain smelly at times because of old exhaust system. Also, the toilet doors open in the lobby, the bad odour spreads creating discomfort.

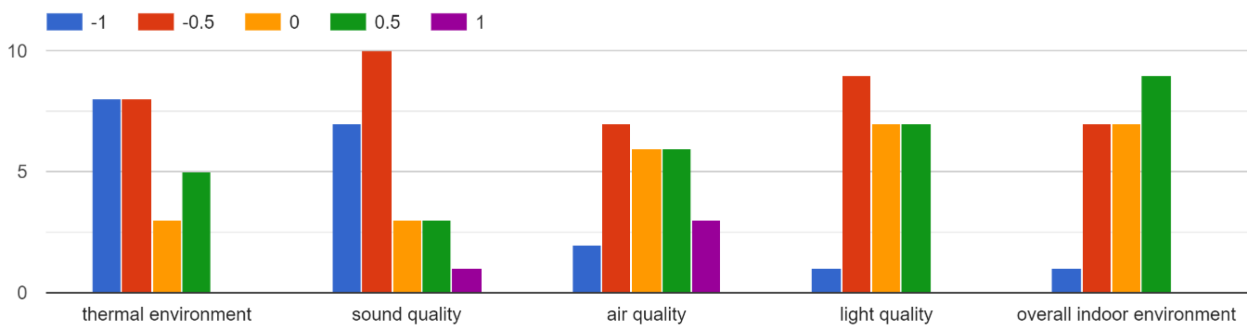


Figure 37 Rating on factors affecting IEQ on scale of -1 to 1

The question regarding technical solutions, control of indoor environment and improvement has mixed reviews from respondents. It is obvious that improvement for daylight, ventilation, insulation, and sound dampening are required in the building. Some suggest opting for switchable systems for controlling temperature and ventilation but these systems should be low priced and easy to install. Very few would prefer high tech solutions so that it better in long term.

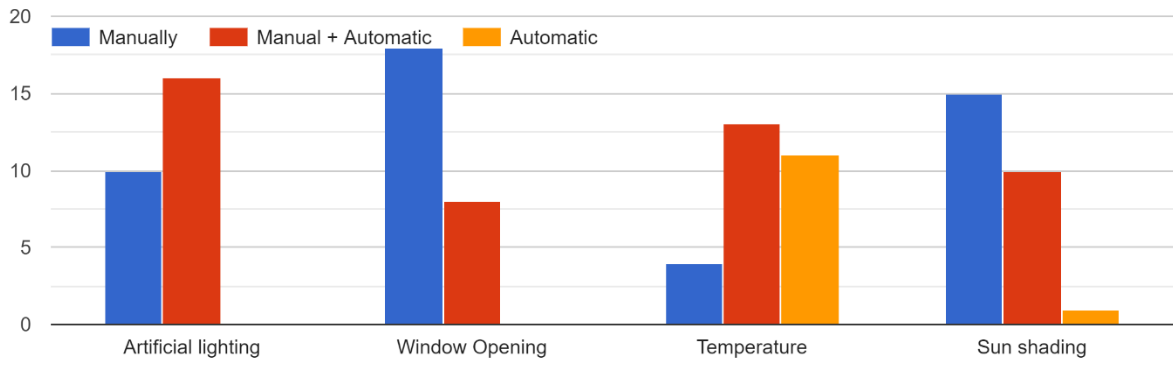


Figure 38 Preferred choice to control elements of building systems.

In conclusion, the survey proved to be very beneficial to streamline the topics that need to be addressed for renovation strategies. However, this first-hand information from occupants' is quite subjective as per various experiences and working styles of the occupants, it really helps to evaluate measures to tackle energy usage behaviour. Additionally, poor internal conditions eventually lead to high heating and ventilation loads. Therefore, the steps ahead involve intervening logical strategies for reducing energy demand and improving IEQ of the building. (See Appendix C)

3.6 Architecture, Envelope and Services

The survey was followed by second building visit that included collecting photos of existing building services, rooms, observations of activities, experience of indoor air quality, thermal comfort and comprehending overall architecture. This visit was also guided by the members of Building Committee of Proteus Eretes.

3.6.1 Architecture

The building has two blocks, the association building De Beuk is connected to Boat storage via a small lobby with door access. De Beuk has two floors with gross floor area of 477 sqm. The floor-to-floor height is 2.8m and overall height of 7m. The design of interior spaces follows the segments of circular plan with inorganic room sizes and placement of furniture. The room sizes are not flexible for future growth of association like committee rooms and kitchen. The kitchen is quite compact which leads to inadequate fresh air circulation. The entrance lobby leads to changing/shower rooms, toilets and committee rooms. It is observed that privacy for toilet and changing room is quite hindered because of such a circulation. Inside the shower room, separation of showers is made using a temporary radiative panel. On first floor, the bar attic quite is spacious connected to balcony facing canal view.

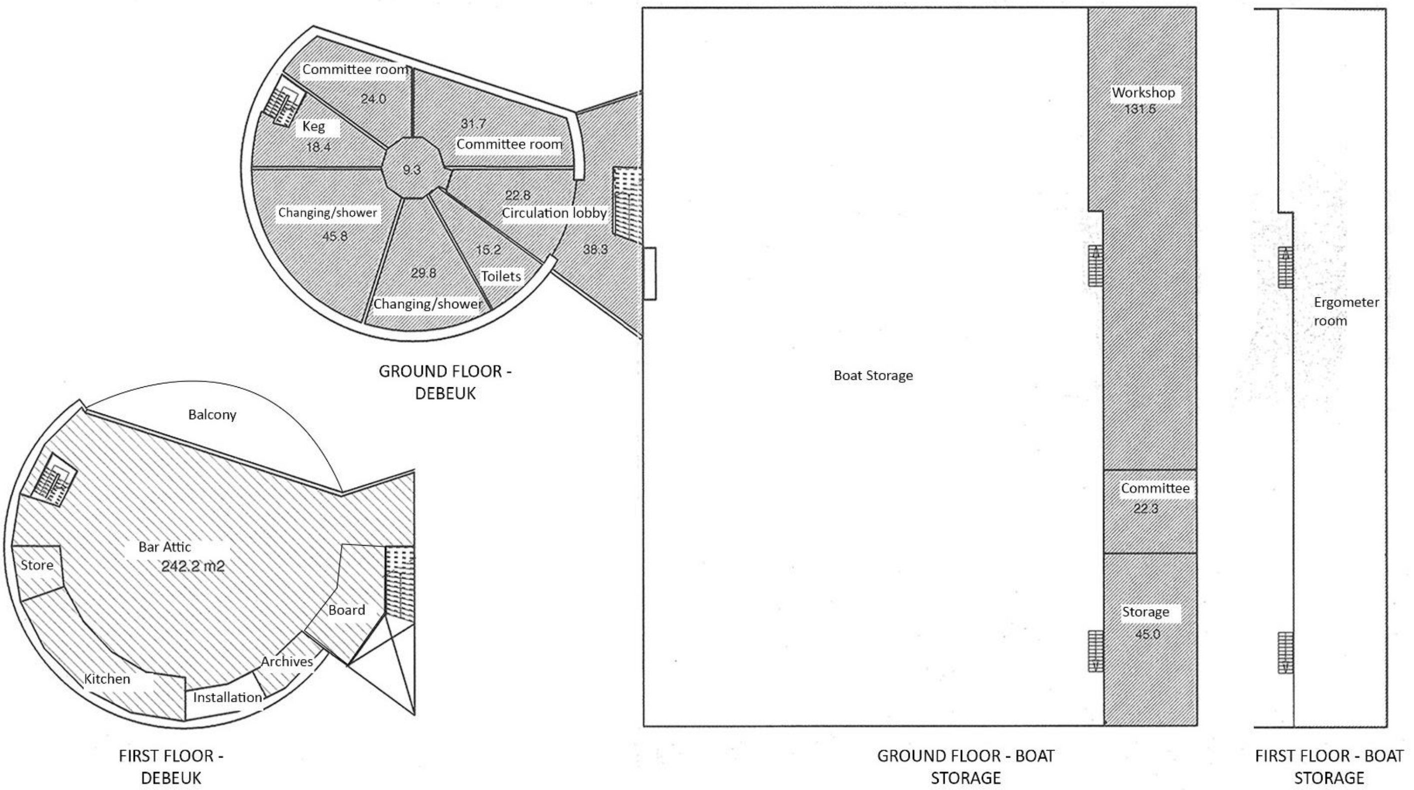


Figure 39 Spatial layout of Proteus Eretes building. Source: (PE Building committee, n.d.)

The boat storage occupies an area of 974 sqm. The adjacent spaces including workshop, storeroom and ergometer room have gross area of 400sqm. The boat shed with height of 5.8m can suffice fleet of more than 100 boats. (See Appendix A)

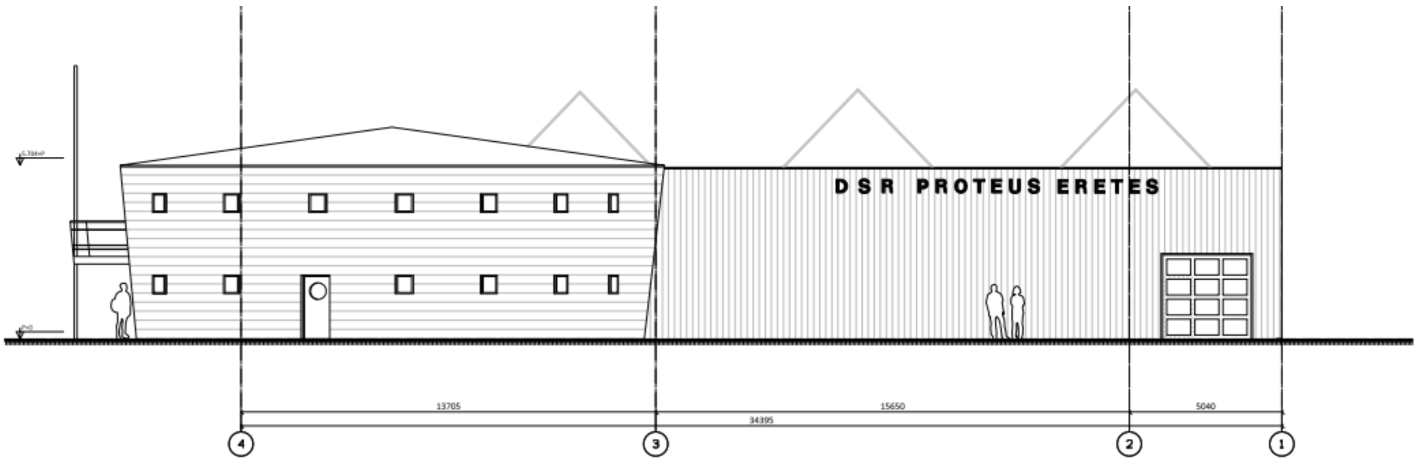


Figure 40 Building elevation, Source: (PE Building committee, n.d.)

3.6.2 Envelope

The opaque construction of De Beuk has a Rc value of 2.5 m2K/W which is less than the minimum Rc-value of 4.5m2k/W defined under Dutch Building Decree (2012). The internal floor is cast in concrete with low thermal resistance because of no insulation material. The load bearing roof is built of heavy laminated truss with member cross section size of 124x350mm. This is further tied by purlins of 59x159mm. Acoustic insulation panels are added in the interiors. However, the Rc-value is 3.8 m2k/W which should be renovated to reach 6 m2k/W. The west façade facing the canal has window to wall ratio of 35%, while the curved façade at the rear side with small openings of 605x605mm has only 7%. Standard double glazing is used in the building with U-value of glazing is 3.2 W/m2k. There are ventilation louvres provided in doors for natural air flow. Air leakage is observed because of deteriorated building structure. The proposal aims to adjust the daylight access by changing the window to wall ratio and using high efficiency glazing to reduce solar heat transmission. Additionally, extra insulation for enhanced thermal performance will be added in suitable location which requires less investment.

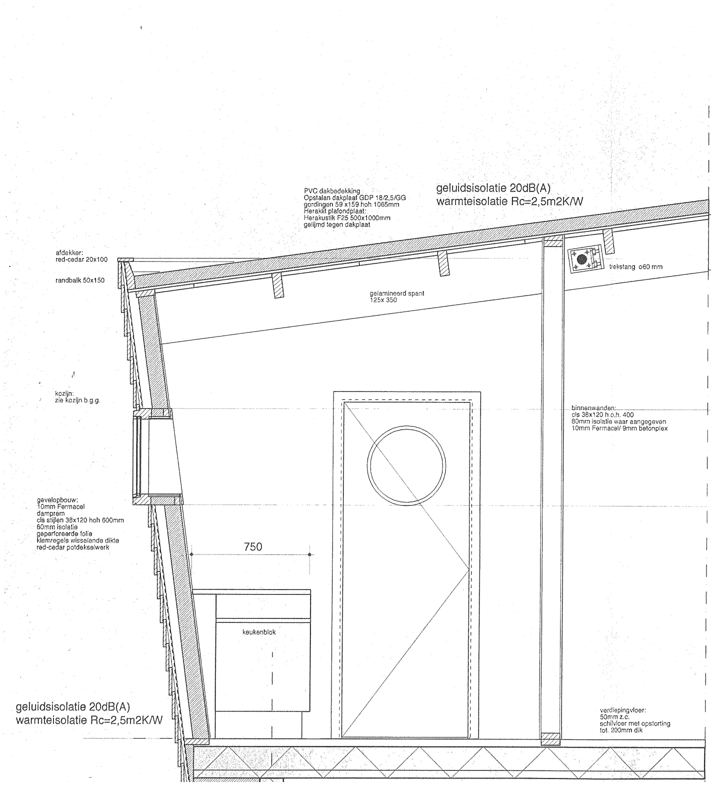


Figure 41 Northeast Facade Section. Source: (Author)

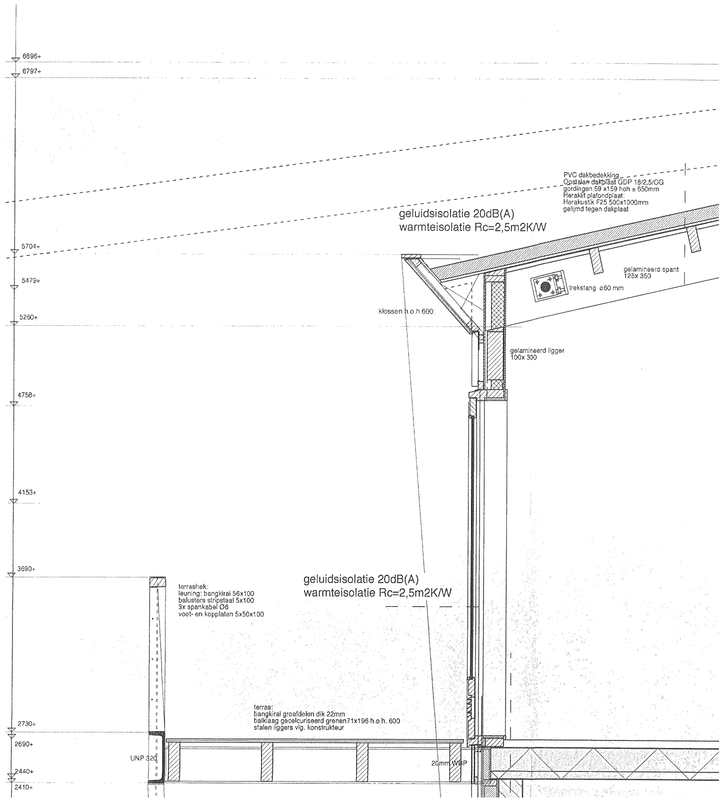


Figure 42 South-west facade section. Source: (Author)

Table 7 Building Construction of De Beuk at Proteus Eretes

DE BEUK			
Opaque element	**Material**	**Specification**	**Thermal properties (with thermal bridging)**
West façade (innermost to outermost layer)	Sand-lime brick	150mm	Rc=2.5 m2K/W , U-value = 0.4 W/m2K
	Wooden frame	38x89 mm	
	Insulation	80mm	
	OSB	9mm	
	Metal Clamping frame	22x38 mm	
	Sheet pile profile PVF coated	40mm	
Curved rear façade (innermost to outermost layer)	Fermacell	10mm	Rc=4.5 m2K/W, U-value = 0.22 W/m2K
	Damp layer	-	
	Styles cls	38x120 - c/c 600mm	
	Insulation	80mm	
	Perforated foil	-	
	Clamping rails varying thickness	-	
	Red-cedar tiles	10mm	
Floor	Wood board finish	50mm	Rc=1.2 m2K/W , U-value = 0.8 W/m2K
	Concrete	200mm	
Roof (outermost to innermost layer)	PVC roofing		Rc=2.5 m2K/W , U-value = 0.4 W/m2K
	Insulation	180mm	
	Laminated truss	125x350mm	
	Purlins	59x159 - c/c 650mm	
	Acoustic insulation ceiling panel	25mm	
	Wooden panel glued to roof	500X1000mm	

The external wall of boat warehouse is built of 300thk brick with PVF coated corrugated steel sheet. The metal sheet is mounted from outside and the appearance is continued for the façade of De Beuk. The pitched steel roof has skylight allowing for daylight in the storage area. The internal wall is single layer timber insulation wall 90mm thk. The ergometer room has glass wall without any operable windows which faces the indoor boat storage. There are no windows in boat storage.

Table 8 Building Construction Boat Storage of Proteus Eretes

BOAT STORAGE			
Opaque Element	**Material**	**Specification**	**Thermal properties (with thermal bridging)**
Warehouse façade	Brick work	300mm	Rc=0.9 m2K/W , U-value = 1.1
	Steel sheet profile PVF 2	40mm	
Internal wall warehouse	HSB panel	10mm	
	Glass wool insulation	80mm	
Floor	Concrete	100mm	
	Steel truss		Rc=0.9 m2K/W , U-value = 1.1
	Skylight panels		
	Glass wool insulation		

3.6.3 Heating and Ventilation in De Beuk

- **Heating**

The heating of spaces and warm water is done using gas boiler central heating system. The installation room on first floor has wall mounted gas boiler connected to the hot water tank. The boiler capacity is 60 kW with dimension 850x500x350 mm and volume of 0.15 m3. The gas boiler is connected to radiator with outgoing heat pipe and incoming cold pipe. There is no underfloor heating in the whole building. The schematic plan for connection of radiators and water tap to gas boiler in the existing building is followed.

Figure 43 Gas boiler and hot water tank. [own pictures]

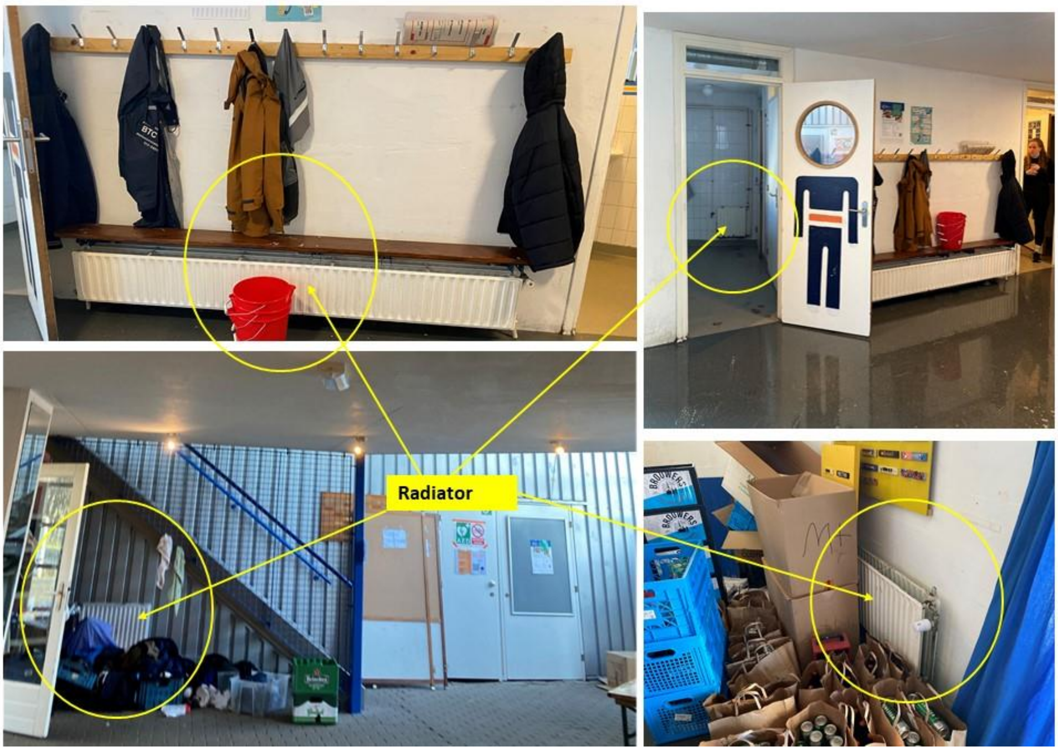


Figure 44 Location of radiator in De Beuk. [own pictures]

Figure 45 Heating layout in De Beuk - Ground floor

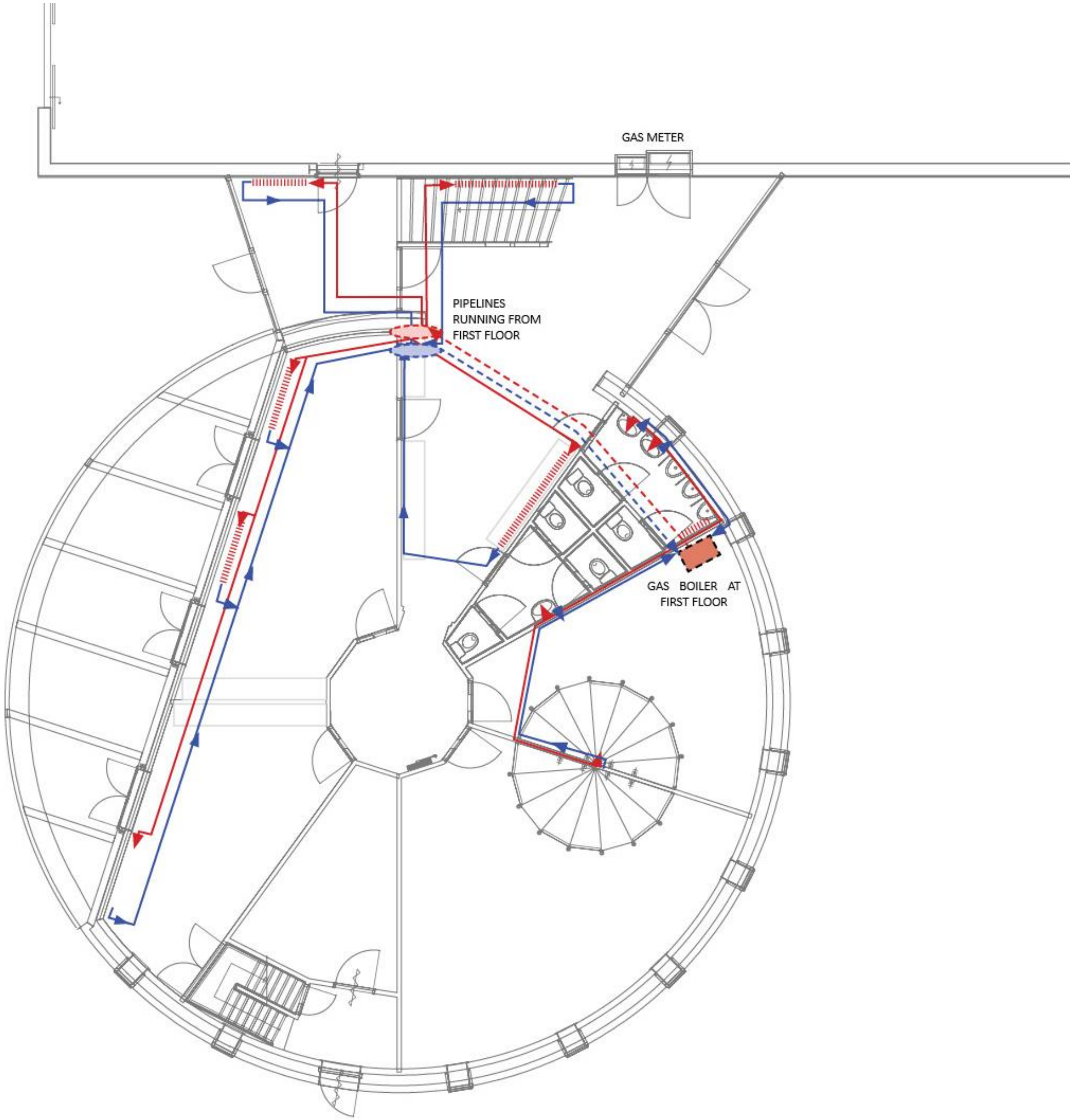
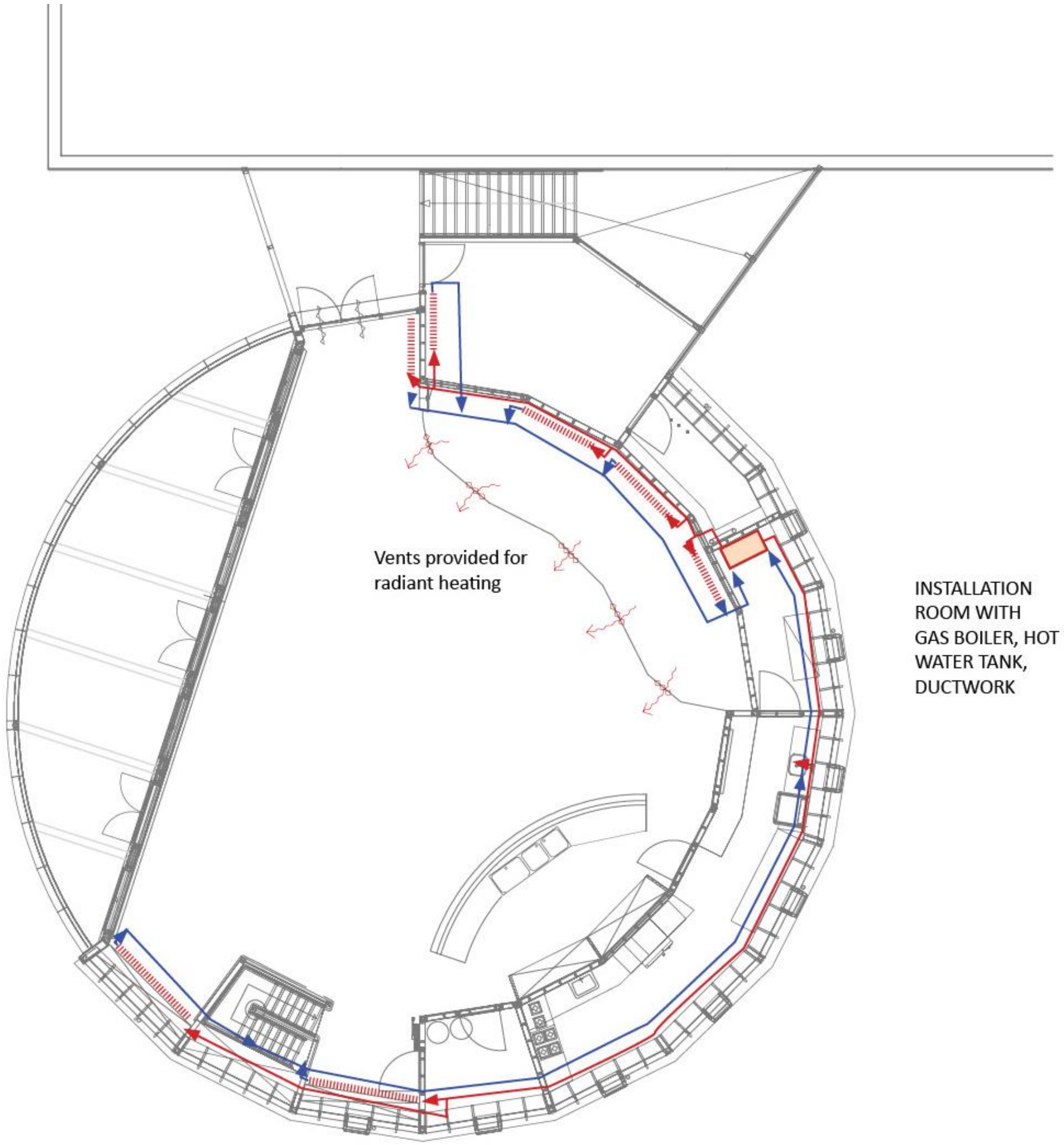


Figure 46 Heating layout in De Beuk - first floor



- **Ventilation**

The existing De Beuk building has mixed mode ventilation system. Either there is mechanical supply with natural ventilation or mechanical exhaust with natural ventilation. The supply air vents are located on the south-east side which allows for cooler air flow in the building. The committee rooms on ground floor have only natural ventilation possible. In the changing/shower rooms there is combination of mechanical supply and natural ventilation with operable windows. The bar attic consists of mechanical supply air only and no exhaust. The following diagram shows the ducts installation for supply air in green, and for exhaust in yellow. The natural ventilation due to door vents and window openings is depicted in blue.

Figure 49 Mechanical supply duct in bar attic [own picture]

Figure 48 Mechanical extract in toilet [own picture]

Figure 47 Natural ventilation through grills in doors

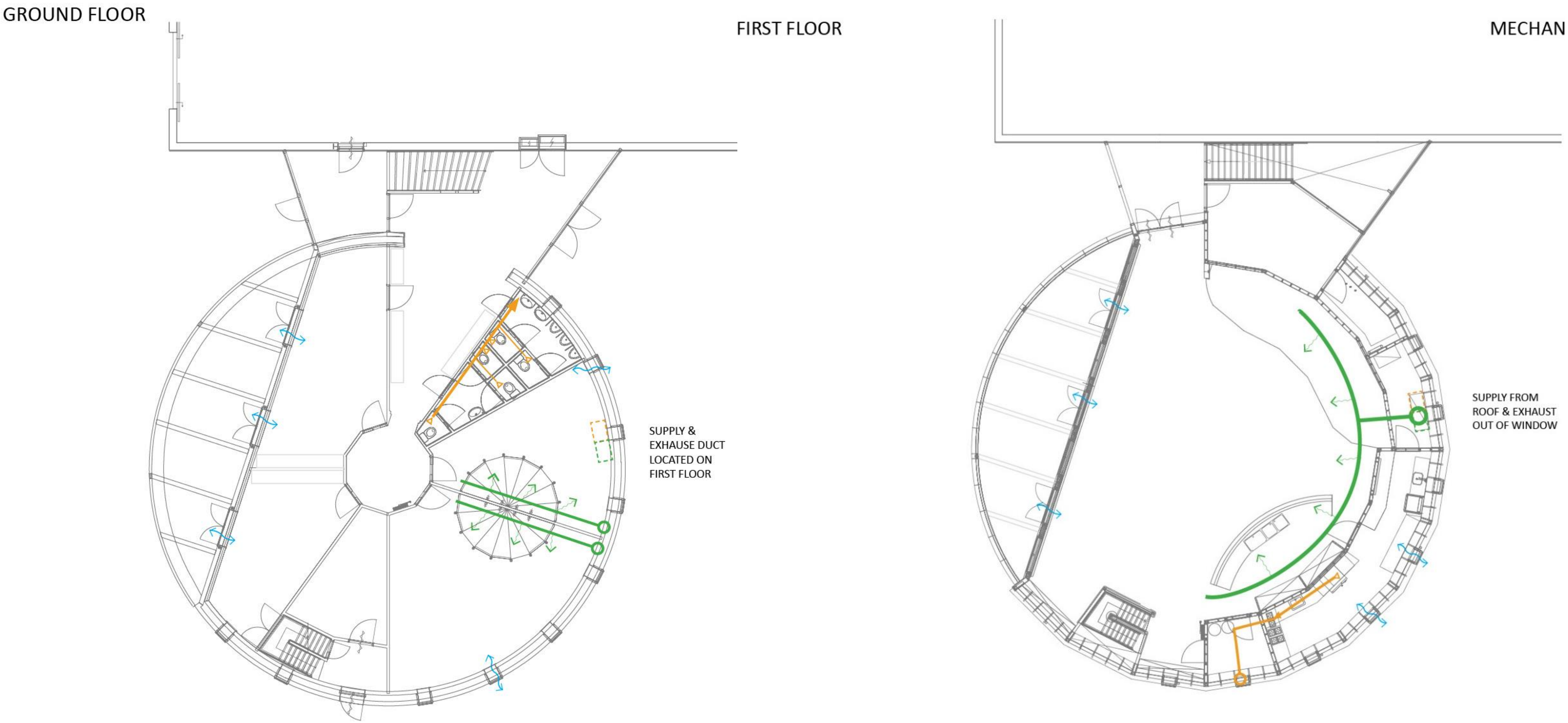


Figure 50 Ventilation supply and exhaust lines. Ground floor (left) and First floor (right)

Generally, most rooms are equipped with radiators, but the location is such that it cannot even heat the space. Radiator on ground floor lobby is out of function. And as can be seen in the figure, because of shortage of space, radiators have been hidden by the storage boxes or furniture, hence reducing the efficiency.

In the bar attic, the radiator is place at the adjacent wall of the main big hall, if it doesn't heat up enough because the space itself has large depth. Interesting to notice in the existing layout is the location of radiators hidden inside the podium in bar attic. The small vent in podium allows for radiative heat transfer to the room. This explains the inefficiency of radiators to heat the space evenly.

However, there is not enough cross ventilation. The exhaust vent for kitchen is connected to the window in adjacent storage room. During excessive use of kitchen in case of parties, the existing situation of ventilation is inadequate for fresh air exchange. Therefore, the odour spread from kitchen to adjacent spaces and contaminates the air for long hours. In fact, the occupancy at bar attic is also high during parties, which causes stuffiness and reduction of air quality because of overall inefficient air changer per hour.

3.6.4 Heating and Ventilation in Boat Storage

- **Heating**

Similar heating system is used in ergometer room and workshop with gas boiler heating system. in ergometer room, heating is only used for hot water. The pipes from the boiler run to the ground floor workshop radiators. The temperature in ergometer is felt at extremes which affects that thermal comfort of occupants negatively.

- **Ventilation**

Balanced mechanical ventilation with double air distribution ducts is used for both supply and exhaust. The ergometer room consists of automated ventilation timer. The supply and exhaust timers are turned on during exercise hours manually and switches off automatically when the timer runs out. There is no heat recovery system. In the ergometer room, the ventilation needs to be increased because of stale air during strenuous workouts. There is inadequate natural ventilation in these spaces.

Figure 51 Ventilation in Ergometer room [own picture]

Figure 52 Heating and ventilation layout in Ergometer room. [own pictures]

3.6.5 Lighting

The illumination in most spaces even during the day is done using artificial lighting. There is not enough natural light because of window to wall ratio being too less. The glazing percentage is 10% for south-east and north-east sides and 45% for south-west façade.

- Suspended pendant luminaires in committee rooms, board room and bar attic.
- Splash-proof lighting in kitchen, shower, circulation spaces, workshop, boat storage.
- Downlight led in toilets, entry, corridor, ergometer room.

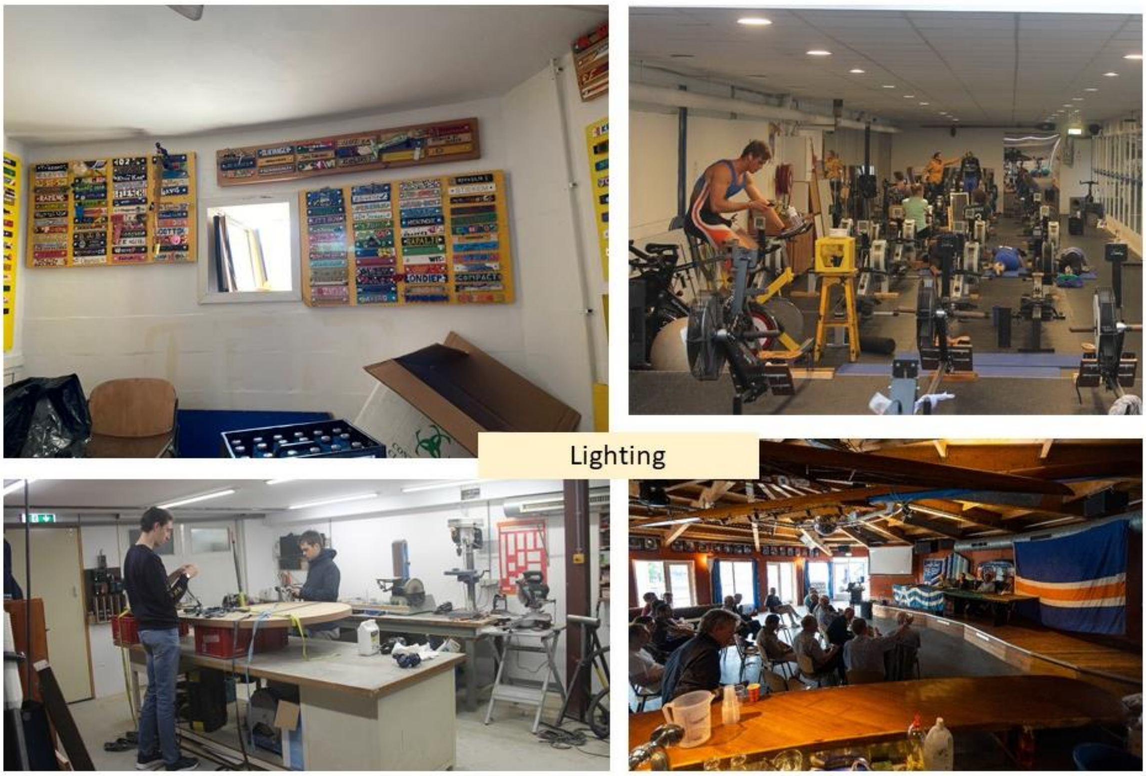


Figure 53 Illumination inside the rooms, [own pictures]

3.6.6 Fire safety

The fire-escape in De Beuk is poorly planned. The area is very small for large crowd to escape the route safely in shortest time required. Fire extinguishers are placed in lobby spaces both on ground and first floor of De Beuk and boat shed.

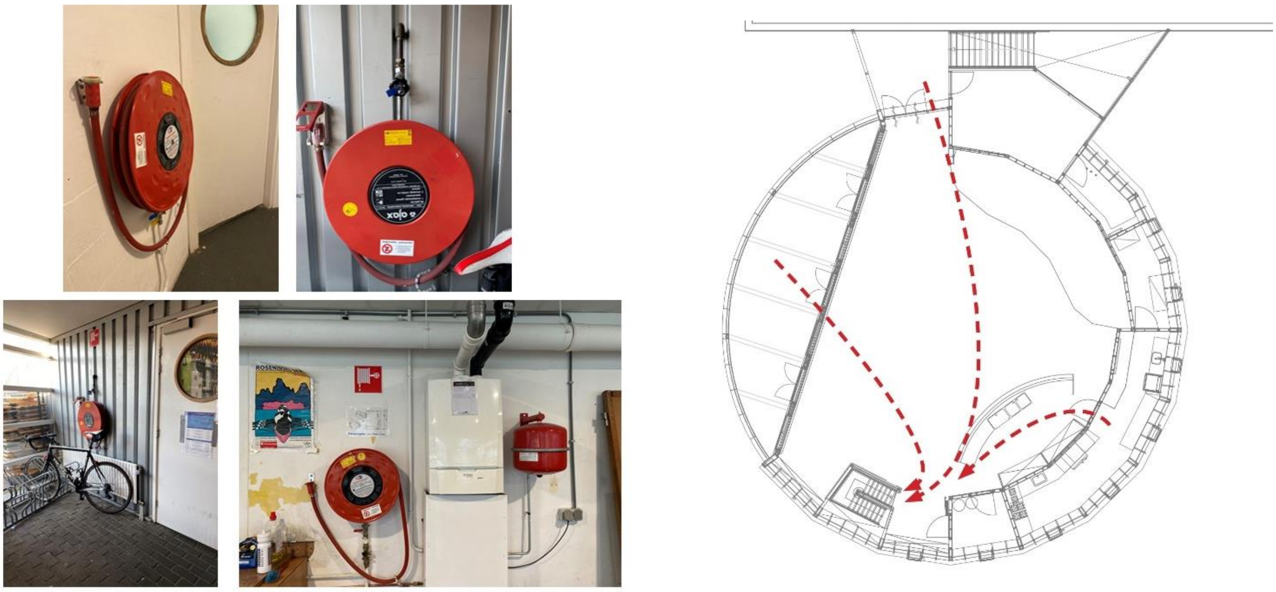


Figure 54 Fire extinguisher in common spaces, [own pictures]

3.7 Energy consumption

Due to outdated building services, withering of building envelope and thermal mass of existing structure, the operation energy demand is high to keep comfortable indoor environment and fulfilling basic needs like hot water and electricity. The energy consumption in 2020 was more than 38000 kWh and gas consumption of 5010 m3 during the latest pandemic year when the Rowing association remained mostly closed. During the annual Owee fest as a part of introduction programme of TU Delft, the rowing club also held festivities where most energy was consumed by decorative lighting loads. The power consumption shot up to 5329 kWh alone in August 2021. In present year, without any restrictions due to pandemic, the rowing club started functioning to full capacity leading to high power consumption and gas use compared to year 2021.

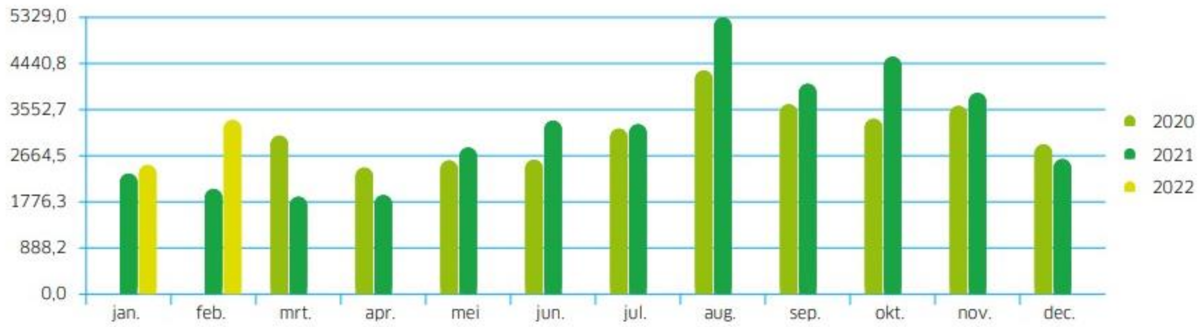


Figure 55 Power consumption in last three years (kWh). Source: (PE Building committee, n.d.)

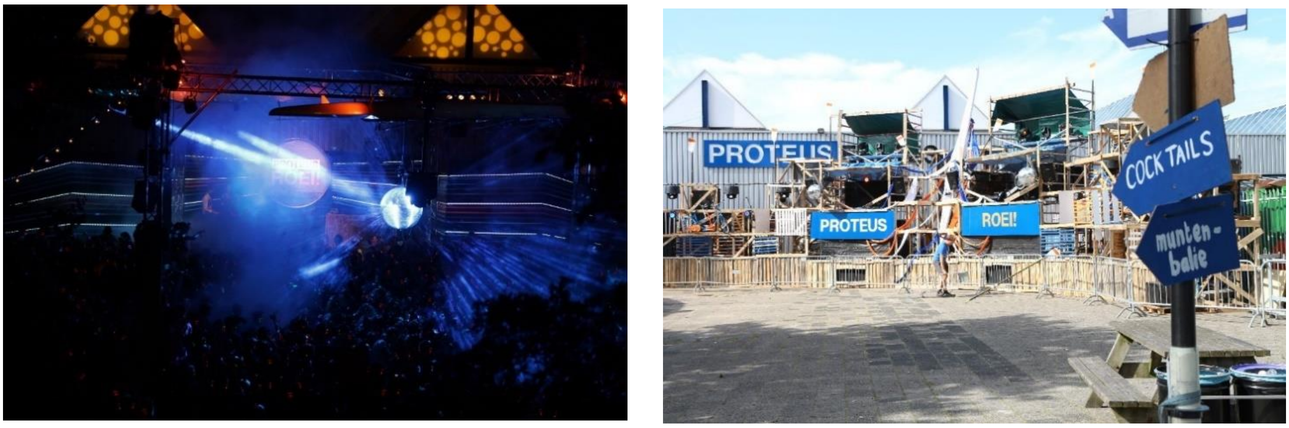


Figure 56 Owee Fest at Proteus Eretes. Source: (ProteusEretes, n.d.)

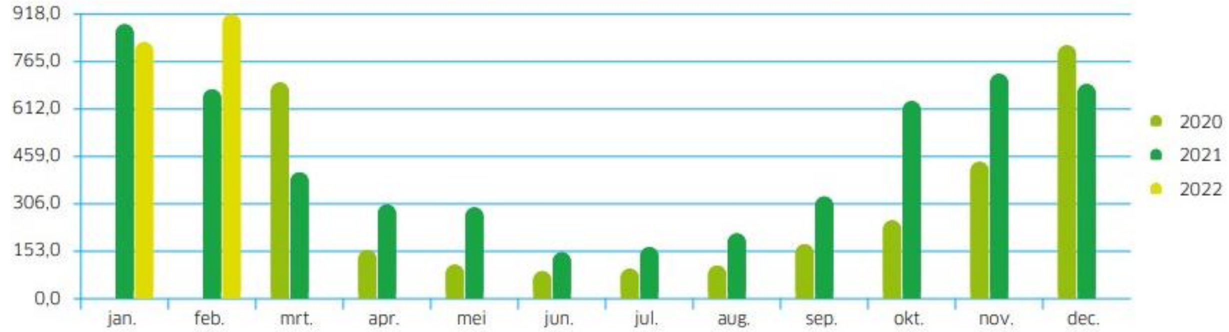


Figure 57 Gas consumption in last three years (m3). Source:(PE Building committee, n.d.)

The electricity bill acquired from Proteus Eretes for the year 2021, provides break up of cost for gas and electricity. The total electricity bill paid was € 8583 and gas total of € 5306. The association is paying the government levies for basic energy tax and tax to boost sustainable energy production which was almost € 4000 is the recent year. This is mainly because Proteus Eretes is yet not contributing as a sustainable building for energy and climate transition.

With the rising gas prices in the Netherlands, the current annual bill of total € 13889 may increase by 30% leading to annual bill of € 18055. This is a threatening situation for the rowing association considering the financial drawbacks they are already facing and high operational energy demand. Hence, the only solution to avoid such a predicament is to invest for the renovation of building towards sustainable energy production and climate transition. (See Appendix B)

3.8 Summary

Architecturally, the appearance of the building is unique however the interior spaces are unsatisfactory for a growing occupancy, nor it is a flexible layout. There is not much freedom of circulation in some areas and hindrances to privacy for toilets and showers. In terms of building fabric, the existing condition leads to heat escaping from zones which leads to poor thermal performance. Air leakage through broken door vents, grills and building cracks also causes poor indoor air quality.

Figure 58 Views of the building. [own pictures]

A summary table of all entire building spaces that call for attention for renovation in terms of design and indoor climate is shown below. The requirement for each space is described, which resulted from case analysis, site visit, occupant surveys and documentation received Proteus Eretes building committee.

Table 9 Overview renovation requirements, (own work)

Room	Description	Issue	Requirement
Bar Attic	Used for social events, drinks, parties, relaxation, free-time	• Inadequate ventilation • acoustics during peak loads • Insufficient natural light	• Sufficient Ventilation • Acoustic insulation • More Daylight
Kitchen	Prepare meals for events, twice a week dinner	• Awkward shape • Insufficient facilities • Exhaust insufficient	• Technical kitchen installations • Dishwashing • Drainage • ventilation
Board room	Board member's daily activities	• Space shortage • Indoor discomfort	• Extra space • Health & safety measure • Heating • Daylight access • Air exchange
Committee rooms	For committee discussions, work	• space shortage • furniture shortage • Insufficient natural light	• Furniture improvement • More rooms • More daylight
Entrance	Entry to hall via double doors	• Unheated space • Cast floor and pavement	• Central positioning • Accessible information
Changing rooms	Changing	• Ventilation • Less privacy	• Ventilation • Lighting • Separate shower
Toilets	Toilets	• Drainage • Bad smell	• Ventilation • Robustness • positioning
Ergometer attic	For indoor workout – cardio, strength training	• Stuffy air due to sweat • Very compact • No heating • No natural light	• Ventilation • Heating option • Accessible toilet • Daylight access
Warehouse & archive	Storage of equipments, waste material, boats, boat repair		• increase storage space
Keg room	Storage of beer tank	• Compact space	• Adequate heat dissipation
Installation room	Heating and ventilation service equiments	N.A.	• Exhaust vent
Balcony	Attached to bar attic	• Could be bigger	• Expansion • Possibility to cover

4. DESIGN PROCESS

Following the case analysis and identifying locations of improvement, integrated climate design strategies for refurbishment are developed. This chapter describes the design evolution and interventions of energy efficient technologies in four steps:

1. Spatial redesigning
2. Façade refurbishment strategies to reduce solar heat gains and losses
3. Energy efficient retrofits for building services - ventilation and space heating
4. Adding renewable energy sources like solar panels for on-site energy

The renovation strategy is a combination of passive building design and active equipment and technology. The design process adopted an approach where new layout and retrofits were evaluated and simultaneously optimized for better functionality of spaces and building services. Also, certain changes in architecture were reckoned through discussions with building committee of Proteus Eretes to meet their recommendation and needs.

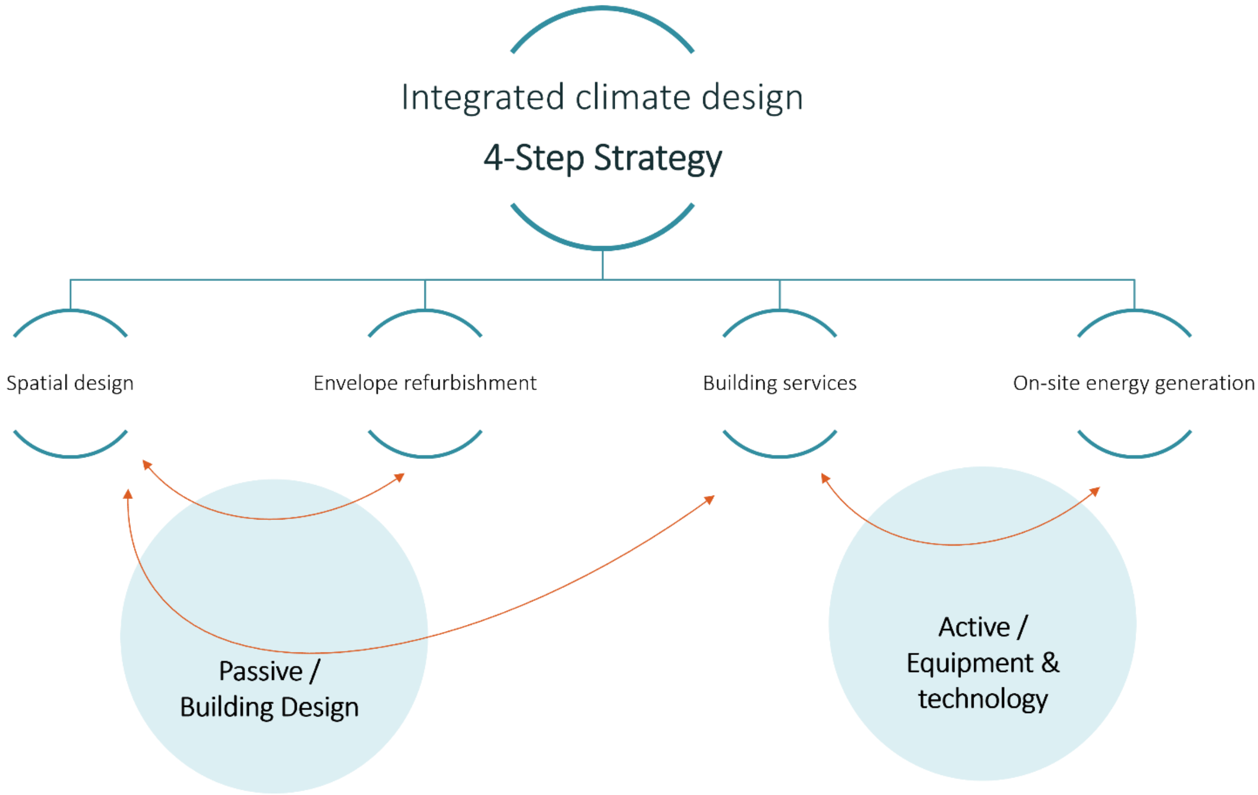


Figure 59 Four-step strategy for integrated climate design

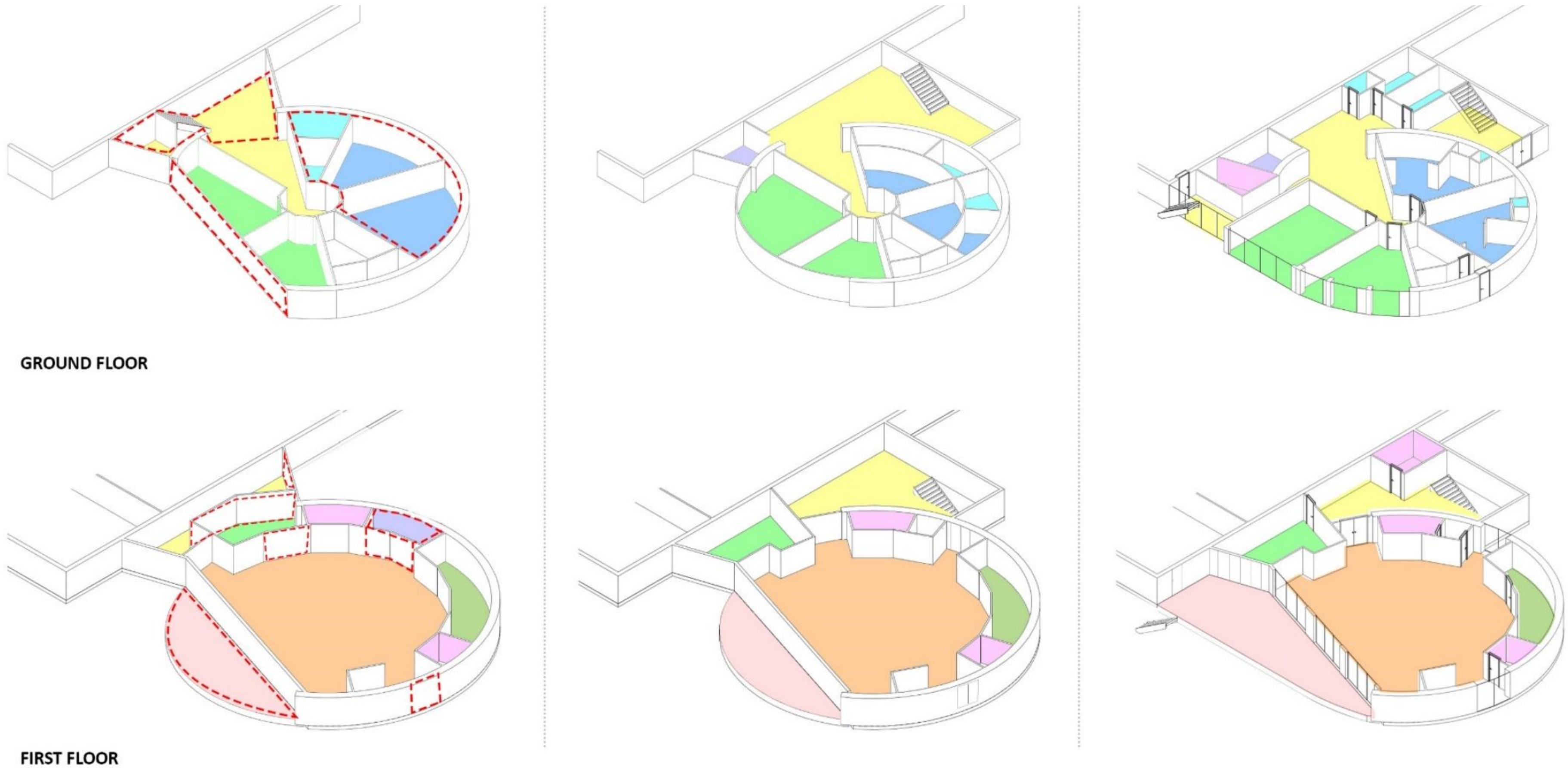
4.1 Spatial Redesigning

4.1.1 De Beuk

With respect to space usage behaviour and problems experienced by user, the association building is redesigned in several steps for better space and indoor comfort shown in sketches. The main criterion for selection includes adequate space, occupant flexibility, daylight access, robustness in toilets and changing rooms, enhanced heating, and ventilation. (see Appendix D)

- **Entrance lobby** space is increased and clear with defined main entrance. This leads to new staircase.
- **Committee rooms:** Initially, the size was increased taking the shape of first floor balcony providing better daylight with new glazing. This was further to a more functional and simpler layout.
- **Changing/shower rooms** were initially increased in area with inclusion of toilets. However, to avoid nuisance in indoor air quality or privacy, the toilets are separated from changing rooms. The space undereath the new staircase has room for new toilets. Additional toilet of size 2.2x1.5m designed for the disabled. This common toilet can also serve those who are gender neutral and prefer neither female nor male toilets. Another improvement includes private shower and single toilet. This is done because all users may not be comfortable with open shower system. Thereby making more robust and defined shower area.
- **Common installation room** of 13.5sqm is laid which would house common building service unit for energy supply to De Beuk and Boat storage. Informed reasoning for common installation room with new building services is further discussed in next section.
- **Circulation on ground floor** Access to canal area via the building is made possible with corridor access. This increase internal circulation also helps to reduce congestion at peak times. The outdoor void in between de Beuk and Warehouse wall is included within the building with storeroom. This is done to avoid trash dumping in that space.
- **Board room** on first floor on north side, has insufficient natural light, hence shifting the room toward south-west façade.
- **Bar attic** south-west façade refurbishment with new full wall glazing.
- **Replacing old installation** room with openable window. Another window is added next to fire escape where the space not utilized. This way natural cross ventilation is enhanced.
- **Balcony is extended** to connect to the boat storage. There are new fire escape stairs from this balcony which opens to canal side. The new ergometer room (which is explained later) is accessible to this balcony.
- **Storerooms** added on ground floor and first floor.
- **Kitchen** is added with grills for exhaust however no change in layout because of compactness of space.

Figure 60 Design Evolution



- Committee room/board room
- Changing/shower
- Toilet
- Circulation
- Installation room
- Store room/Archive
- Bar Attic
- Kitchen
- Balcony
- Location of changes

Committee room size increased taking the shape of first floor balcony. Possibility of more daylight with new glazing.

Changing/shower rooms are increased in area with inclusion of toilets.

Board room toward south-west façade.

Common installation room.

Replacing old installation room with openable window.

Bar Attic with larger window to wall ratio.

Better layout for committee rooms.

Added store room on ground floor replacing the outdoor void space.

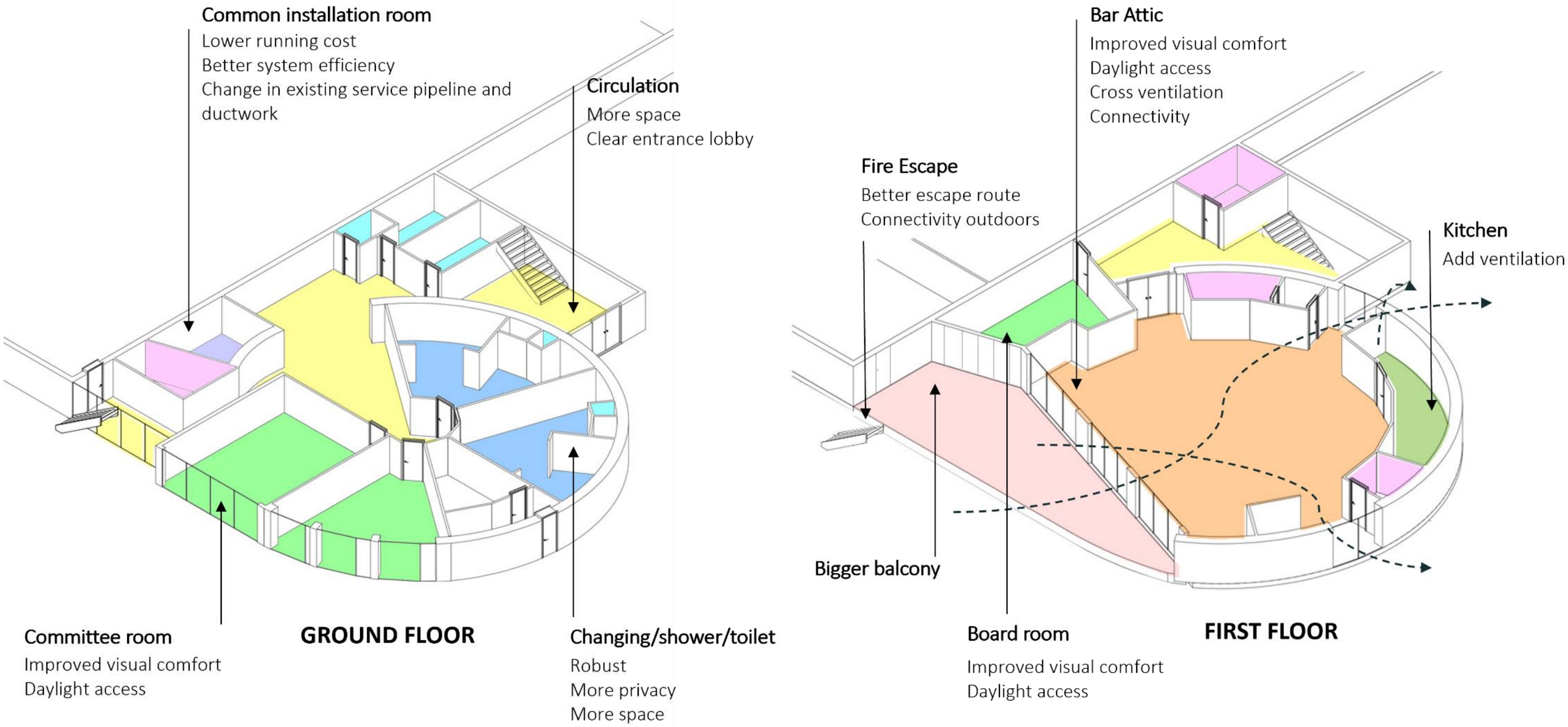
Toilets separated from changing room to avoid nuisaince and protect privacy.

Adding Common toilet for the disabled/gender neutral.

A private shower and single toilet added in changing room.

Improved Ciruclation access to water banks. Amd fire escape through bigger balcony

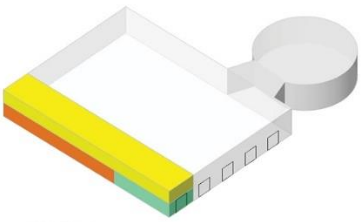
Figure 61 Proposed design



4.1.2 Boat storage

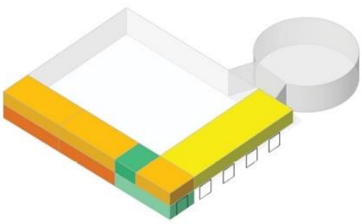
The primary focus for redesigning interiors in boat storage is to solve the issues of ergometer room. Currently, the ergometer room has no daylight and extreme temperatures are felt, specially in summers. Also, as the association is growing the current space is limited for daily use.

Various conceptual massing options are developed with of internal functions. Three options shown with location of ergometer room (yellow) and additional utility and office spaces. the design option 1 is selected for the given criteria. The extent of changes with this option are much less compared to option 2 and 4. The ergometer room is located on south façade with view towards the canal and access of daylight unlike the existing case.

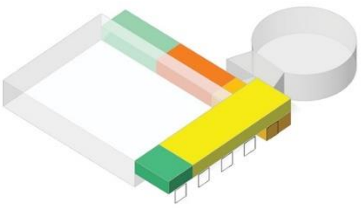


EXISTING

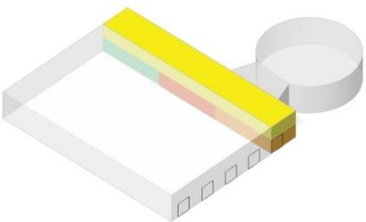
Ergometer Workshop Offices Storage Utility



OPTION 1



OPTION 2



OPTION 3

	Views to outdoors	Daylight	Connection to DeBeuk	Extent of changes	Volume
OPTION 1	★★★★★	★★★★★	★★★☆☆	★★☆☆☆	★★★★★
OPTION 2	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★
OPTION 3	★★★★★	★☆☆☆☆	★★★★★	★★★★★	☆☆☆☆☆

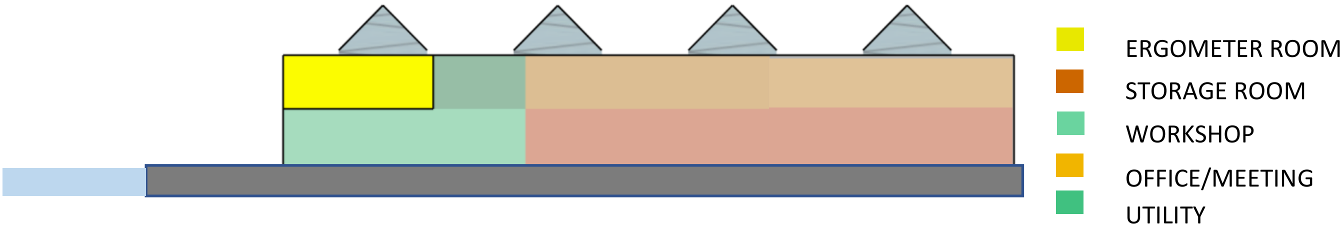


Figure 62 Selection criteria for design options

Analysing the detailed section for reconstruction of this space has limitations that need to be overcome; height of ergometer, possible clash with door access outside and shifting the boats stored occupying the height. Given door height is 3m and head space above is 2.5m. To utilize this space for spacious ergometer room with clear height of at least 3m, reconstruction of roof is proposed. This includes truss construction, reusing existing ducts for ventilation, larger surface area of roof to install PV panels, possibility for skylight and south-west façade glazing.

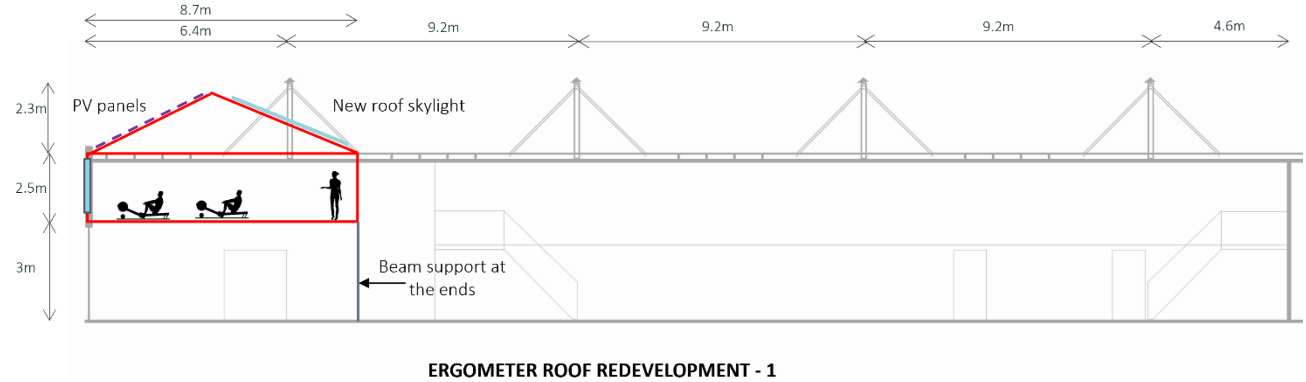


Figure 63 First redevelopment of roof structure for new Ergometer room

First redevelopment of roof:

Removing the existing first roof beam and constructing new truss solution with less deep roof slope, more clear height of ceiling. However, the limitation here is the horizontal supporting beam that takes the load of adjacent roof truss. This would require more labour and expenses to fully redo because the whole beam would be deconstructed along with second roof.

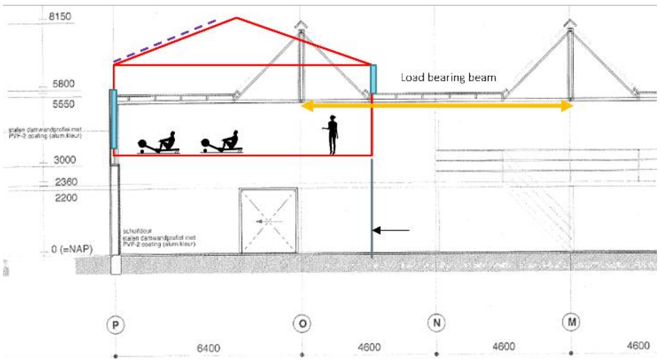


Figure 64 Support beam(yellow) as structural constraint

Second redevelopment of roof:

Due to the stated limitation, a more convenient renovation is depicted here. Using the north slope of existing roof and reconstructing the south slope with larger truss. This option is feasible to provide voluminous ergometer room, with north skylight, PV panels and daylight access. The clear height reaches up to 5m, descending to 2.5m at the wall supports. The load of the floor beam can be supported at the ends.

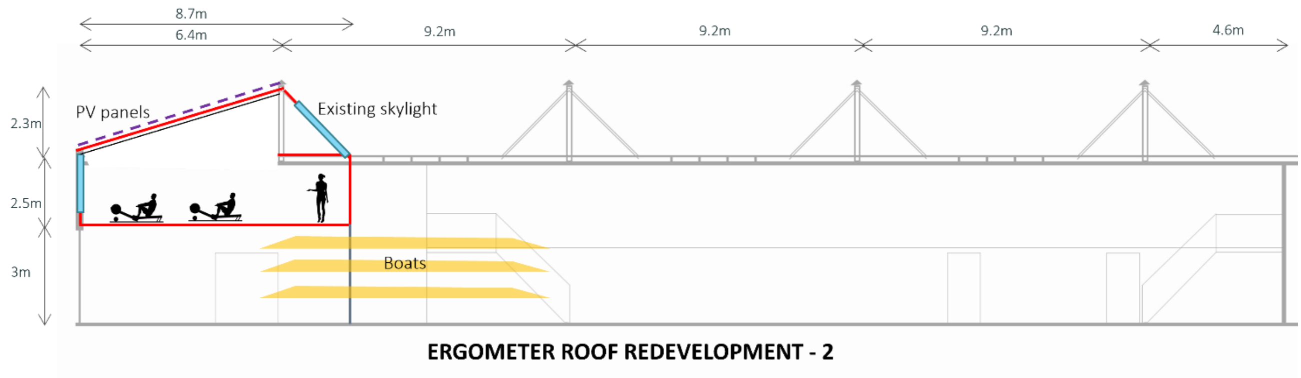
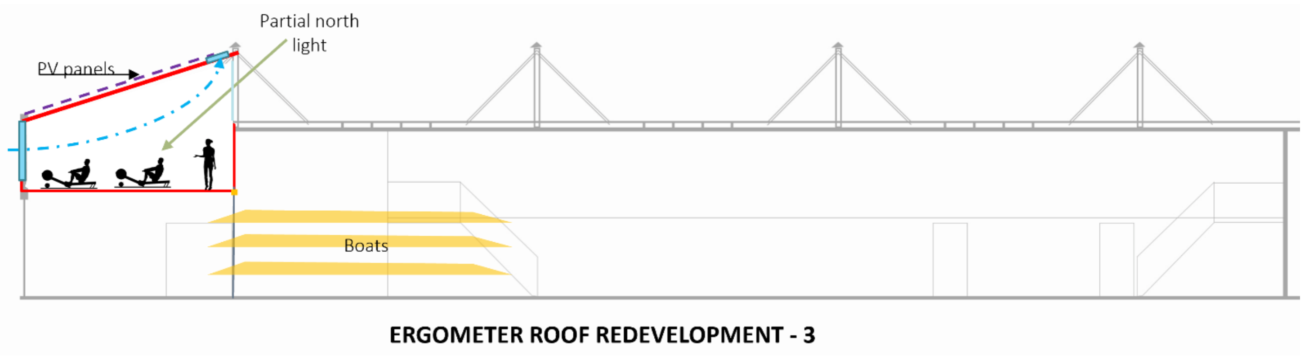
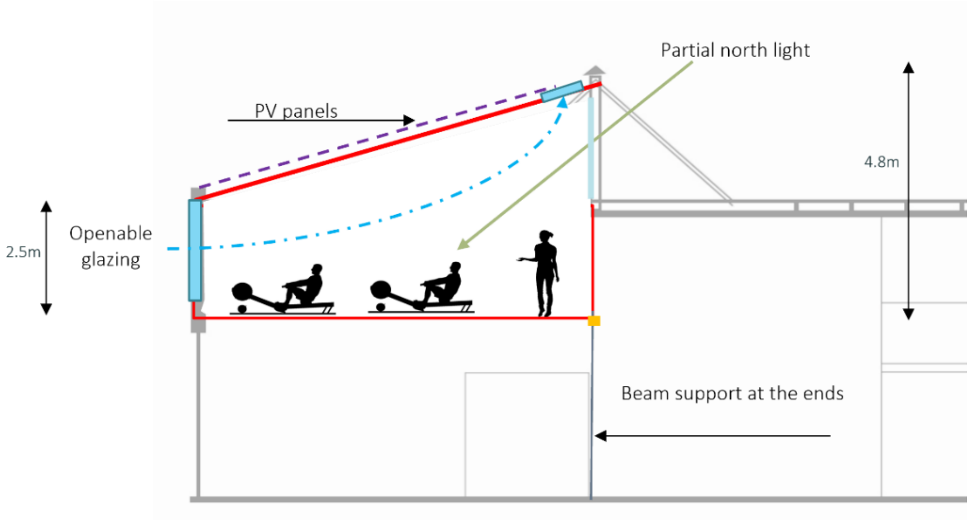


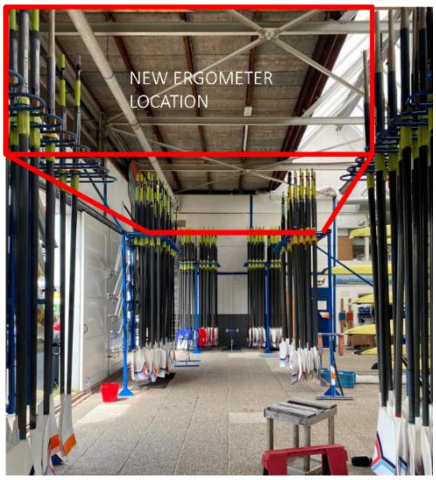
Figure 65 Second redevelopment of roof structure for new Ergometer room

Third redevelopment of roof:

Previously the room depth is 8.7m (taking the depth till roof end), which is too large and redundant. Hence, considering a depth of 6.4m (following the structural grid too) without the existing roof slope included is designed. Same truss is used as rear wall which would have glazing panels for north light to enter. Openable skylight in the new roof construction is also option for stack ventilation. I-beam for vertical load transfer shall be used to support the span of 30m.







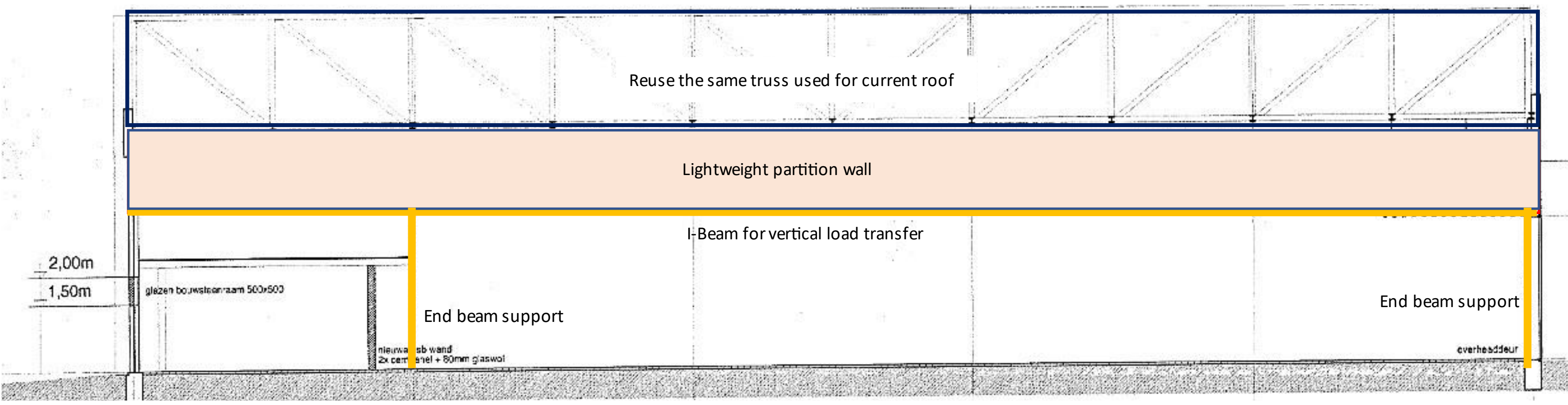
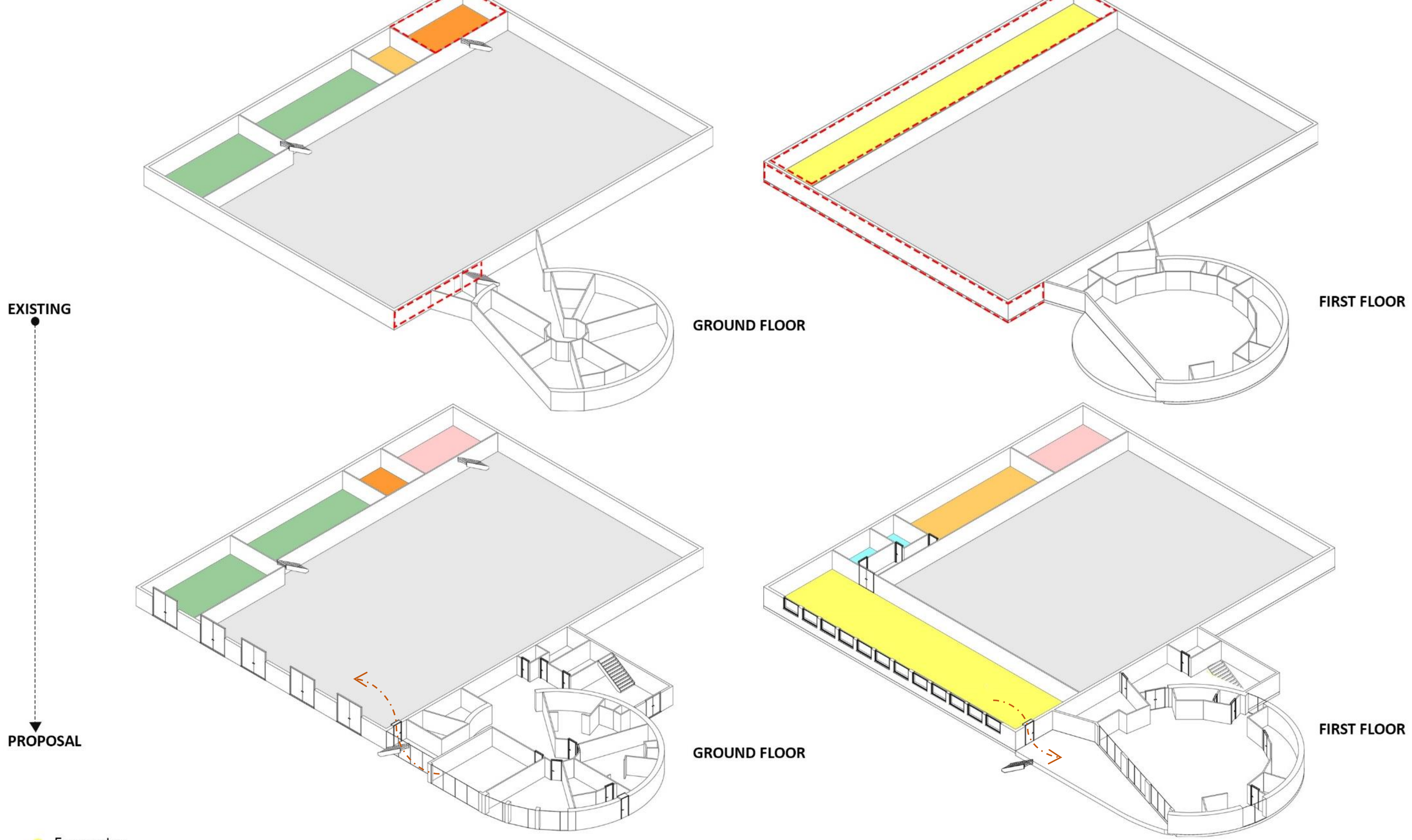


Figure 66 Third redevelopment of roof structure for new Ergometer room (top) Additional structural support requirement (bottom)

Figure 67 Design Evolution



- Ergometer
- Storage
- Office/Multi-purpose
- Workshop
- Strength training room
- Toilets
- Location of changes

Access to boat storage from De Beuk is changed on ground floor. Additional utility space like toilets, store room, circulation lobby are planned on first floor.

A double height strength training room replacing the old storage space.

New ergometer room on south-east facade. This is connected to balcony of De Beuk and fire escape.

Multipurpose hall is added which can be either used as office cubicle, study hall, recreational studio.

4.2 Façade refurbishment strategies

In this section, interventions are for building envelope are proposed based on literature finding for energy efficiency and thermal performance, market research and as per the need of the project. The selection criteria for the choices made includes daylight access, improved insulation, airtightness, user comfort and architectural appeal. The design choices are validation for energy and thermal comfort in the next chapter that covers the simulation phase.

4.2.1 De Beuk

Roof: The circular laminated truss roof has Rc-value of only 3.7 m2k/W. Two options are developed to improve the insulation of roof to reach Rc-value of 6 m2k/W. First option suggests complete renovation of roof to reach insulation efficiency and second option with placement of ETFE cushions above the existing roof. However, both the options demand high labour and expenses. The structural system would have to be redesigned too to achieve that. Therefore, option 2 with addition of internal insulation is the most feasible. Adding cellulose panels of 130mm thickness internal can reduce the heating load in bar attic.

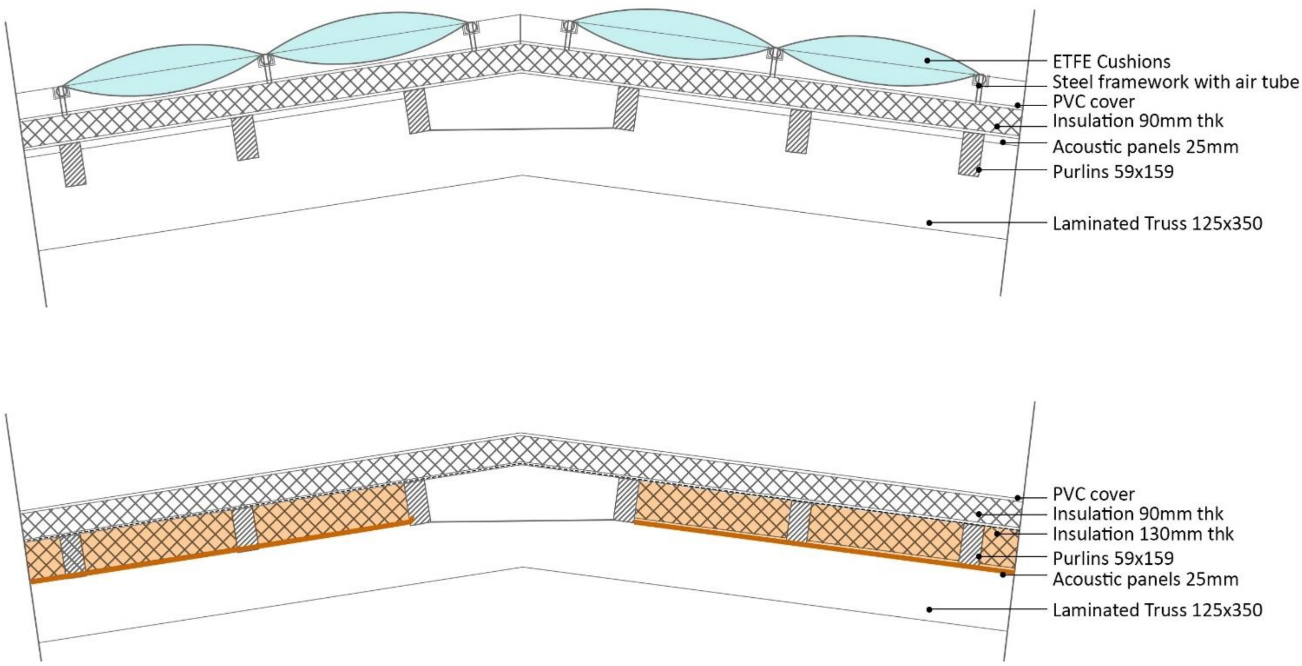


Figure 68 Roof over Bar Attic, Option 1 - Installation of ETFE over existing roof (top), Option 2 - Adding interior insulation material (bottom)

Another option of adding a lightweight sedum green roof was analysed. Green roofs are able to reduce ambient temperature, purify outdoor air, regulate indoor temperature and also act as rainwater buffer. However, green roofs can be expensive and would require higher maintenance. Therefore, the idea was not followed.

High efficiency glazing: Window to wall ratio is increased by 50%. This largely impacts daylight entering the building and visual comfort. Using a *Double glazing with low-e coating* will be used as this reduces the solar heat gain while retaining the visual light transmittance. In this way heat losses are reduced and making it suitable for both heating and cooling climate.

Building Integrated Photo-Voltaic (BIPV) panels applying to windows, skylights, or awnings. The façade can generate energy with BIPV. With BIPV panels on glass, a semi-transparent façade system comes into play which allows partial sunlight and partial shading, depending on the customization and requirement of panels.

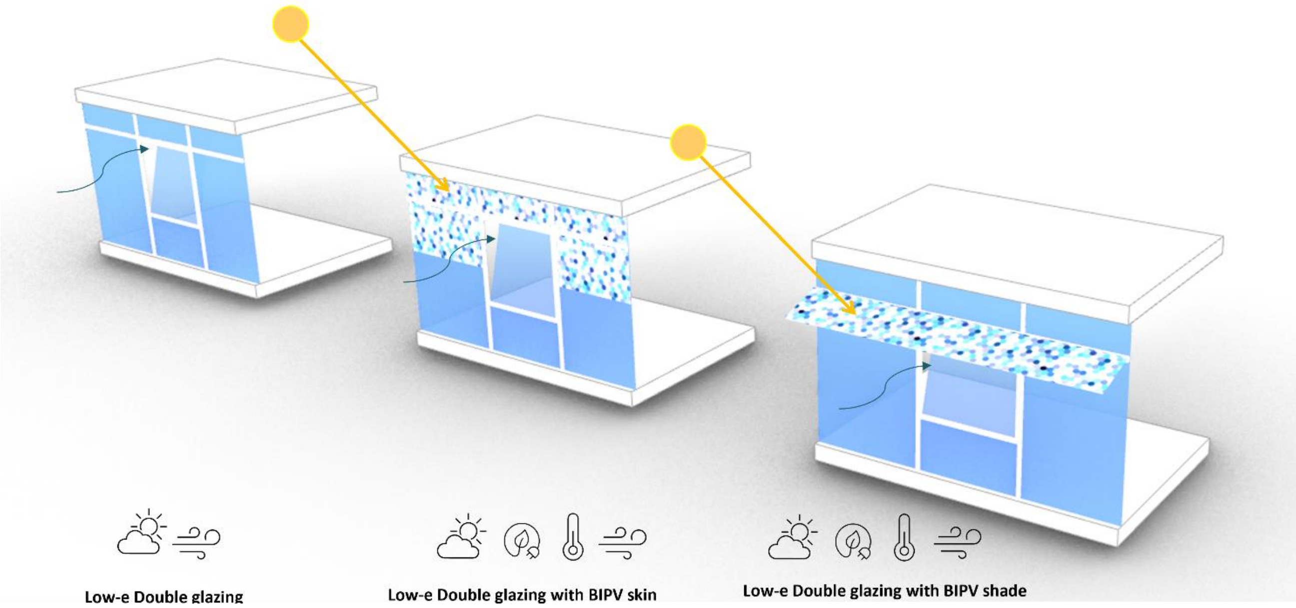
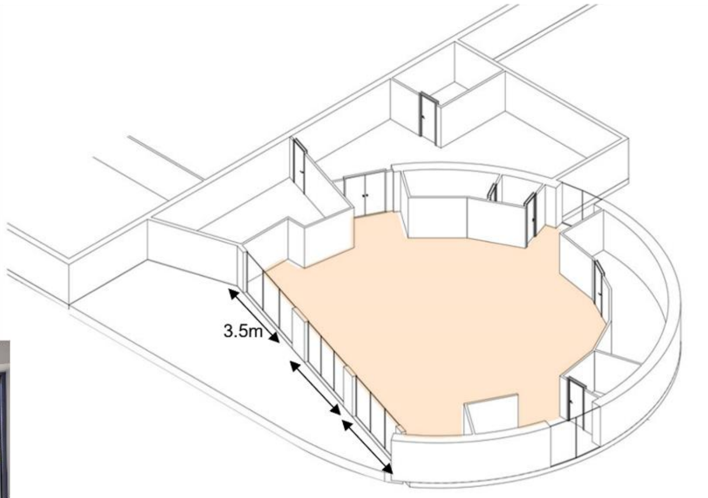


Figure 69 Options developed for energy efficient glazing systems

For balcony opening in bar attic, two types of doors are compared bifold doors and sliding doors. Both the types have very good thermal efficiency and visual appearance. Bi-fold doors give seamless views to outdoors when in open condition making the interior spaces very open-air compared to sliding doors. From market research, it is also noted that affordability of bi-fold doors is more than a sliding door. However, bifold doors require space to fold onto itself internal or externally while sliding doors simply slide on horizontal track. The choice for bar attic boils down to functional aspects of space and cost. In architectural context, the bi-fold doors enhance the ambience of room and allows unobstructed view to the outdoors, specially during high occupancy hours at parties or events. Also, opting for aluminium bi-fold doors allows for easy installation, it is lightweight and available in varying configurations. For even more enhance thermal performance, aluminum-wood frame is a reasonable choice.

Bifold doors. Source: Solarlux

Sliding door. Source: Smartwin



ATTRIBUTE	BIFOLD DOORS	SLIDING DOORS
Thermal efficiency	Excellent	Very good
View when open	Excellent	Very good
Space saving	Good	Excellent
Wind durability	Good	Excellent
Visual appearance	Excellent	Excellent
Ease of access	Yes	No
Configuration types	Various	Limited
Affordability	More affordable	Less affordable

Figure 70 Bar attic door options

Given the span of single opening 3.5m, a bi-fold door with 5 panels is suitable. Three such doors can be installed in the bar attic as shown in plan. A Solar lux SL-97 bi-fold door is based on aluminum-wooden frame, providing high thermal insulation, airtightness, wind resistance and improved energy savings. It has U-value of 0.8 W/m2K and slim sight line of 97mm.

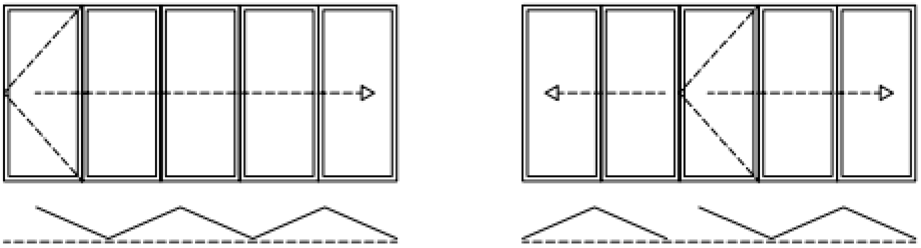


Figure 71 Bifold door mechanism. Source: Solarlux

Skylight: Further measures are taken to improve the natural light in the De Beuk specially in the rear side. A round skylight like an oculus opening not only allows daylight but has an aesthetic appeal for the bar attic. The round window concept can be better trailed back to historical context of Proteus Eretes association which relates to the saying 'het venster hemelsblauw' meaning the window sky blue. The 'venster' design can be identified in association's quarterly publication.

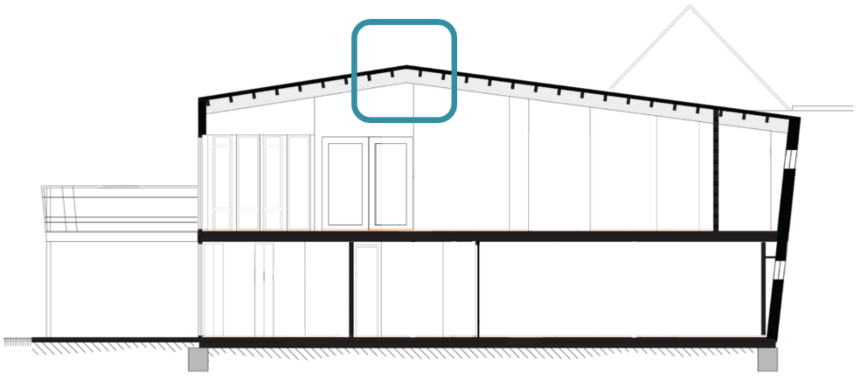


Figure 72 Round skylight for the roof of bar attic

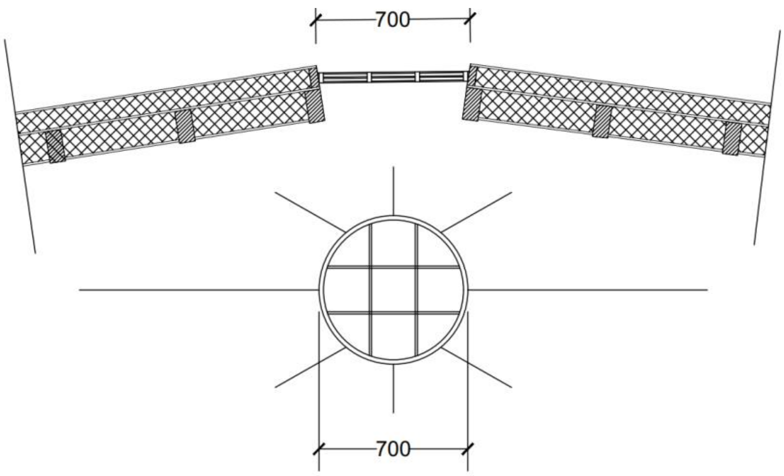


Figure 73 'Venster' publication by Proteus Eretes depicting the round window

4.2.2 Ergometer

The new ergometer room has a glazing percentage of 85% and high visual comfort. This south-west façade also captures large amount of solar radiation, which means the cooling demand may increase in summers. Glazing option should allow natural ventilation through window openings, ventilation grills or façade system that allows air cavity for circulation of air. Secondly, the name board acts as a shading element and also reduces heat gain reducing the cooling demand.

A cheaper option is double glazed curtain wall with intermediate openable panels. Using this system for exterior wall of ergometer room and the interior wall with openable windows, allows cross ventilation. Eventually, this reduces the ventilation loads, positively impact air quality and the enriches user interaction with nature-oriented design of space. The existing roof skylight on northern side has panels which can be made openable for stack effect ventilation. The round glazing adds on to the previous comment about the historical context of the association.

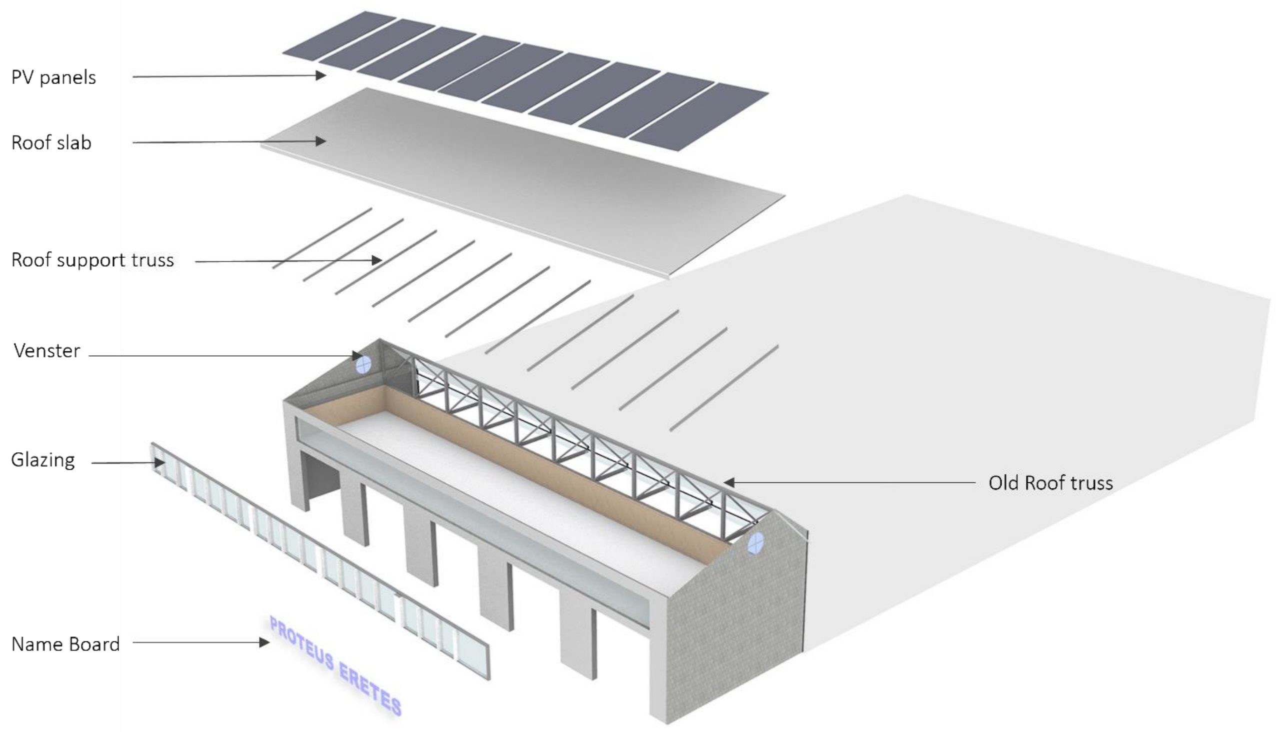


Figure 74 New ergometer view

4.3 Improvement of building services

The active strategies that include sustainable building services and energy efficient equipment which largely reduce the operational energy demand and increase the indoor environmental quality are proposed in this section. Before explanation on choices for building services and technology, certain measures for changing the layout of existing installation room, heating pipelines and ductwork are considered in correspondence to the new layout. Several schemes are designed for location of installation room with heat pump unit and heat recovery ventilation (HRV) for both the buildings, De Beuk and Boat storage.

Scheme 1 – Common Installation room with heat pump and HRV

While redesigning the spatial layout of rowing accommodation, the idea was jotted on creating a common installation room connecting De Beuk and boat storage. This room consists of common heat pump with electric boiler for heating in two buildings with buffer water tank and heat recovery unit. The electricity would be generated by solar panel combined with grid electricity if needed. The source of heat pump is water heat exchanger, details explained in further topic.

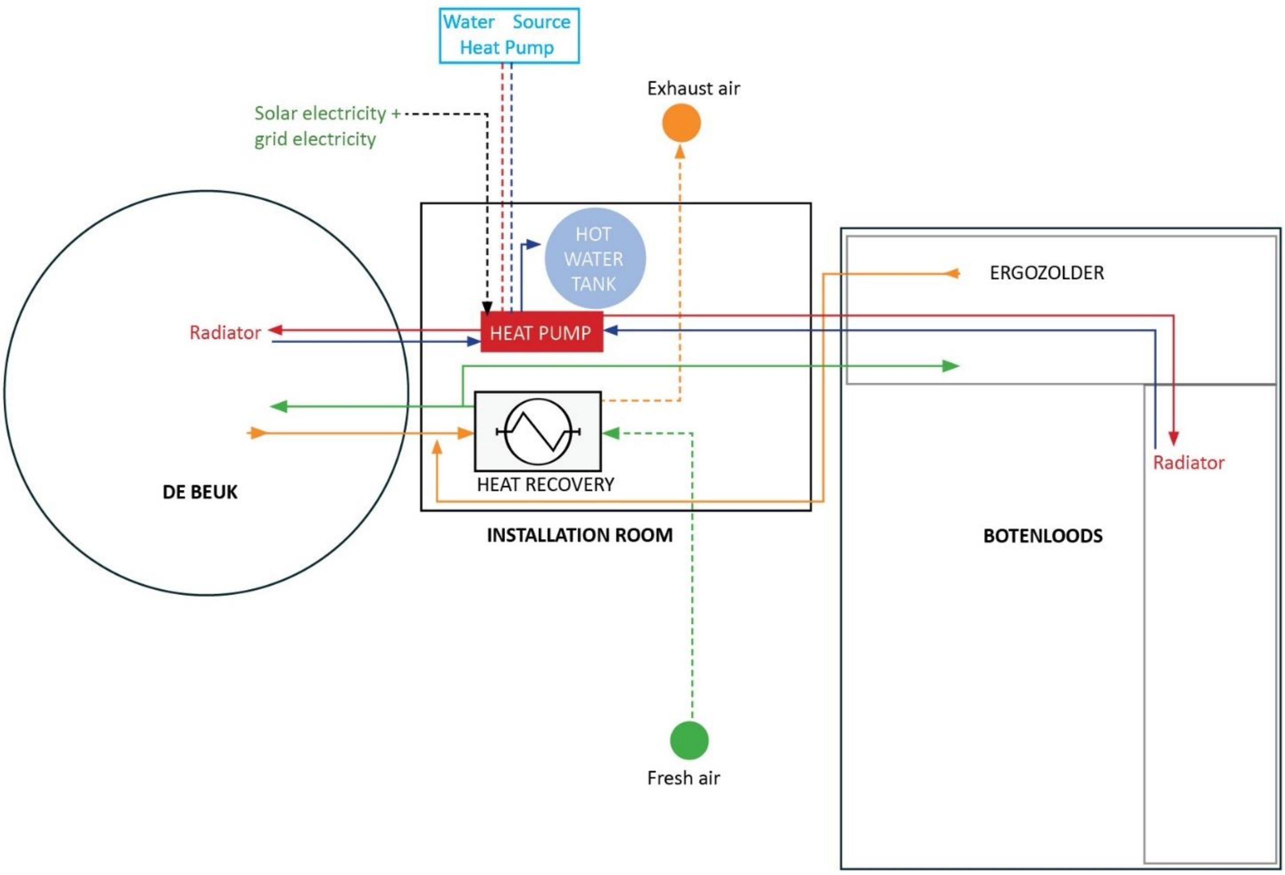


Figure 75 Heating and Ventilation layout scheme 1

Scheme 2- Common HRV, using existing installation rooms with heat pump

In this scheme, common heat recovery unit is installed whereas the heating is done separately with individual heat pump for De Beuk and Boat storage. The existing installation spaces are used in this layout which also consists of existing hot water tank. Extra number of pipelines would be required for two separate heating systems.

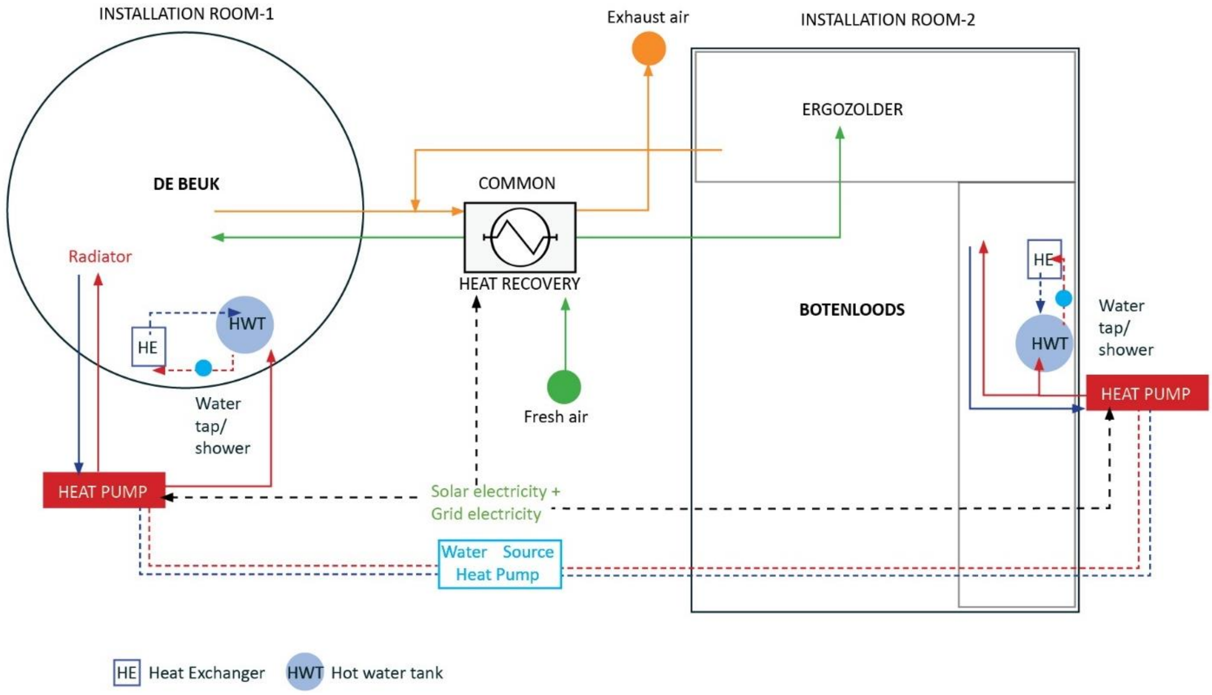


Figure 76 Heating and Ventilation layout scheme 2

Scheme 3 – Separate installation room with separate units

Both buildings have separate heating and ventilation system. Here again, the double ducting and pipelines systems would be needed for two blocks considered separately. The heat recovery can be added to existing mechanical ventilation unit in boat storage.

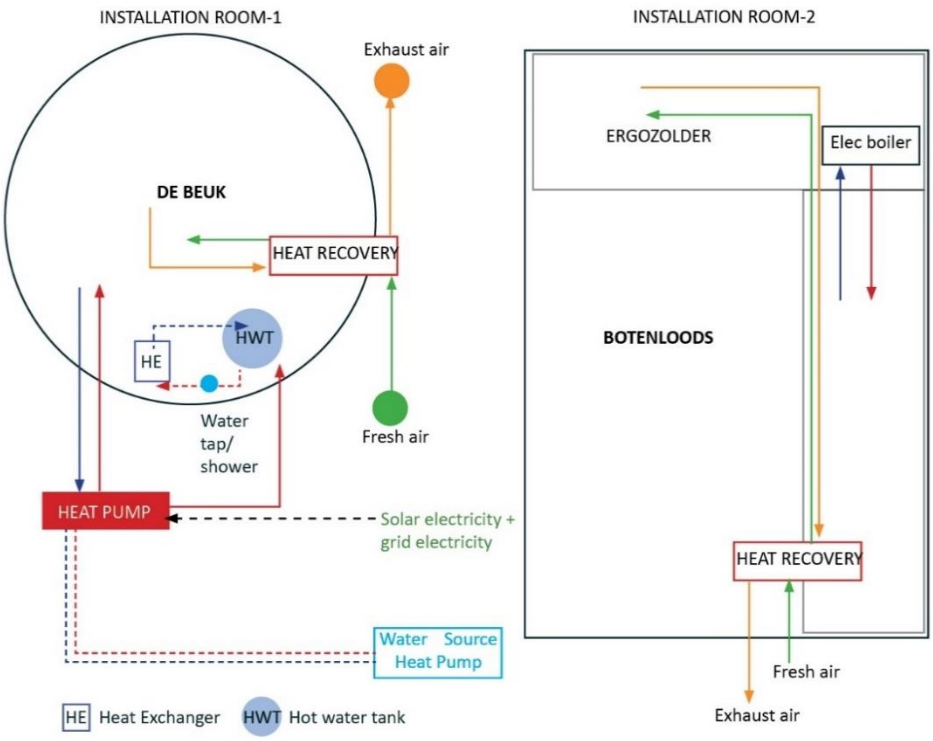


Figure 77 Heating and Ventilation layout scheme 3

These schemes are compared on the factors stated in table. The first scheme with common installation room is a future-proof design solution for improvement in building services. Although, the extend of alteration in heating pipelines and ductwork is high and the initial cost too, this scheme results in higher efficiency compared to other installations. The running cost in long term is also low since only central systems are used for heating and ventilation, instead of installing separate units for De Beuk and boat storage. Installation of separate units would require extra source lines to heat pump which makes the option redundant. Subsequently, exploration is done for energy efficient equipment and technology that are proposed further to logically fit in chosen scheme for heating and ventilation.

Table 10 Comparative analysis of heating and ventilation schemes developed

	SCHEME 1	SCHEME 2	SCHEME 3
	COMMON INSTALLA-TION ROOM	COMMON HEAT RE-COVERY, SEPARATE HEAT PUMPS	SEPARATE INSTALLA-TION ROOMS
Extent of changes in spatial design	Additional room in the same layout	Additional space for MHRV unit	Not much change
Extent of change in pipeline and ductwork	Complete change	Ventilation ducts will change	No change, reusing the same lines
Efficiency	High	High	Low
Installation cost	High	Moderate	Low
Longer time span	yes	Maybe	No
Lower running cost	Yes	Maybe	No

a. Canal water heat exchanger as source of Heat pump

The sources for heat pump are already discussed in literature. This topic discovers an interesting edition to use water as source of heat pump, a quay wall with heat exchanger. Since Netherlands has extensive canals across the country, the quay walls are an opportunity to act as a source for heat pumps and thus contribute to sustainable heating solutions. The research by AMS institute together with TU Delft, explored that the canal water could be collected in summer, stored in the subsurface and used in winter with the help of heat exchanger connect to heat pump system for single building or multiple blocks. The energy quay wall incorporates thermal energy via sheet piles or concrete piles installation stretched along the whole renovation quay wall (Haasnoot et al., 2020).

A highly conductive steel collector is welded to the quay wall, extracting energy from the surface water, and transferring it to a distributor via hoses filled with glycol. The heat pump transforms the temperature difference into energy that can be used.

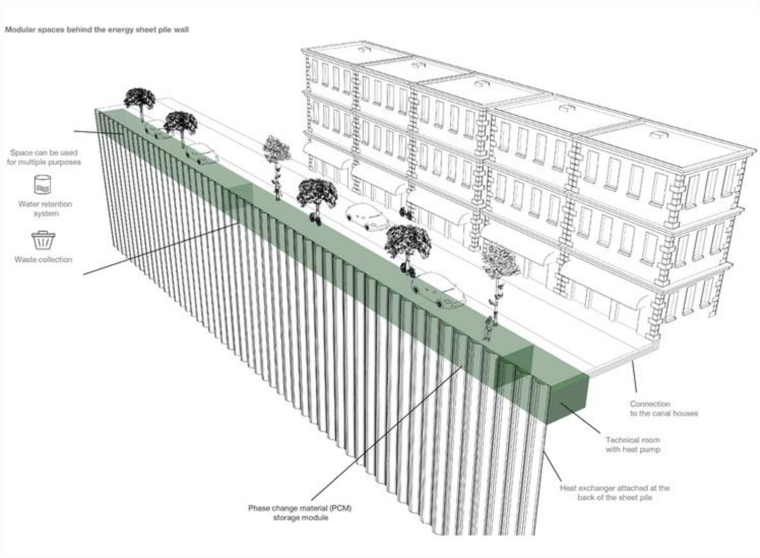


Figure 78 Quay wall as heat exchanger using sheet piles. Source: (Dang & Voskuilen, 2021)

In situation where only an individual building requires separate heating source, smaller standard water heat exchangers with high extraction capacities and COP values can be used instead of sheet pile system. The water heat exchangers are available in various capacities and sizes in the market. These are suitable for houses on water, houseboats, and specially rowing accommodations which are located on canal side. These heat exchanger panels are made of high-quality UV-resistant polypropylene and are extremely suitable for generating sustainable energy. (see Appendix E)

Figure 79 Water heat exchanger / Aquathermy. Source: (Mefa, n.d.)

Based on parameters of efficiency, lifespan, running cost and seasonal performance factor, or water heat exchanger is suitable choice compared to air source heat pump and ground source heat pump. Particularly for Proteus Eretes, this is advantageous as it has low operating costs, uses relatively constant water temperature, and easily accessible from canal. In fact, the new location of installation room can have easy connection of pipes with water exchanger as shown in schematic section. The size of the heat exchanger is 3.6mx0.95mx1.1m.

Table 11 Comparison between air source heat pump, ground source heat pump and water heat exchanger.

Item	Air Source Heat Pump (ASHP)	Ground Source Heat Pump (GSHP)	Quay wall heat exchanger (water heat exchanger)
Seasonal Performance Factor	1.8-3.4	2.5-5.6	3-5
Ideal for retrofit for existing building	Yes	Yes	Yes
Lower installation cost	Yes	No	Yes
Requires less space for installation	Yes	No	Use of canal subsurface
Better efficiency at low outdoor temperature	No	Yes	Yes
Less noise	No	Yes	Yes
Lower running cost	No	Yes	Yes
Longer lifespan	No	Yes	Yes
Low carbon & zero pollution	Yes	Yes	Yes

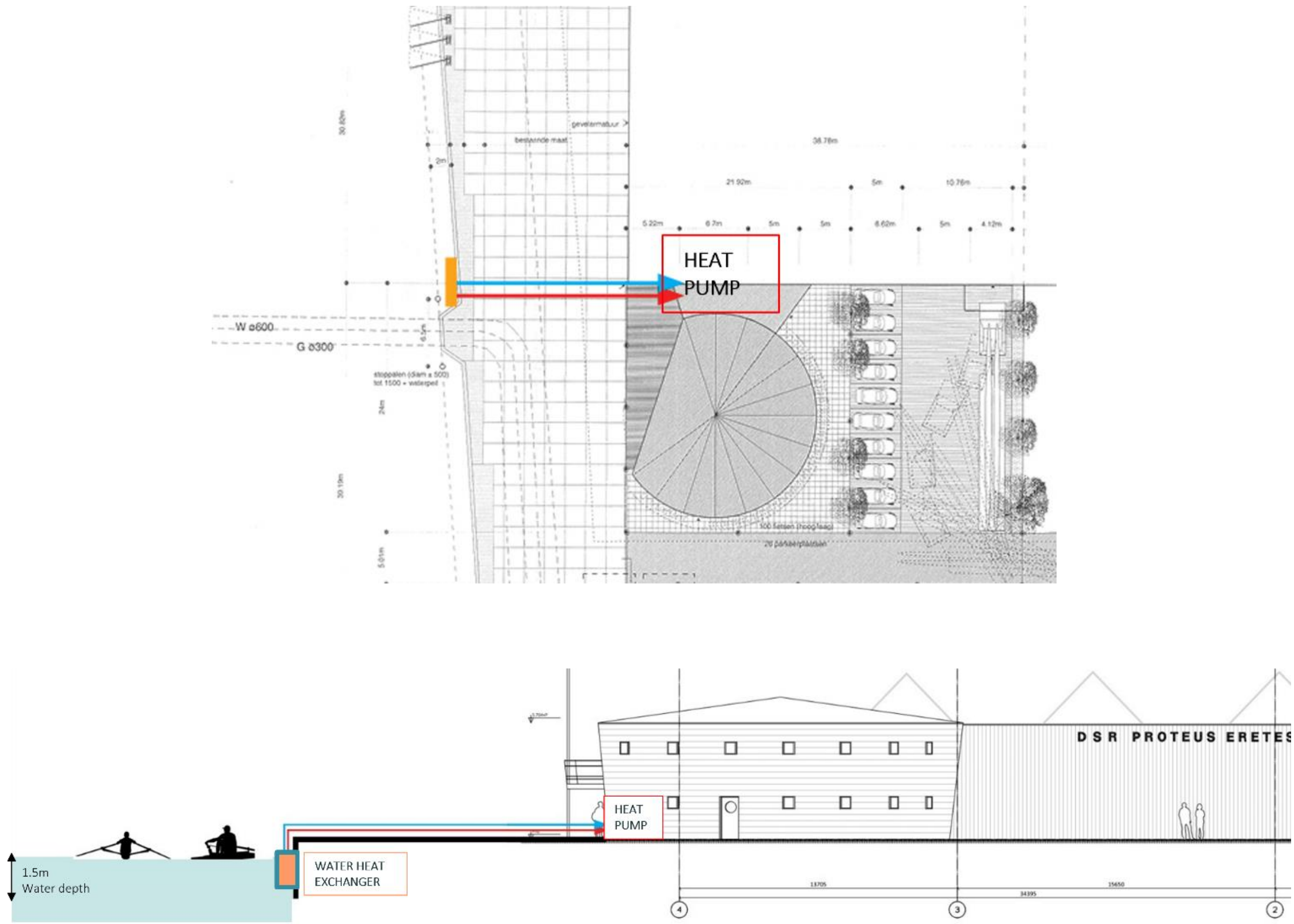


Figure 80 Site section showing water heat exchanger connection to new installation room of Proteus Eretes

b. Space heating and domestic hot water

Gas boiler which has high carbon emission will be replaced by heat pumps which rely on renewable energy sources. The combination of heat pump with solar collector will add to sustainable heating solution in the building.

Low temperature radiators will replace the traditional radiators in the building since these radiators extend heat evenly along the space. Both De Beuk and boat storage have separate hot water tank for the supply of domestic hot water. These can be reused in connected to new heat pump system. The following layout shows the layout of heat pipe and cold pipe for new heating system that is connected centrally from common installation room.

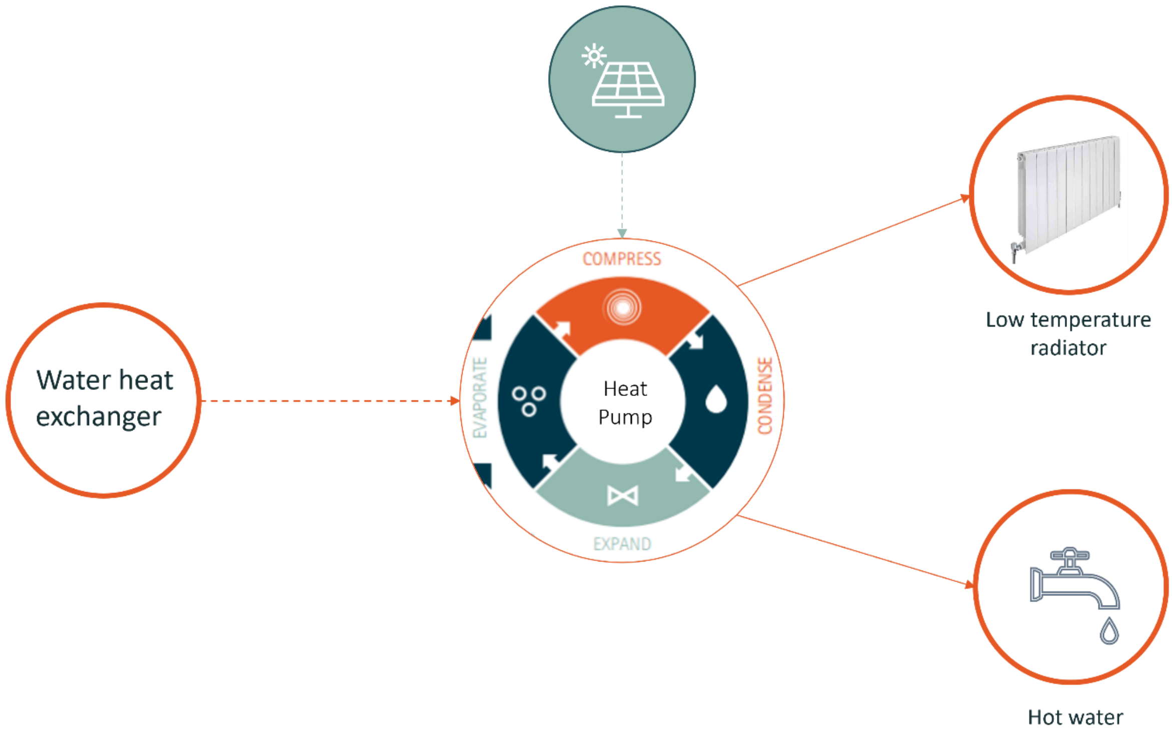
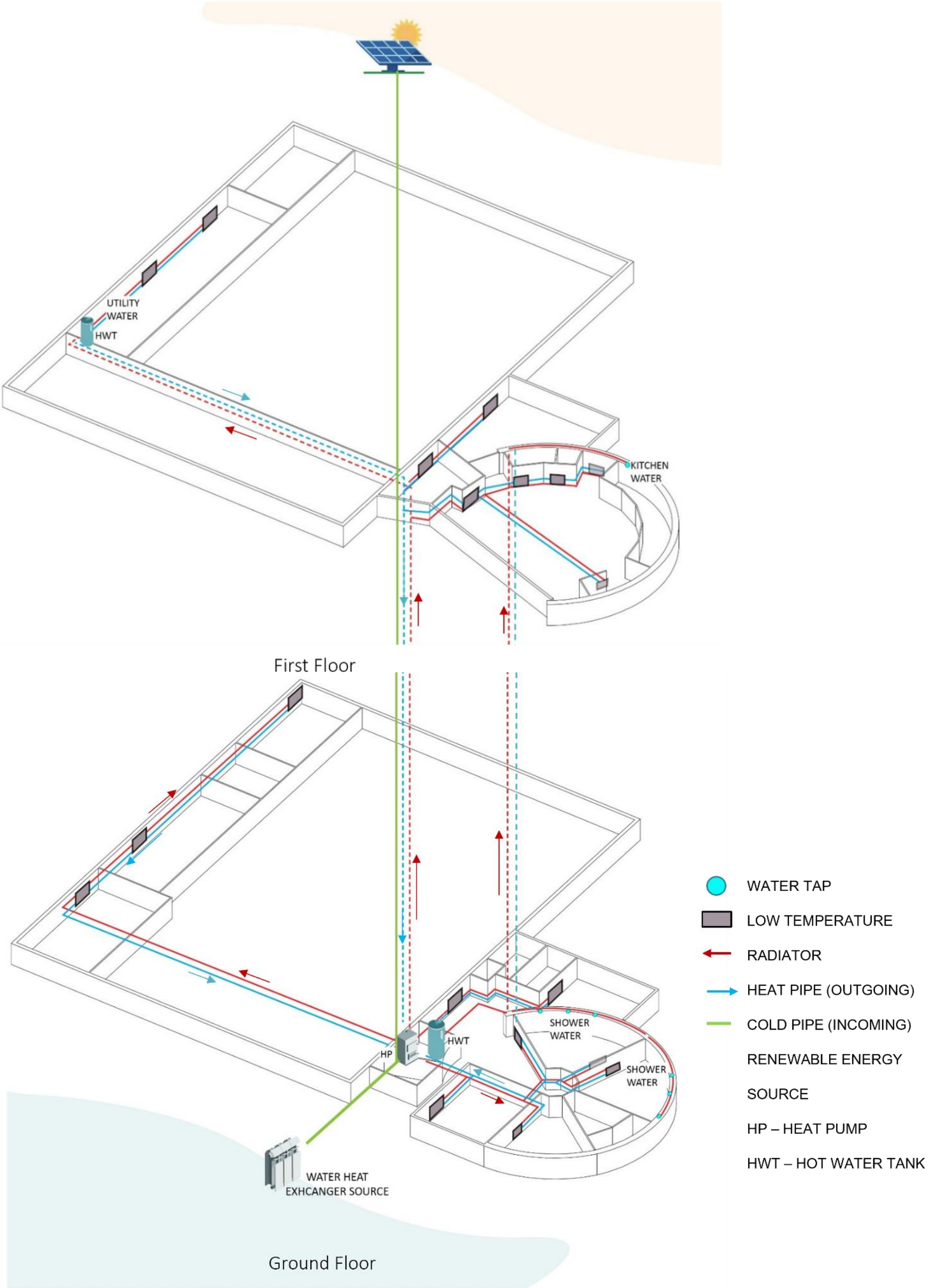


Figure 81 Map for heat flow

Figure 82 Proposed heating system and connection lines in renovation plan of Proteus Eretes



c. Heat recovery ventilation

To design for good indoor air quality, fresh air requirement for each room is calculated. The minimum values for outdoor air flow rate per person and outdoor airflow per unit floor are considered from EN 15251. There are three methods by which minimum fresh air requirement is calculated: ASHRAE method for minimum outdoor ventilation rate for breathing zone, air flow rate by air change method and air flow rate by activity level and outdoor CO2 concentration.

The ventilation capacity is calculated for normal occupancy and peak occupancy hours. With changing activity level, occupancy level and CO2 concentration, the fresh air requirement are calculated using online tool Airmasters Ventilator calculator. (see Appendix F)

The main factors affecting the ventilation amount are occupancy density, minimum outdoor air flow rate required per person or per sqm., metabolic rate and minimum air change per hour. For high occupancy hours, the activity level and number of people are increased, specially in bar attic during events or parties.

Table 12 Parameters affecting ventilation requirement

	Area (m2)	Height (m)	Outdoor air flow rate per sqm (l/s-m2)	Outdoor air flow rate per person (l/s-m2)	ACH	No. of people (normally)	Activity level (low)	No. of people (peak)	Activity level (high)
Committee rooms (3 rooms)		2.8	0.3	2.5	2	18	1.1	27	1.1
Bar Attic	155	3.4	0.7	4.9	6	20	1.2	70	3.6
Circulation	177	2.8	0.3	2.5	2	4	1.2	6	1.2
Ergometer	195	3.6	1.5	7	8	15	4	30	4
Strength training room	47	5.6	1.5	7	6	10	4	15	4
Multi-purpose hall	100	3	0.3	2.5	2	10	1.2	20	1.2

The decision is based on higher ventilation amount calculated or a balanced value out of the three methods (highlighted in orange). In committee rooms, the airflow rate is considered for normal occupancy since it is unlikely that these rooms reach high occupancy. On the other hand, bar attic, ergometer, training room and multipurpose hall are likely to have high occupancy density during peak hours. The total ventilation requirement is 16401 m3/hr to provide good indoor air quality.

Table 13 Ventilation requirement for normal occupancy and high occupancy calculated with different methods

VENTILATION REQUIREMENT						
	DE BEUK			BOAT STORAGE		
Normal occupancy	**Committee rooms (all)**	**Bar Attic**	**Circulation**	**Ergometer**	**Strength training room**	**Multi-purpose hall**
	m3/hr	m3/hr	m3/hr	m3/hr	m3/hr	m3/hr
Minimum air flow rate required ASHRAE method	317	743	123	1431	141	55
Air flow rate by ACH method	711	3162	991	5616	1579	600
Air flow rate by activity level, Outdoor CO2 conc. method	774	1224	547	2040	1360	504
High occupancy	**Committee rooms (all)**	**Bar Attic**	**Circulation**	**Ergometer**	**Strength training room**	**Multi-purpose hall**
	m3/hr	m3/hr	m3/hr	m3/hr	m3/hr	m3/hr
Air flow rate by activity level, Outdoor CO2 conc. method	1010	8568	547	4080	2040	816
Total (m3/hr)	**9465**			**6936**		
Grand total (m3/hr)	**16401**					

The maximum capacity of ventilation is thus considered for higher occupancy hours. However, at normal occupancy hours the ventilation requirement is much less. Due to varying occupancy rate and changing course of activities, demand control ventilation is the most suitable choice.

The ventilation system includes a CO2 sensor which measures CO2 concentration and sends a single to control module. This can also be used for temperature, humidity, and VOC readings. The control module further sends signal to motorised damper to create a variable air volume system (VAV). The damper proportionally adjusts the airflow according to CO_2 level inside the duct. The control module is connected to common heat recovery unit

The variation of people in the building leads to a pressure change in the ducting system. The heat recovery units, which includes a constant pressure DCV system, adjusts the airflow to each situation, favouring a greater temperature comfort and energy savings (Figure 84).

Three conditions are explained for ventilation in bar attic in Figure 85. Firstly, when the room is empty, the pressure level in duct is stabilised with partially open damper and minimal air flow. Next, people start filling in the room because of which the CO_2 sensors activate sending signal for increased amount of airflow required. This increases duct pressure level in partially open damper. Finally, when the room is fully occupied, the motorized damper fully opens to stabilise the pressure level and allowing higher air flow.

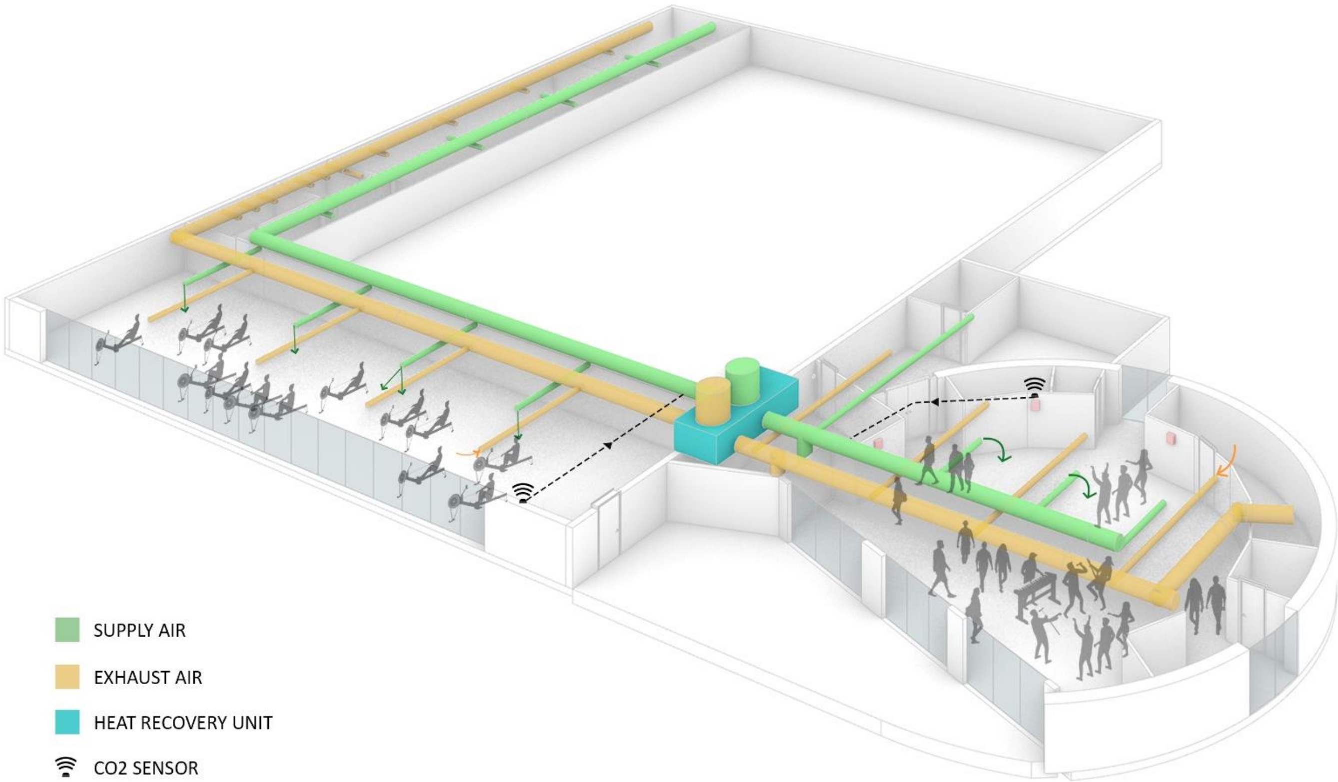


Figure 83 Heat recovery ventilation system with CO2 sensor

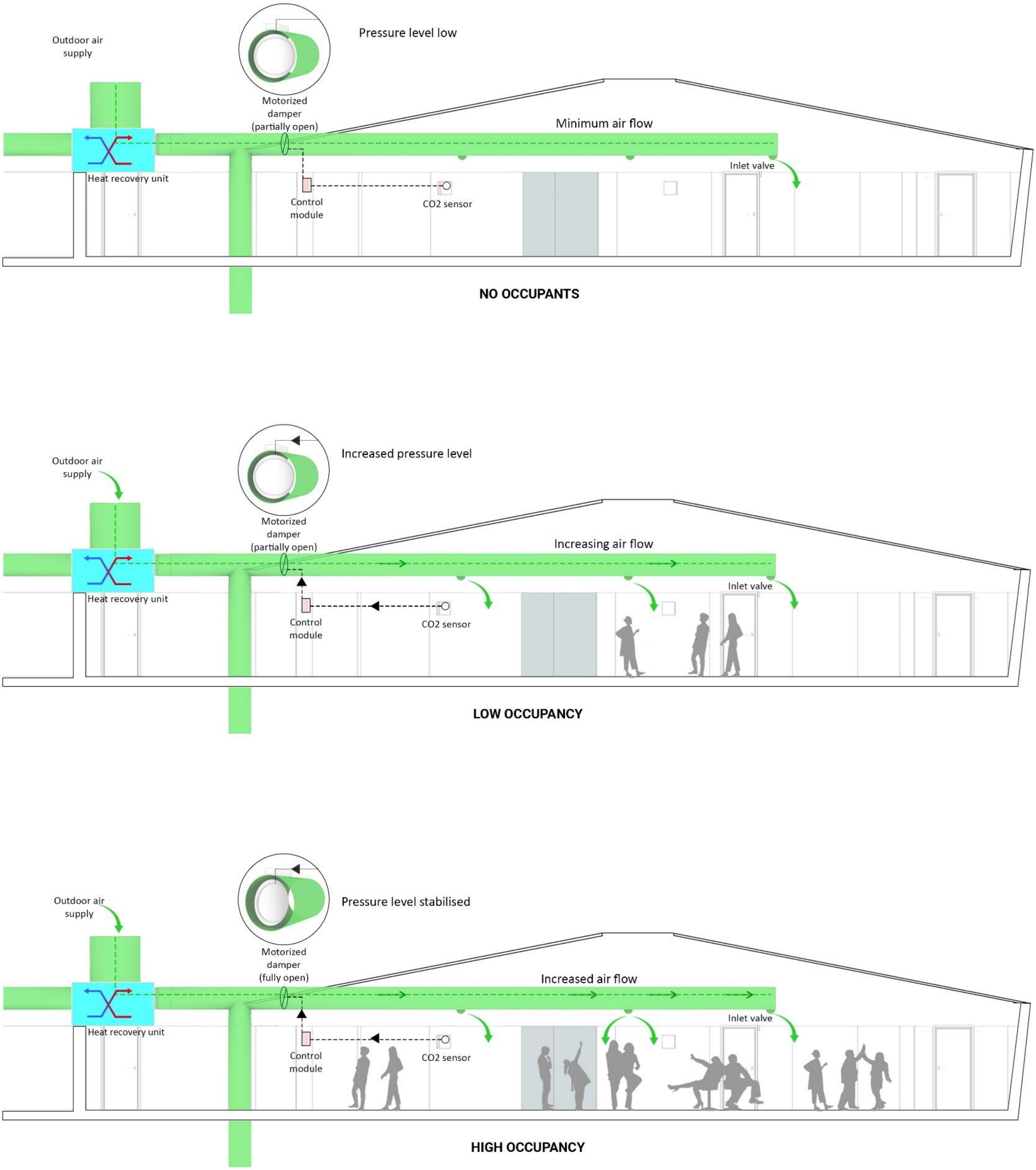


Figure 84 Ventilation control system at different occupancy hours

d. **Solar tubes**

The installation of solar tubes technology is quite beneficial to further reduce lighting loads. These tubes have internal reflective surface. The light is captured in the glass dome at the roof, which gets reflected within the tube and distributed via a diffuser into the room. This is an effective method specially for refurbishment projects where there is limitation to reconstruction façade openings.

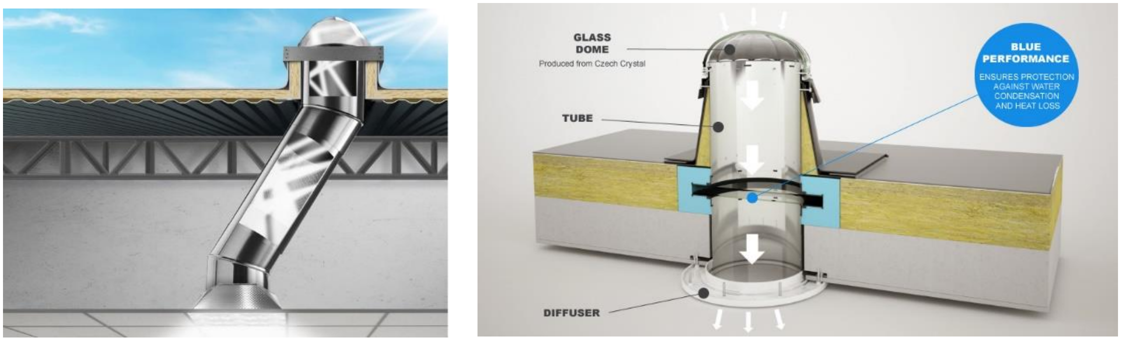


Figure 86 Solar Tubes. Source: (Solatube, n.d.)

The north-east facade of De Beuk caters very less natural light (kitchen and changing rooms). It is also difficult to renovate this façade because of the compactness of design and interior spaces. Therefore, daylight tubes will be installed. These daylight tubes provide high visible light transmittance and have low thermal impact because of low solar heat gain. The product is available in variable sizes ranging from 250mm to 750mm diameter, with adjustable angles in duct. The installation is possible on all types of roofs and facades. Additionally, these will be installed in the workshop at Boat storage. (see Appendix E)

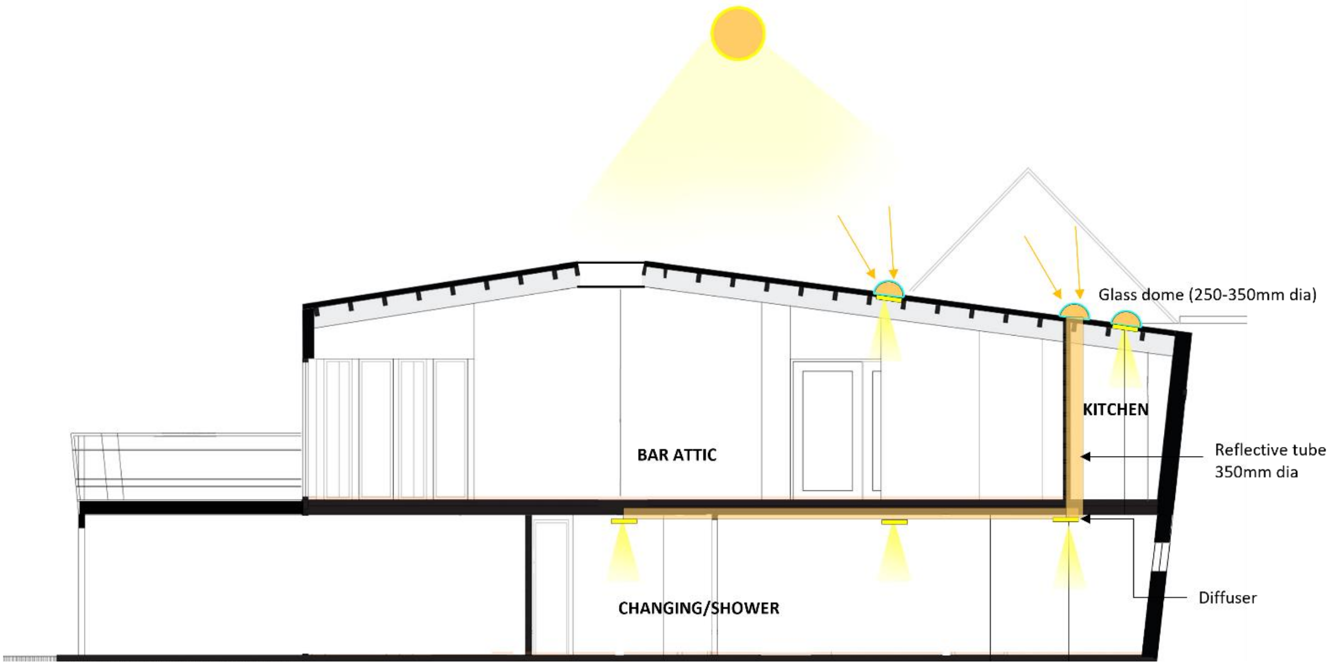


Figure 87 Installation of solar tubes in De Beuk

4.4 Adding PV for on-site energy

In addition to façade integrated PV, the roof of boat storage is suitable location for adding array of PV panels. The structure of existing sloped roof is not strong enough to support array of PV and it acts as a skylight. Therefore, the new roof of ergometer and existing flat roof is to be considered for PV installation. The area including new roof and existing flat roof is 480sqm.

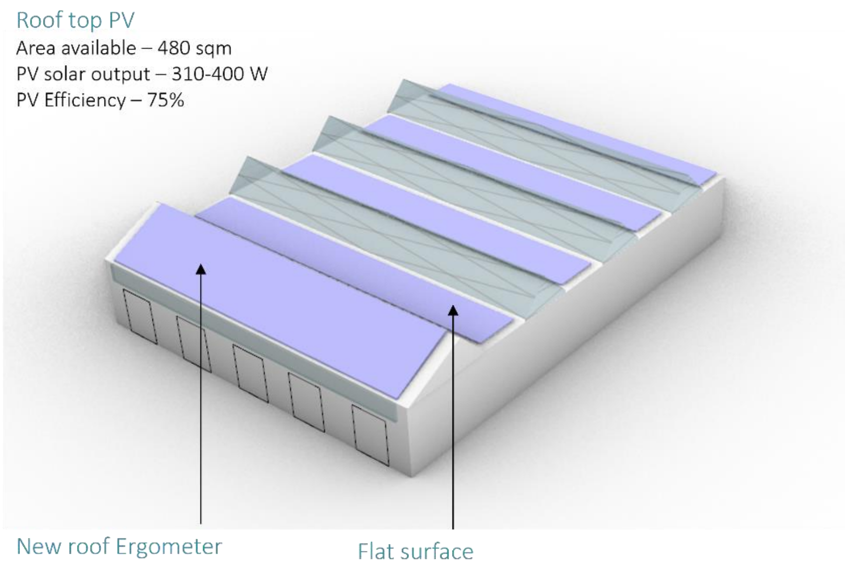


Figure 88 PV panels on the roof of Boat Storage

A high efficiency PV with solar panel output of 310-400W shall be used. The number of modules of PV needed to meet the annual energy requirement is assessed in the next chapter. This shall also include the energy generated by building integrated PV façade in De Beuk.

4.5 Summary

Various strategies for improving thermal mass system, openings, heating, and ventilation were discussed. Integrating passive design strategies with active equipment technology, the proposed design is further validated for energy, comfort, and daylight. The planning concepts are modelled in Design Builder software and assessment is performed in the following chapter.

5. ENERGY & COMFORT ASSESSMENT

This chapter shows the assessment performed for energy and comfort to validate various design strategies explained earlier. Thermal comfort is evaluated according to comfort classification level using ATG method as per ISO74 and energy criteria is justified on overall primary energy reduction as per BENG calculations.

Using design builder software, the assessment has been carried out. Four essential steps that are considered: modelling the building, input parameters for simulation, optimization based on previous design strategies, evaluation on energy and comfort.

Design modelling: Using the CAD plans design builder model is developed, with each internal space as 'zone'. The model is quantified, and specifications are given with input parameter data:

Location: The energy plus weather (epw) file from 2020 for Amsterdam is added to the software for location.

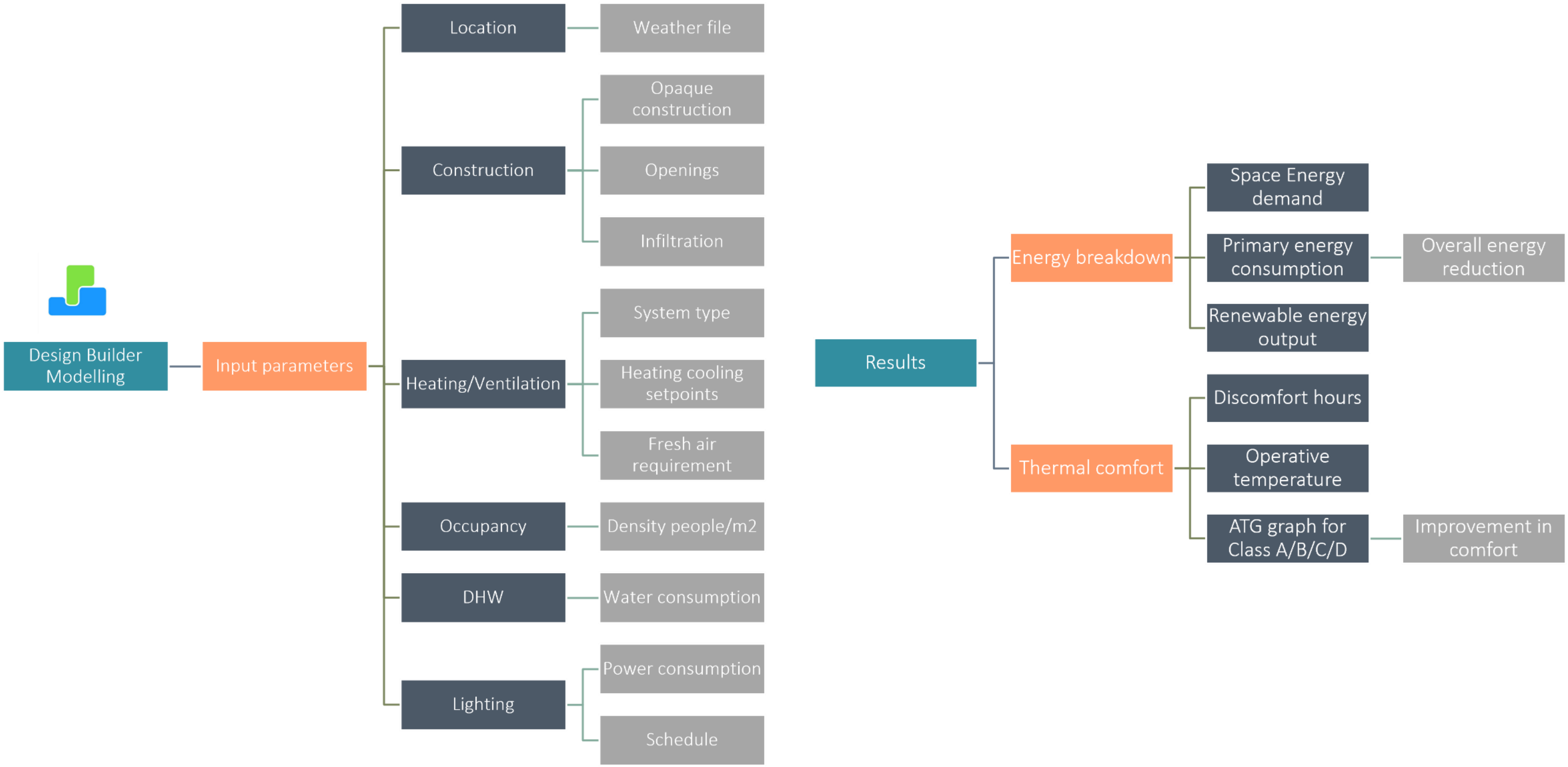
Construction: The material is composed in design builder for opaque construction and openings as per the existing situation. In the baseline scenario, the thermal properties are considered with possible thermal bridging in construction. For the proposal, the material is optimized with required specification and thermal properties without any thermal bridging.

Opening: Façade openings sizes are also designed as per the window to wall ratio which is in existing design and further redesigned for proposal. Overhang and internal blinds for solar shading in summers is also tested for improvement in results.

Heating and ventilation: This data is filled and modified under the detailed HVAC loop. Each room is given a heating and cooling setback depending on the function of room. Radiator/convective heating is used. For ventilation, mixed mode ventilation is set to true which is a combination of natural ventilation and mechanical ventilation. The air change per hour (ac/h) for kitchen, toilets and shower is set 12 ac/h, 10ac/h, and 10 ac/h respectively. While for meeting room the minimum requirement is 4 ac/h and bar attic is minimum 7ac/h. The minimum fresh air requirement for each room is set according to calculations made earlier.

The model data used for heating and cooling energy outputs is based on 'ideal loads' operation in the software. hence the values used for energy demand are the zone cooling and zone heating has been evaluated. There is no active cooling equipment (like air handling unit) involved in the existing or proposed model, rather mechanical ventilation which includes system fan power and pump are modelled. Using the 'room ventilation' setting, system fan energy is determined. Fan pressure rise of 400Pa is considered since there is presence of natural ventilation combined with mechanical ventilation. In existing case the efficiency of fan is 70% while in proposal, the fan efficiency is changed to 85%. The modelled HVAC system for proposal uses an auxiliary energy of 10 kWh/m2 while in existing case with default energy of 3kWh/m2 has been considered.

Figure 89 Steps performed for Design builder calculation



Occupancy: Different zones are assigned activity type which provides occupancy schedule as per the function of space. The density of people per m2 is calculated for each floor area separately. This also effects the fresh air required in that zone.

DHW: The daily hot water requirement in 120 l/day. This data is only used for kitchen, toilet, and shower.

Lighting: The lighting power is used from default lighting schedule generated from activity type. Lighting control is adjusted to reduced lighting loads in case of daylight access through windows and skylight.

Energy Generation: The design proposal includes energy generation with PV panels on roof of boat storage and BIPV on façade of De Beuk. This is set under DC inverted option for generation tab.

Initially, the simulation and optimization for the two buildings is carried out individually to quantify energy and comfort outcome. Later, the final energy consumption is combined for two buildings and then compared with the existing total energy consumption. The simulation is carried out for annual, monthly, daily, and hourly periods. The results obtained from simulations are used for further calculation and breakdown of energy for heating, ventilation, and lighting. Thermal comfort assessment is tabulated for Bar attic and ergometer room. Both these rooms have high occupancy and activities in summers specially. Also, the façade of the new ergometer and bar attic has south-west orientation with maximum solar exposure. Using comfort grid from Design Builder, outdoor mean running temperature and operative temperature for annual total hours are plotted in excel for ATG graph. For ease of evaluation, certain spaces were excluded from the calculation such as the storerooms and storage area for boats.

5.1 De Beuk

Three scenarios are developed for assessment. For a holistic comparison, each scenario is dealt with additional renovation strategy that helps to improve energy savings and thermal comfort:

Scenario 1: Existing (baseline) – Existing gas boiler heating with radiator and mixed mode ventilation without heat recovery

Scenario 2: Existing with building service retrofits – Mechanical Heat recovery ventilation and heat pump for space heating and DHW

Scenario 3: Proposed - Renovation layout, façade refurbishment, building service retrofits – Spaces redesigned, high efficiency glazing, BIPV glazing, higher air changes per hour, MHRV and heat pump for space heating and DHW, improving thermal mass by reducing infiltration and adding internal roof insulation

The following table for input parameters for the comparison of three scenarios simulated for De Beuk are depicted:

Table 14 Input parameters for De Beuk

Input Parameters Debeuk			Scenario 1 Existing	Scenario 2 Existing with Heat recovery ventilation	Scenario 3 Proposed - Renovation Design
Construction	Façade Opaque parts (innermost to outermost layer)		150mm brick, 80mm insulation, 9mm OSB, 22x38mm metal frame, 40mm sheet profile	150mm brick, 80mm insulation, 9mm OSB, 22x38mm metal frame, 40mm sheet profile	150mm brick, 80mm insulation, 9mm OSB, 22x38mm metal frame, 40mm sheet profile
	R-value Façade opaque parts (m2-k/W)		2.5	2.5	3.7
	Roof Opaque parts (innermost to outermost layer)		Acoustin insulation panel, Purlins 59x159, Laminated truss 125x 350, 180mm insulation, PVC roofing	Acoustin insulation panel, Purlins 59x159, Laminated truss 125x 350, 180mm insulation, PVC roofing	Acoustin panel, 130mm Cellulose insulation, Purlins 59x159, Laminated truss 125x 350, 180mm insulation, PVC roofing,
	R-value Roof opaque parts (m2-k/W)		3.7	3.7	6.7
	Infiltration (ac/h)		0.7	0.7	0.3
	Openings		Standard double glazing	Standard double glazing	6-13-6 mm low-e double glazing with argon gas filling
	U-value of glazing (W/m2-k)		3.2	3.2	0.9
Occupancy	Density (people/m2)	Bar Attic	0.2	0.2	0.2
		Committee rooms	0.11	0.11	0.11
		Showers	0.1	0.1	0.1
Heating	System		Boiler, water radiator	Heat Pump + Electric boiler, low temperature radiator	Heat Pump + Electric boiler, low temperature radiator
	Setpoint temp.	Bar Attic	23	23	23
		Committee rooms	22	22	22
	Setback temp.	Bar Attic	12	12	12
		Committee rooms	12	12	12
Ventilation	System		Natural ventilation + Mechanical exhaust OR supply	Mechanical heat recovery ventilation + natural ventilation	Mechanical heat recovery ventilation + natural ventilation
	Setting		on 24/7	occupancy profile per zone	occupancy profile per zone
	Fresh air Debeuk (m3/h) (excl. infiltration)		868	868	868
DHW	System		Boiler	Heat Pump Boiler	Heat Pump Boiler
	Water consumption (l/day)		120	120	120

5.1.1 Energy Performance

Scenario 1 – Existing

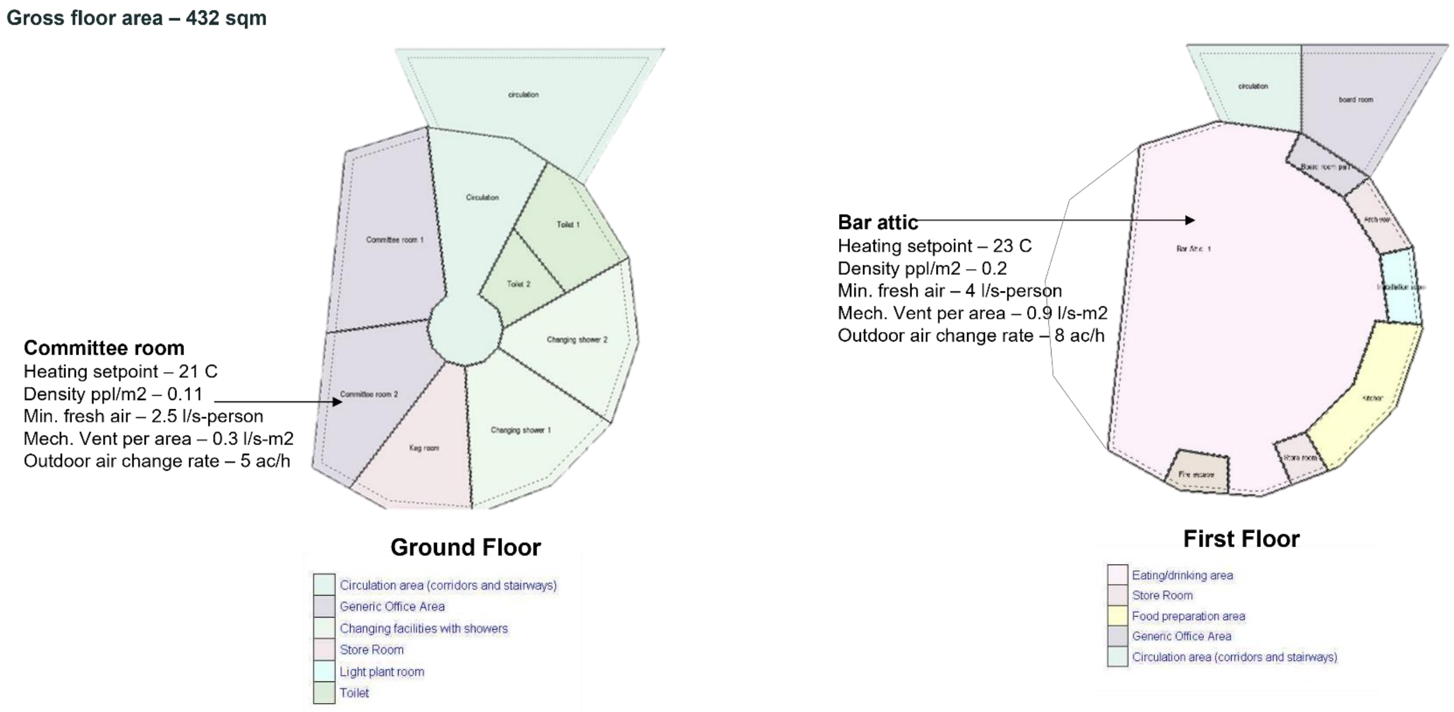


Figure 90 Design builder plan - Existing

Through the results for existing situation, it is quite evident that the heating contributes to majority of primary energy consumption. The heat gain and energy consumption graph (fig 92) show that heating energy even reaches as high as 36kW in winters for certain days. Since there is no active cooling installed in the building, the operative temperature reaches 30°C in peak summer days. The thermal resistance of building envelope is quite low, the heating demand in winters increases to achieve the defined heating setpoint temperature of 22 °C.

The energy result from design builder is used for annual primary energy calculation. The primary energy factor (PEF) for gas is 1.15 and electricity is 1.45 as per EPBD fact sheet (Hitchin et al., 2018). The fuel breakdown energy is multiplied to PEF which gives the annual primary energy consumption. The input for gas boiler efficiency is kept 0.85. The lighting is set to CFL fluorescent lights.

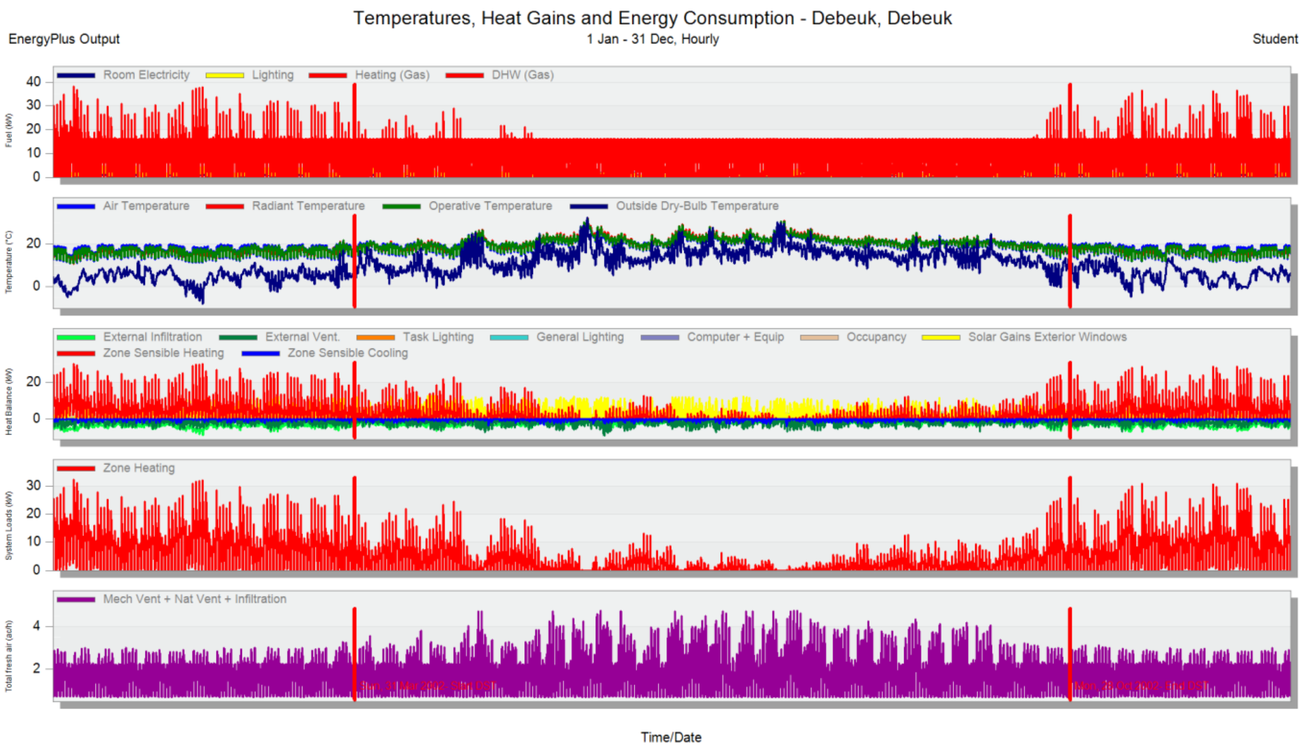


Figure 91 Heat balance, energy consumption and temperature graph - Scenario 1

The ventilator energy is not calculated with Design Builder, for which the following equation is used. The pressure the ventilator can delivery in condition with mechanical supply and exhaust without heat recovery is considered as 0.8 kW/m3/s (van der Spoel, 2019). The ventilation amount for existing case is explained in Appendix F.

Ventilation energy (kWh) = 0.8 *(kW/m3/s)* * *Ventilation amount (m3/hr)* * *operation hours / 3600*

Ventilation energy (kWh) = 0.8 (kW/m3/s) * 9344 (m3/hr) * 4248 / 3600

Ventilation energy (kWh) = 8820 kWh

Out of total energy consumption, 28% is used for space heating and 54% for domestic hot water. The total primary energy consumption is 163MWh.

Table 15 Energy Results for the existing case

SCENARIO 1	Energy Demand (kWh)
Heating (gas)	33626
Cooling	2472
Lighting	10687
Total	**46785**

SCENARIO 1	Fuel Breakdown (kWh)	Primary energy factor (PEF)	Primary Energy Consumption (kWh)
Heating (gas)	39560	1.15	45494
System fans	8820	1.45	12789
Lighting	10687	1.45	15496
DHW (gas)	77633	1.15	89278
Total			**163057 kWh**

Scenario 2 - Existing with heat recovery and heat pump installation

In this scenario, only the HVAC design changes are made. Heat pump (HP) with COP of 4 is used and mechanical heat recovery ventilation (HRV) is added with efficiency of 90%. There is no refurbishment for building envelope and construction. So, the energy demands remain the same as previous. The system fan energy for heat recovery ventilation has pressure delivery rate of 1.0 kW/m3/s. This gives a ventilation energy of 11026 kWh.

Ventilation energy (kWh) = 1.0 (kW/m3/s) * 9344 (m3/hr) * 4248 / 3600

Ventilation energy (kWh) = 11026 kWh

Table 16 Energy results for existing case with heat recovery and heat pump

SCENARIO 2	Fuel Breakdown (kWh)	PEF	Primary Energy (kWh)
Heating (HP+HRV)	12466	1.45	18076
System fans	11026	1.45	15988
Lighting	10687	1.45	15496
DHW (HP)	18330	1.45	26579
Total			**76138 kWh**

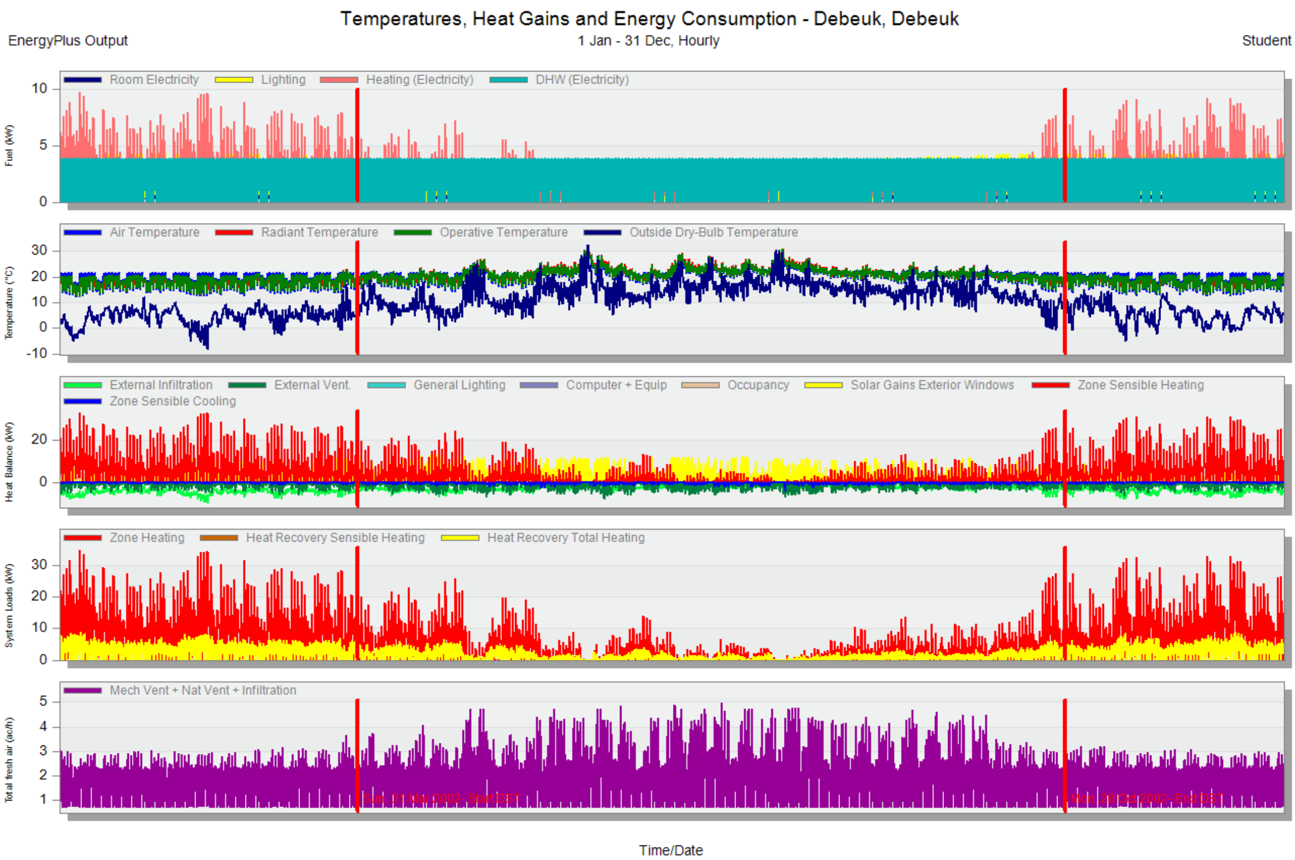


Figure 92 Heat balance, energy consumption and temperature graph - Scenario 2

The case helps in analysing how much saving in energy is possible by only retrofitting building services. There is large reduction in heating energy consumption both for space heating and DHW, up to 54% combined. The total energy savings are 59.6% compared to scenario 1. (see Appendix for more graphs from design builder). However, increase in fan energy by 20% with heat recovery ventilation.

Table 17 Improvement in energy savings

Scenario	Total Energy (MWh)	Energy savings (%)
Existing	163	-
Existing + heat recovery & heat pump	**76**	**+ 53**

Scenario 3 – Proposal: Renovation layout, façade refurbishment, building service retrofits

New plan is modelled in design builder with additional spaces and circulation. The total building footprint is increased to approx. 500 sqm. The heat pump COP is kept to 4. Firstly, the major construction changes are included i.e., high efficiency glazing with WWR almost 90%. The U-value of glazing is 0.8 W/m2K, solar heat gain coefficient of 0.6, and light transmittance of 75%. The glazing of committee rooms on ground floor has been integrated with PV panels.

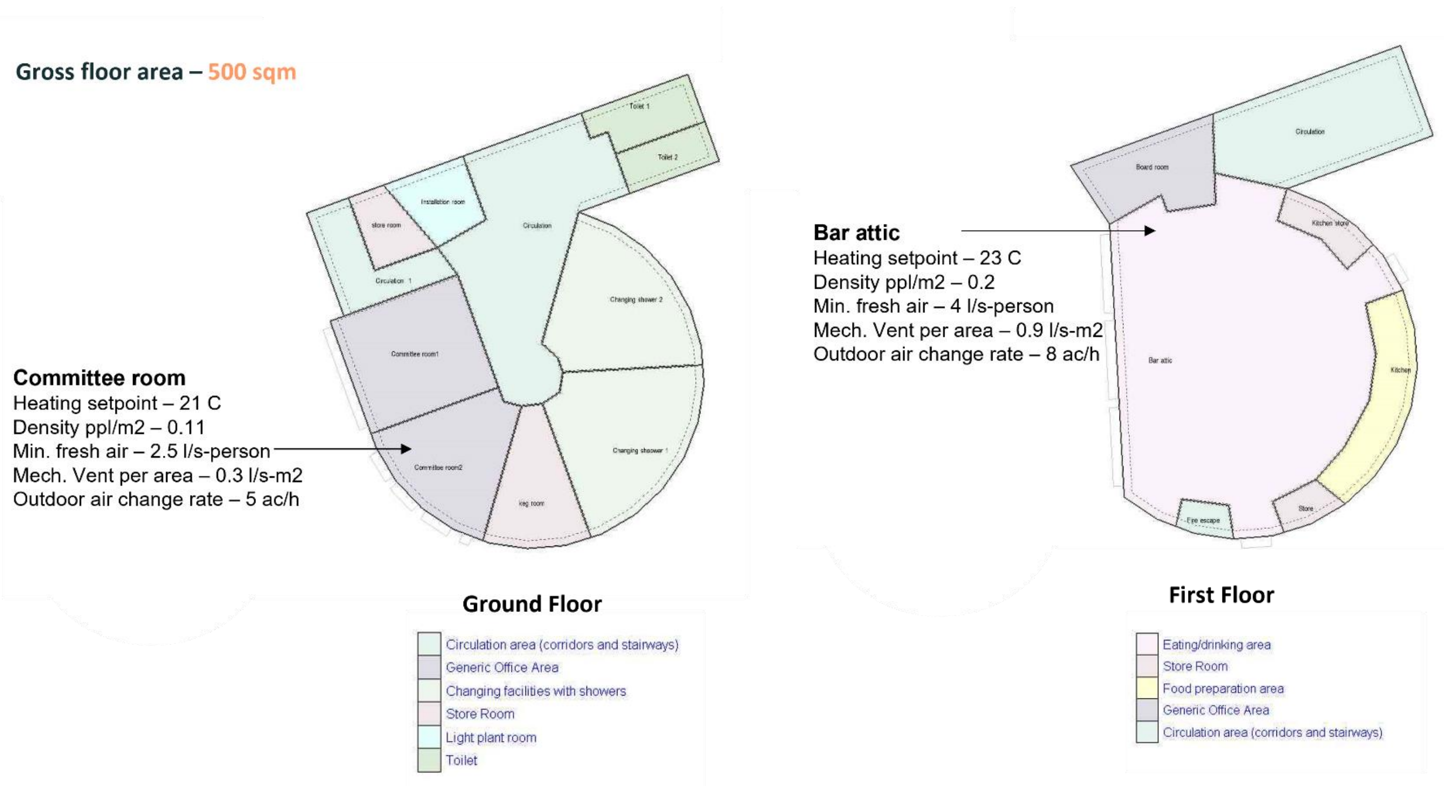


Figure 93 Design builder plan - Proposed

This is followed by envelope refurbishment to improve thermal performance by adding insulation and reducing infiltration rate. Interior roof insulation is added that increases the Rc-value to 6.5 m2K/W and infiltration rate of 0.3 ac/h.

Infiltration rate has effect on heating demand because higher the infiltration rate means higher air leakage through building cracks or wholes which increments heating demand. With new envelope design, it is expected to have airtight construction. This results in 67.2% reduction in space heating compared to baseline. However, there is a bit increase in cooling load. The lighting demand has reduced by 7.2%. The overall energy demand is reduced by 48% in the proposed design.

SCENARIO 3	Energy Demand (kWh)
Heating	11038
Cooling	3425
Lighting	9914
Total	**24377**

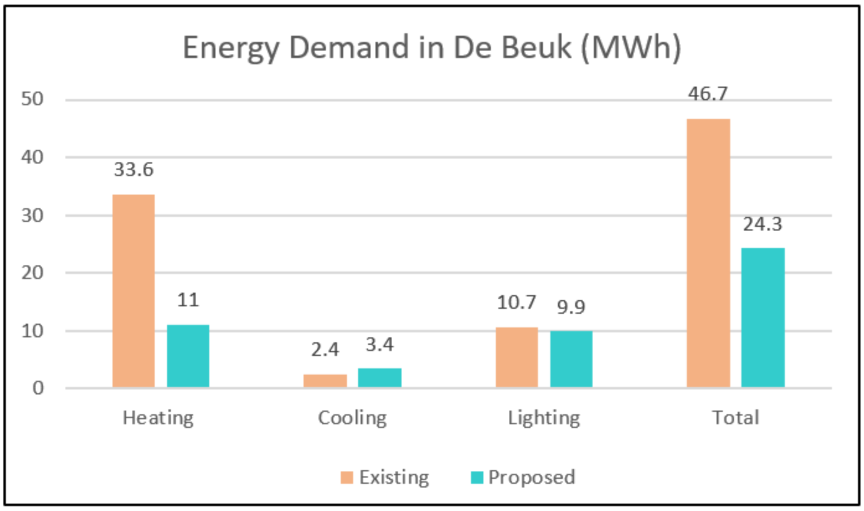


Figure 94 Energy demand in proposed case

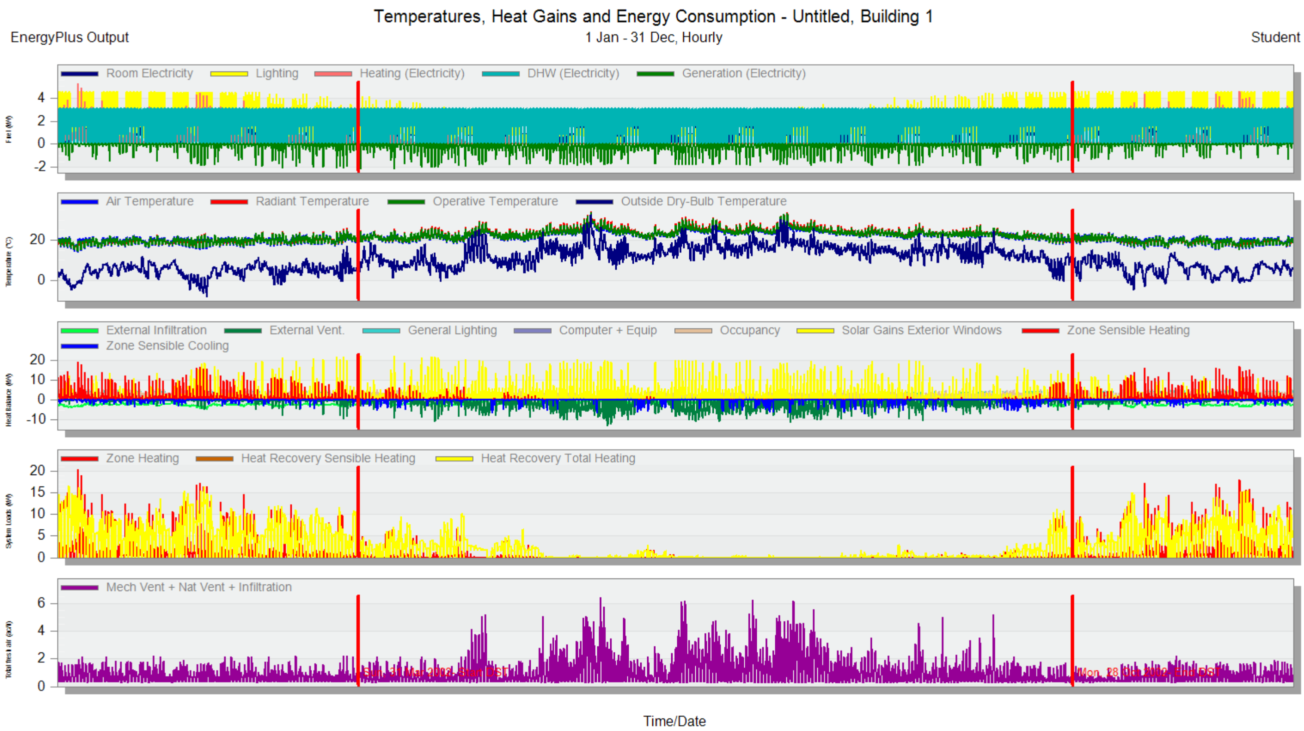


Figure 95 Heat balance, energy consumption and temperature graph - Scenario 3

From the heat gain and energy consumption, it is observed that most of the heat from zones is recovered by heat recovery and even distribution of heat is supplied. The solar gains through windows are slightly higher which causes higher cooling demand. The fuel breakdown shows much less heating energy consumption. The previously calculated ventilation amount for high occupancy hours in proposed design is used for fan energy consumption.

Ventilation energy (kWh) = 1.0 (kW/m3/s) * 9465 (m3/hr) * 4248 / 3600

Ventilation energy (kWh) = 11169 kWh

The fan energy has increased by 26% to provide good indoor air quality at all occupancy hours. In this calculation, primary energy factor which was taken earlier is not considered since the energy will be produced by on-site renewable energy sources. Overall, 76% savings on energy consumption is possible with renovation of the building. So, the primary energy consumption of De Beuk proposal is 38.6MWh. By using BIPV façade, there is annual energy generation of 1838 kWh which is considered later combining with on-site generation using PV.

Table 18 Energy consumption and energy savings in proposed case

SCENARIO 3	Primary energy consumption (kWh)	Increase/decrease %
Heating	2759	-92%
System fans	11169	+26%
Lighting	9914	-36%
DHW	14751	-83%
Total	**38593**	

Scenario	Total Energy (MWh)	Energy savings (%)
Existing	163	-
Existing + HP HRV	76	+59.6%
Proposed	**38.6**	**+76%**

5.1.2 Thermal Comfort

Existing

The simulation output is used to build ATG graphs for classification of thermal comfort. The existing building comes under Alpha building type because of absence of active cooling system. As per ATG, the acceptable PPD is 10% for Class B, 15% for class C, 25% for class D. Thermal comfort of Bar Attic is analysed. The comfort temperature limit for Bar Attic is set as 19^{o}C - 28^{o}C. The outdoor mean running temperature and operative temperature for the annual hourly period of 4248 hours are plotted for ATG graph. The graph shows that 37.9% of occupied hours exceed limit of Class B (max. 10% discomfort). It also exceeds the Class C requirement. Either it become too hot in summers or too cold in winters. Hence, the room falls under Class D thermal performance which is not an acceptable situation.

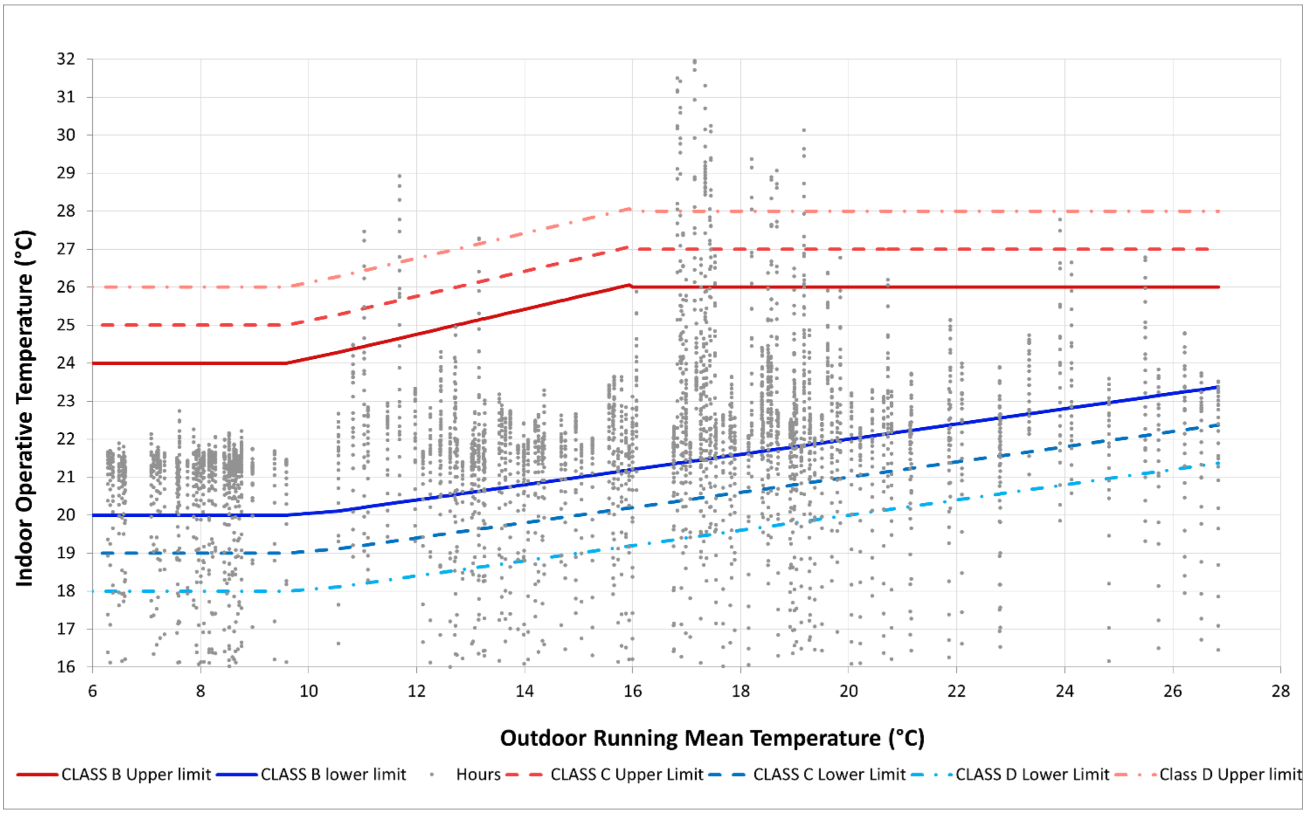


Figure 96 Thermal Comfort ATG graph existing case

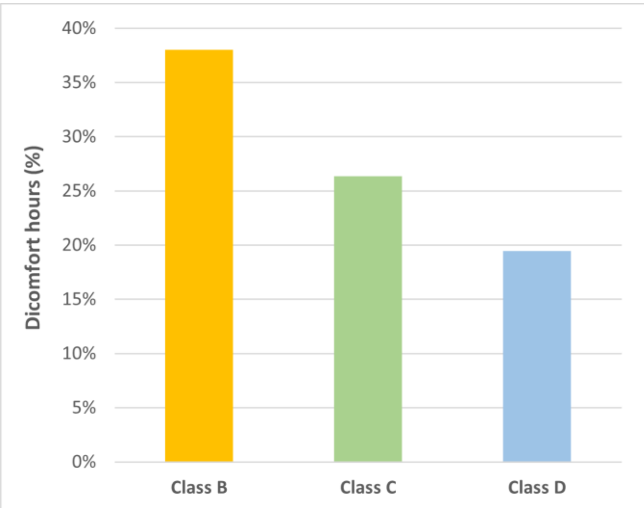


Figure 97 Discomfort hours % for each class

Thermal Performance	Class D	Unacceptable
Bandwidth	No. of discomfort hours	% of discomfort time
Class B	1614	37.99%
Class C	1119	26.34%
Class D	827	19.47%
Total hours	3560	

Proposed

For proposed refurbishment and services, there is reduction in discomfort hours to 1091. The winter comfort has improved a lot which is due to improved insulation and heat recovery. However, it is observed that there is still overheating in summers, the discomfort hours are quite high. Almost 22% cross the Class B bandwidth. The category remains Class D. the total discomfort hours have reduced.

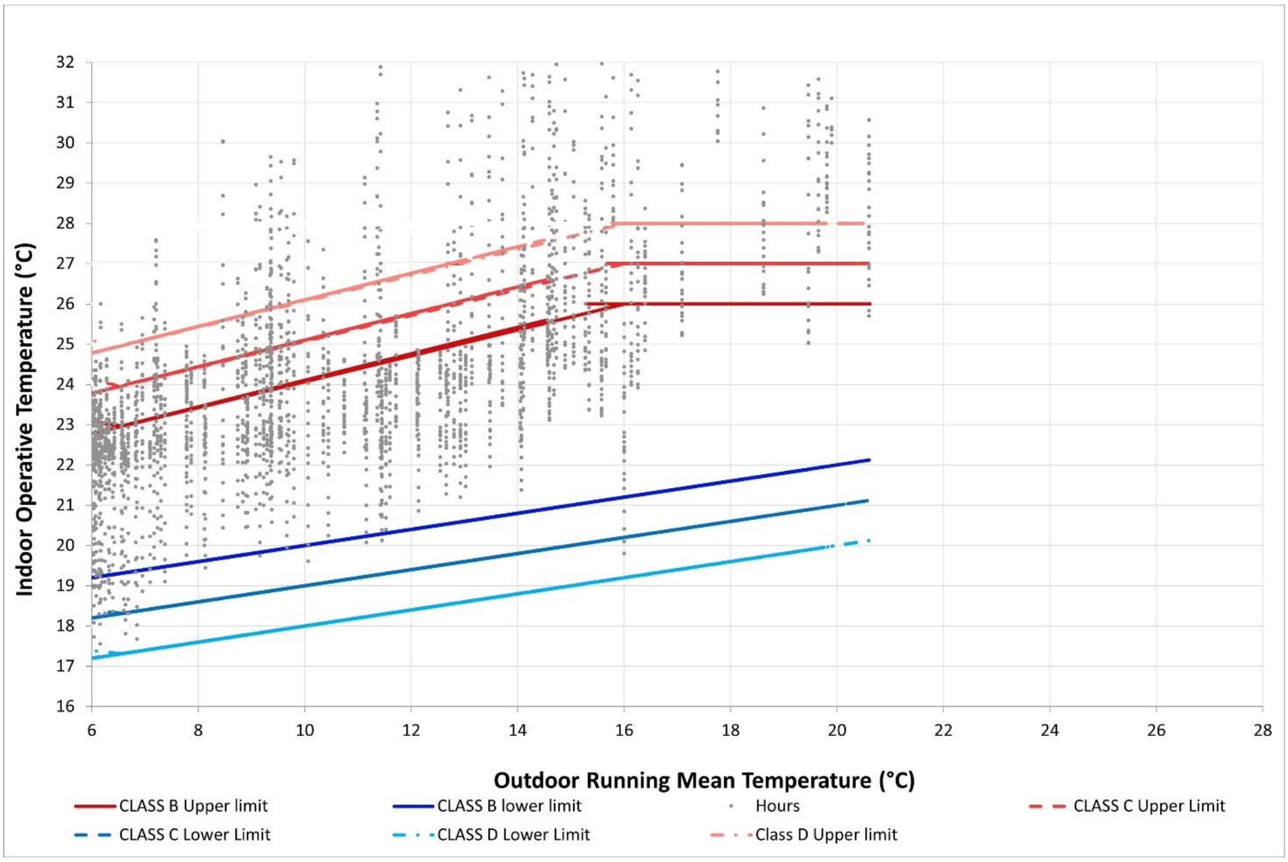
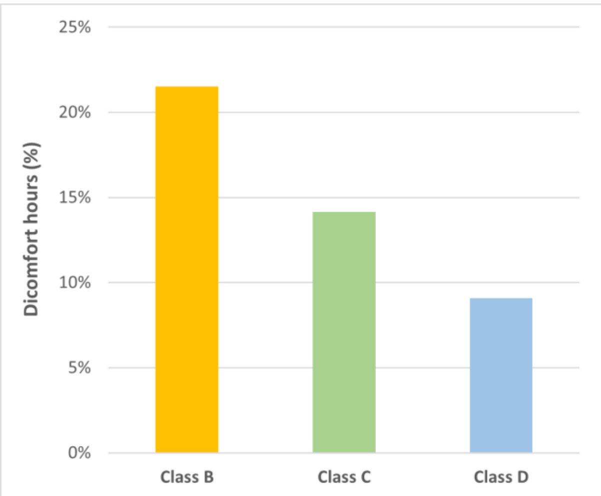


Figure 98 Thermal Comfort ATG graph proposed iteration 1



Thermal Performance	Class D	Unacceptable
Bandwidth	No. of discomfort hours	% of discomfort time
Class B	914	21.52%
Class C	601	14.15%
Class D	386	9.09%
Total hours	1901	

Figure 99 Discomfort hours % for each class

Further optimization in the software for minimum discomfort hours based on three parameters is performed: heating setpoint temperature, cooling temperature and window to wall ratio. The simulation resulted in several iterations recommended reduction of WWR to 70% and heating and cooling setpoint of 20ºC and 24ºC respectively. Another change is made to natural ventilation require for minimum indoor temperature of 24. The results show improvement in summer comfort. The discomfort hours have reduced to 513 hours. Hence, the thermal performance of room is acceptable falling under Class B, with PPD of less than 10%.

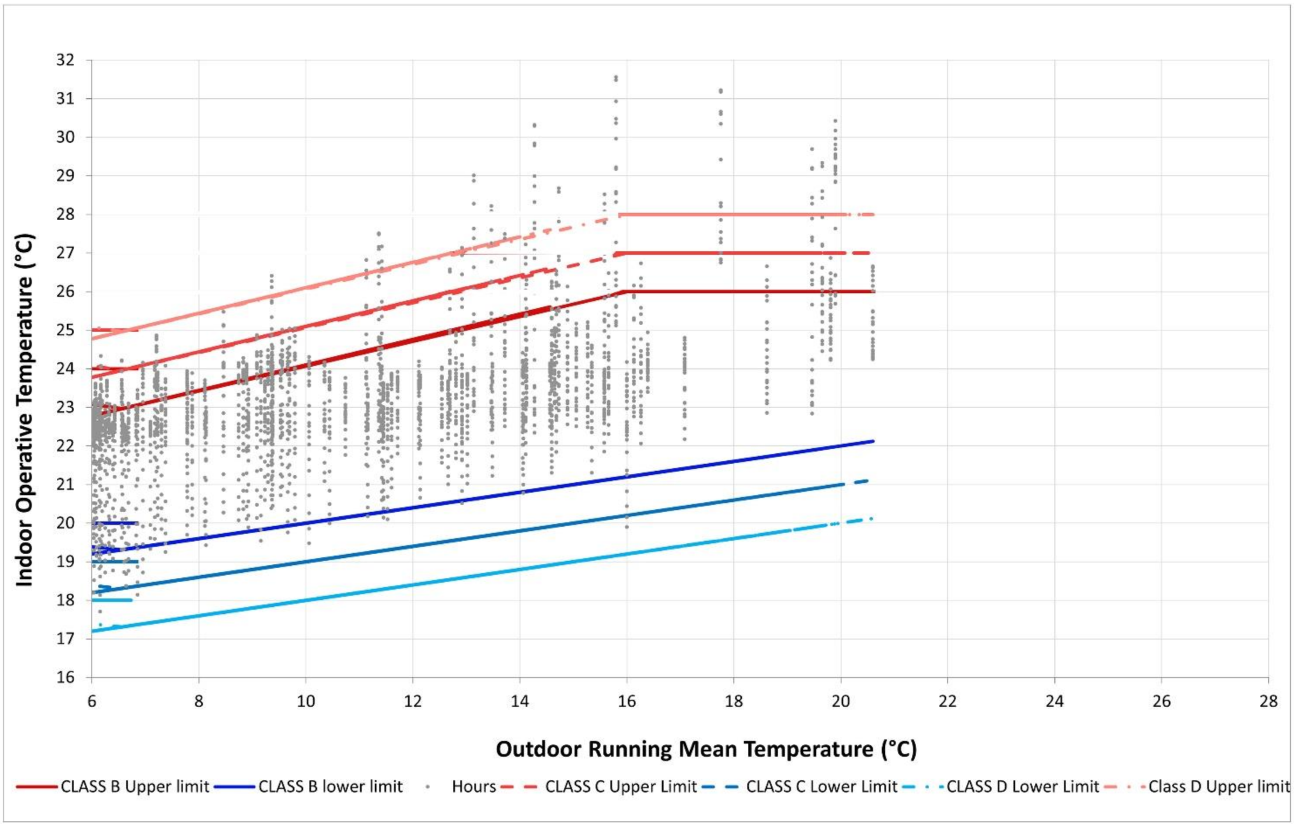


Figure 100 Thermal Comfort ATG graph proposed case after re-optimization

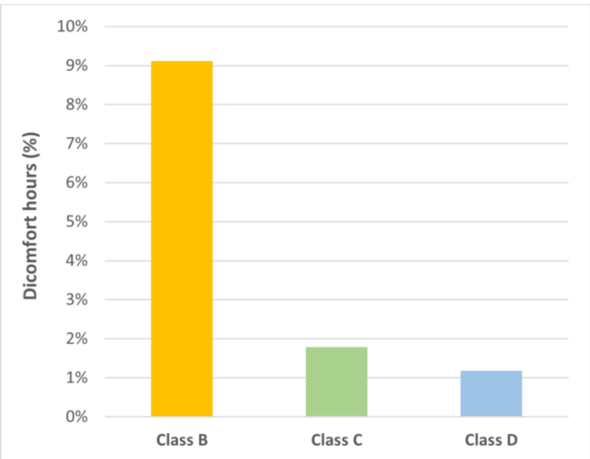


Figure 101 Discomfort hours % for each class

Thermal Performance	Class B	Acceptable
Bandwidth	No. of discomfort hours	% of discomfort time
Class B	387	9.11%
Class C	76	1.79%
Class D	50	1.18%
Total	513	

In earlier calculations for energy, it was noticed that the cooling demand was high which is possible with the earlier temperature setting and glazing percentage. From the thermal comfort iterations, the ideal comfort temperature should remain between 20-24ºC and glazing percentage of south-west should be reduced to 70%, unlike the previously proposed 90%.

5.1.3 Daylight

Existing

Daylight simulation is carried out to observe difference daylight access since the window to wall ratio has been changed. The window to wall ratio is 30%. The visual light transmittance for standard double glazing considered is 67%. The daylight map here shows the ground floor and bar attic in De Beuk. In real situation, most rooms have insufficient natural light and dependency more on artificial light. The illuminance level as per the simulation is negligible, specially on the north-east curved façade where window to wall ratio is below 10%. Although, the software mention 0 lux level, this is not the real situation, there is some amount of natural light entering from the small windows on the north-east side. The maximum illuminance achieved is 992 Lux in the baseline scenario.

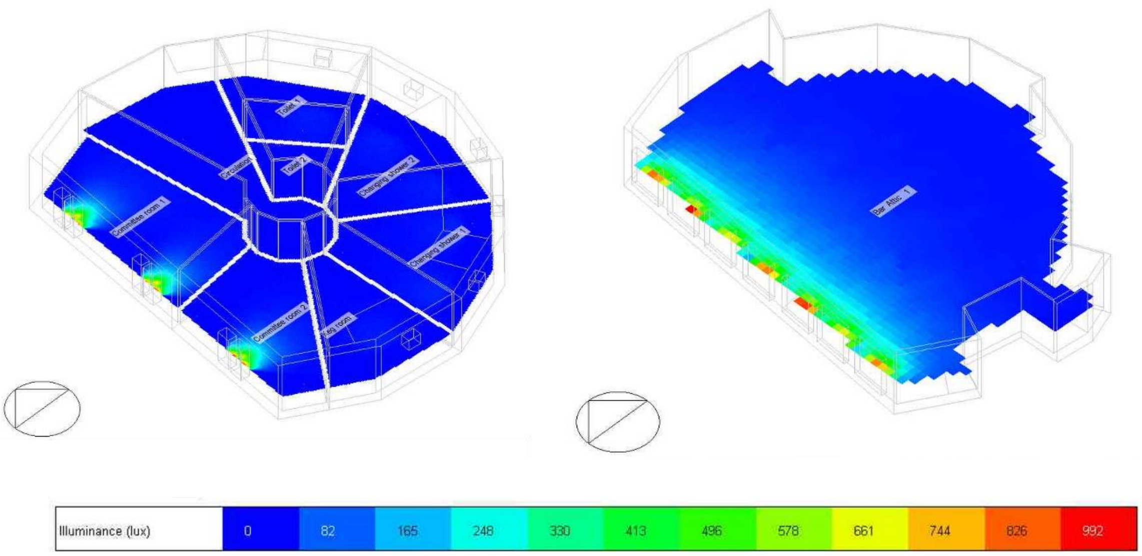


Figure 102 De Beuk - existing scenario - Daylight analysis

Proposed

The glazing percentage is increased by 35% which leads to substantial increase in daylight. In bar attic, there is contribution from round skylight and new windows provided on the curved facade. The overall lighting loads are reduced by 24%. With new glazing, the illuminance level reaches up to 2392 lux. The software doesn't have options to correctly model solar tubes. Therefore, it is also expected that solar tubes will further reduce the lighting consumption.

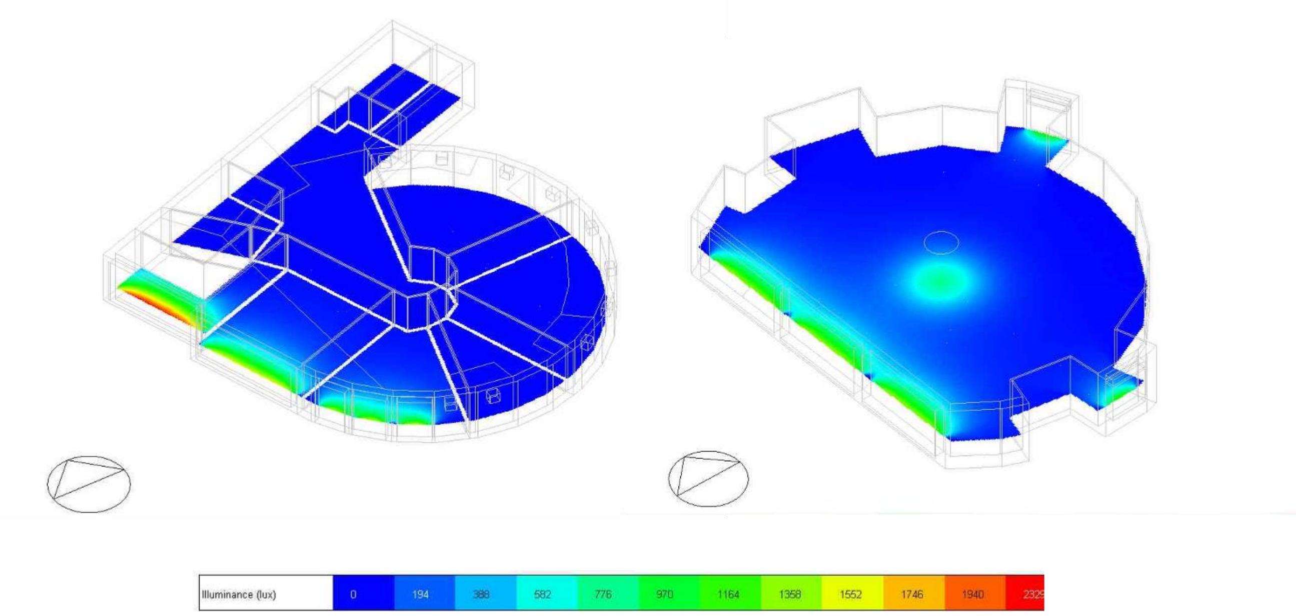


Figure 103 De Beuk - proposed scenario - Daylight analysis

5.2 Boat Storage

The main purpose for redesigning spaces in boat storage, is to have proper facilities for ergometer room with adequate ventilation and daylighting. For simulation, the warehouse where boats are stored are excluded from thermal calculations since there is no active heating or cooling provided. It is expected that in proposed design the overall energy loads might increase due to increase in functional space of 195sqm.

Two scenarios are modelled in design builder:

Scenario 1: Existing – With existing gas boiler heating and mechanical supply and extract. There is negligible natural ventilation considered.

Scenario 2: Proposed – New design of Ergometer with 195sqm in addition to existing spaces. Mechanical Heat recovery ventilation and heat pump for space heating and DHW.

5.2.1 Energy Performance

Scenario 1 - Existing

In this building block, there is less requirement of domestic hot water in real situation. In ergometer, no space heating is required. The workshop has radiators and involves extract ventilation only. The HVAC model for existing design has gas boiler heating with an efficiency of 0.85 for space heating and domestic hot water. The input for DHW is 0.1 l/m2-day for workshop and ergometer. It is observed from the result, out of total energy consumption 57% is consumed by lighting only. This is because there is no natural light entering the workshop, ergometer, and storage. The roof skylight is blocked by false ceiling in existing ergometer room, not effective leading to high lighting loads. The annual total primary energy consumption is 57.6 MWh.

Figure 104 Design builder floor plans

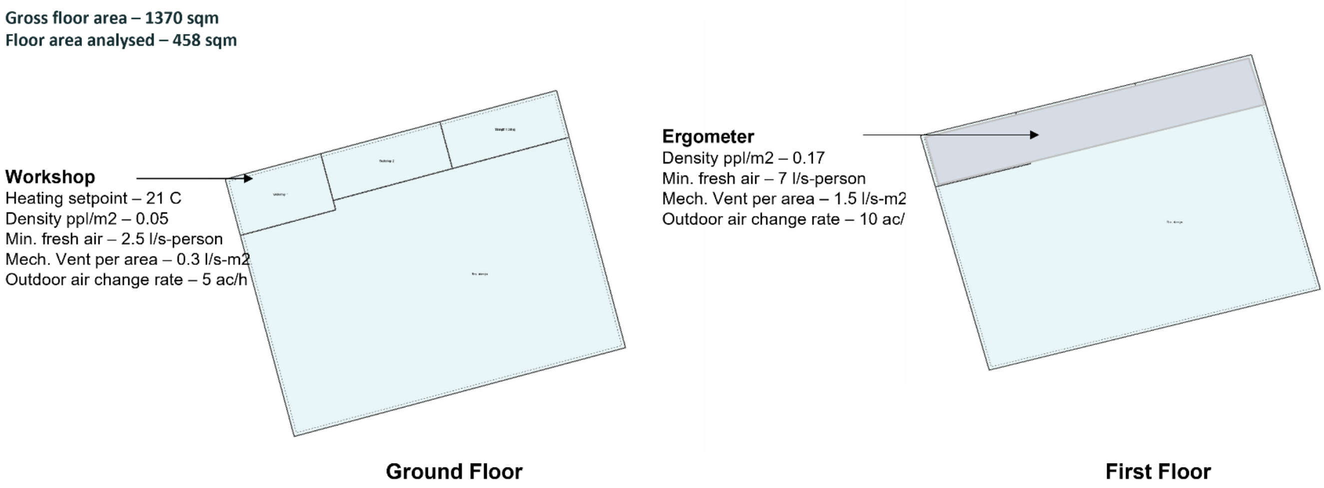


Table 19 Energy results for existing case

SCENARIO 1	Energy Demand (kWh)
Heating (gas)	14133
Cooling	3519
Lighting	19936
Total	**37588**

SCENARIO 1	Fuel Breakdown (kWh)	Primary Energy Factor PEF	Primary Energy Consumption (kWh)
Heating (gas)	16627	1.15	19121
System Fans	3852	1.45	5585
Lighting	19936	1.45	28907
DHW	740	1.15	851
Total	**38178**		**57604**

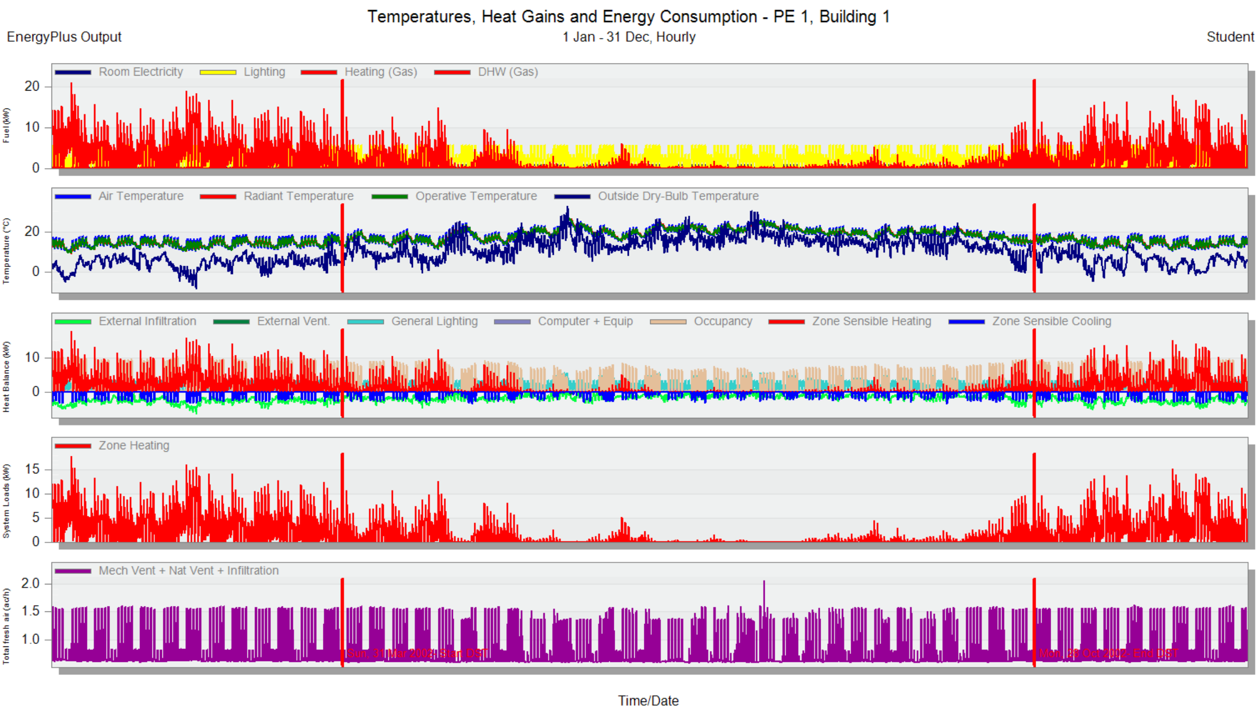


Figure 105 Boat storage Scenario 1- Hourly heat balance, energy consumption, temperature chart

Scenario 2 – Proposal

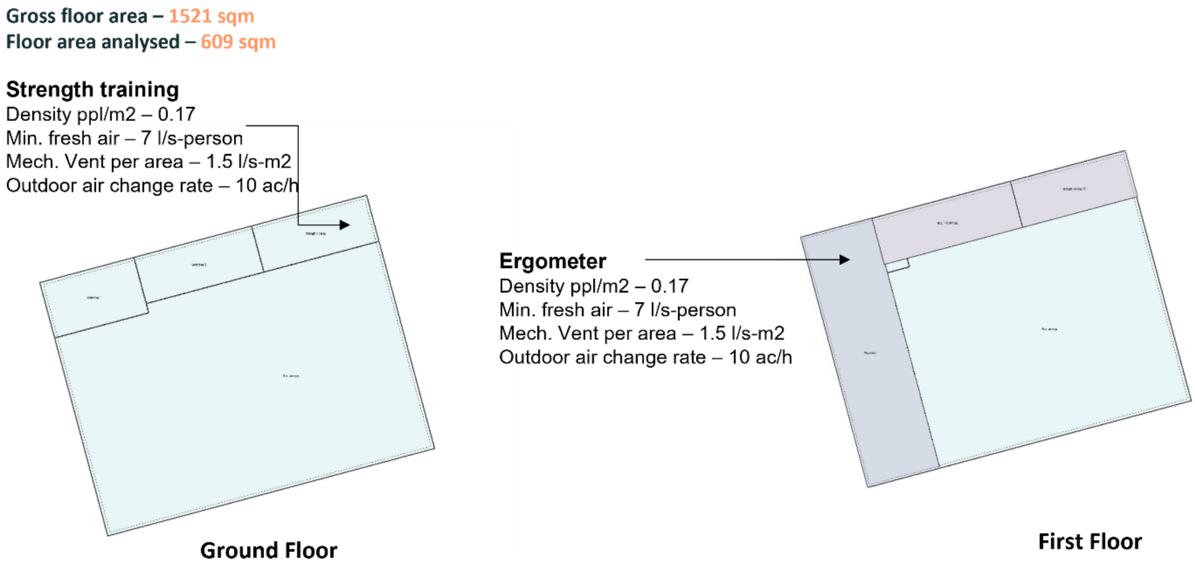
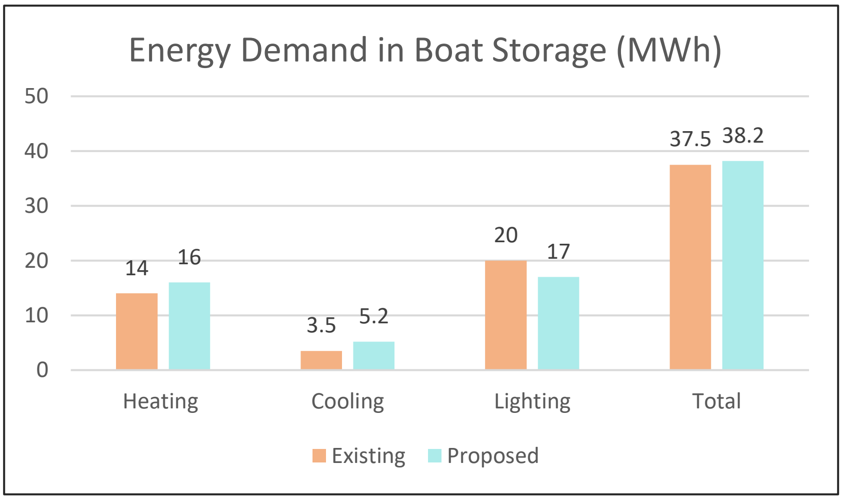


Figure 106 Design builder plans for proposed

The proposed design of ergometer is modelled in this case. And new activity type for strength training room and multipurpose room are set. Gas boiler heating is replaced by heat pump and mechanical ventilation with heat recovery. The COP for heat pump is 4. Unlike baseline scenario, the proposal takes in account new envelope with facade glazing and using the roof skylight for multipurpose hall and strength training room. High efficiency glazing with U-value of 0.9, SHGC of 0.6 is used for ergometer room. Best practice LED lights are used in the model. A considerable reduction in lighting consumption is recorded. Heating and cooling demands have risen as expected due to increase gross floor area by 195sqm as expected.

Figure 107 Energy demand in proposed case

SCENARIO 2	Energy Demand (kWh)
Heating	16262
Cooling	5268
Lighting	17436
Total	**38966**



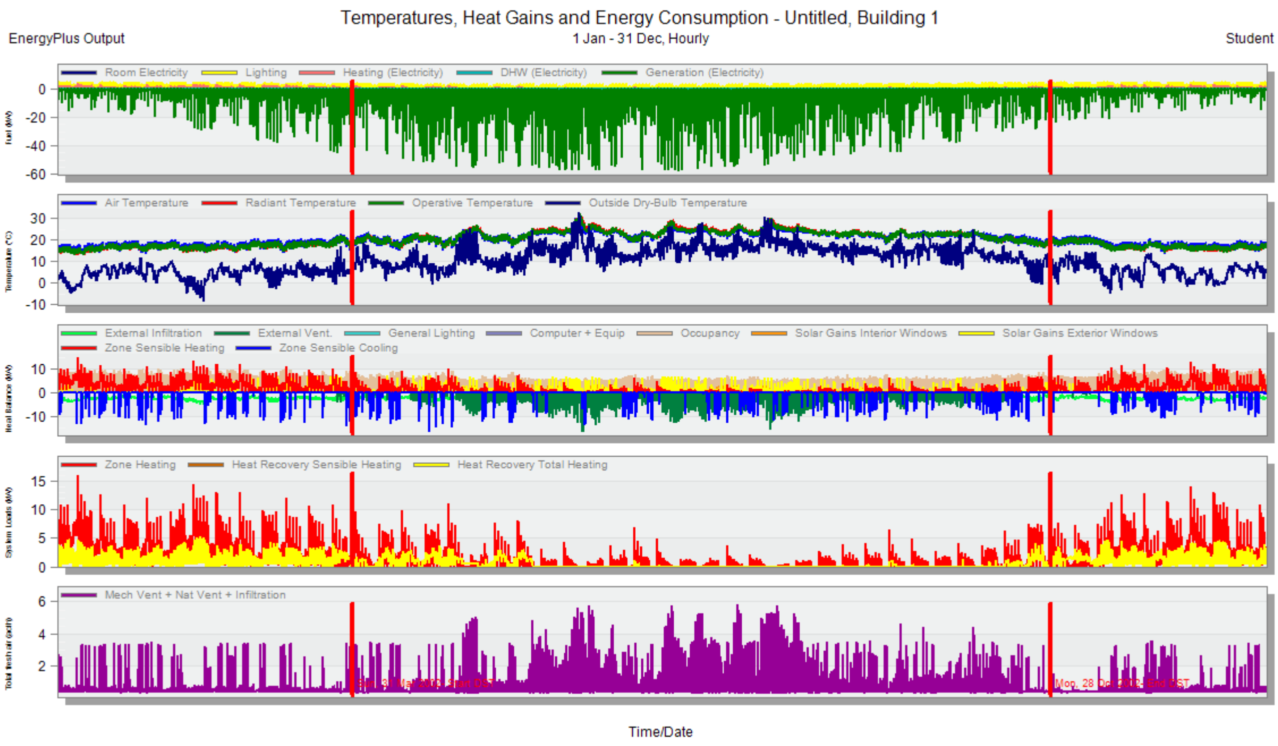


Figure 108 Boat storage Scenario 2- Hourly heat balance, energy consumption, temperature chart

On the other hand, in terms of primary energy consumption, the total has reduced by approx. 56% compared to existing situation. In this case, primary energy factor for conversion is not considered as the proposal implements using on-site PV electricity instead of grid electricity. The heating energy consumption have reduced to large extent by using heat pump instead of gas boiler. With heat pump system, heating requirement for hot water has reduced. There is net energy saving of 12.5% compared to existing.

Table 20 Energy consumption and energy savings in proposed case

SCENARIO 2	Primary energy consumption (kWh)	Increase/ decrease %
Heating (HP+HRV)	4065	-82%
System fans	8185	+32%
Lighting	17436	-12.5%
DHW (HP)	115	-84%
Total	**29801**	

Scenario	Total Energy Consumption (MWh)	Energy Saving %
Existing	57.6	-
Proposed	29.8	**+48%**

On-site PV Energy:

Furthermore, taking in account energy generation by PV from roof array, the total energy generation is of almost 62 MWh annually. The PV arrangement includes panels on south oriented roof slope and flat roof of boat storage. BIPV generation is 1.8 MWh (1838 kWh) combining this gives total on-site energy generation of 63.8 MWh. The energy requirement for De Beuk and Boat Storage combined is 67 MWh. The only electricity consumption that would be supplied from grid is 3.2MWh.

Table 21 Energy generation by PV

Fuel Energy Demand (MWh)		PV Energy Generation (MWh)	
De Beuk	38	BIPV Facade	1.8
Boat Storage	29	Roof PV	62
Total	**67 MWh**	**Total**	**63.8 MWh**

5.2.2 Thermal comfort

Existing

Ergometer room is analysed for thermal comfort classification. The comfort temperature limit is set between 16-19 C. The natural air change per hour in existing is assumed as 5 ac/h. In existing case, no heating is present. The analysis period is taken annually for schedule between 8:00hr-22:00hr. The total number of hours are 4695. The graph shows that 41% of occupied hours exceed limit of Class D (max. 25% discomfort). The indoor environment shows extremes of climate experience in the current ergometer room.

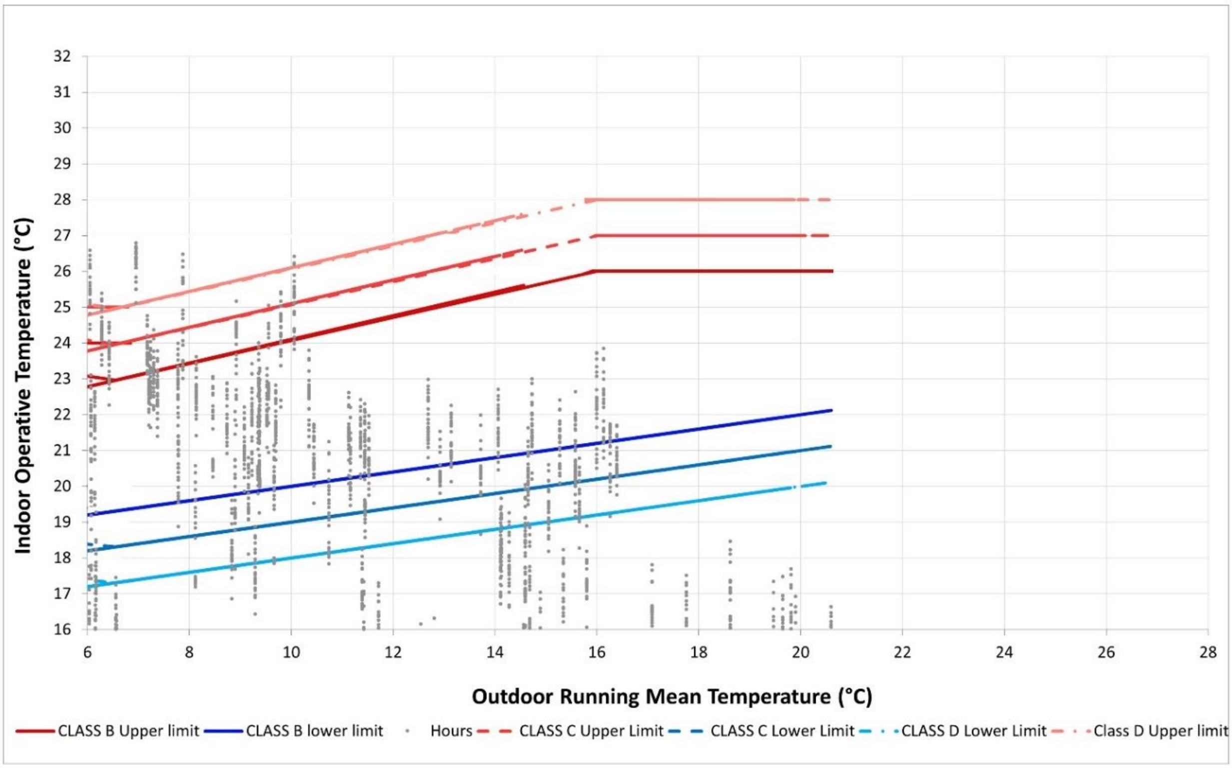
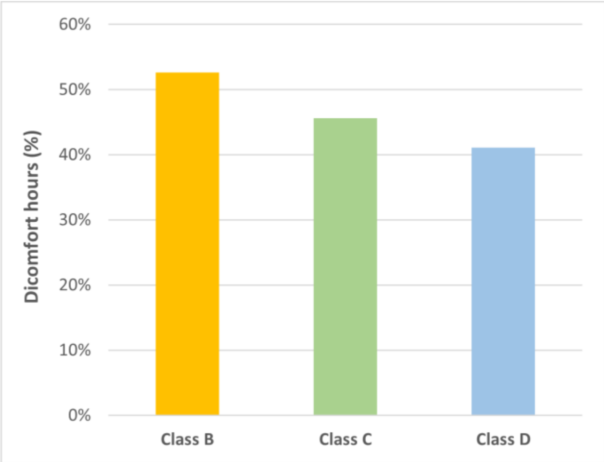


Figure 109 Thermal comfort ATG graph existing case

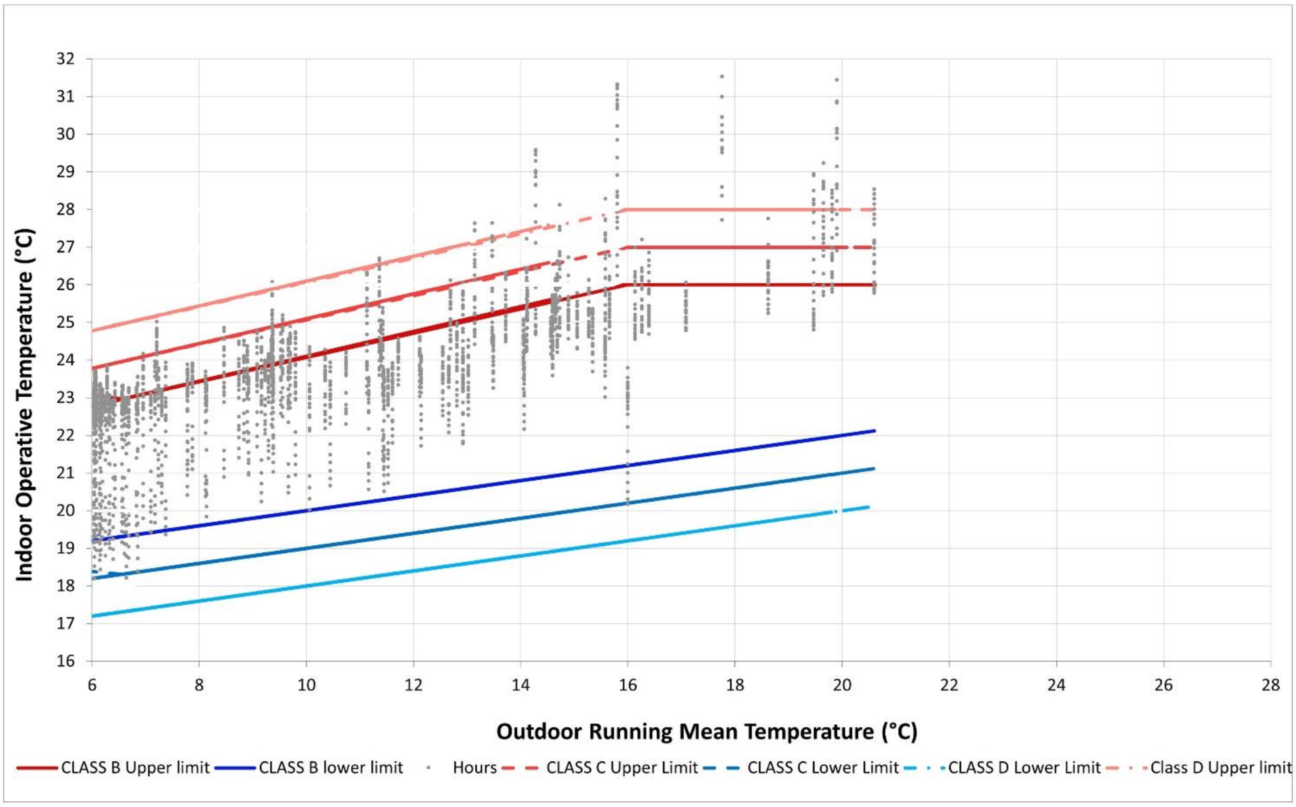


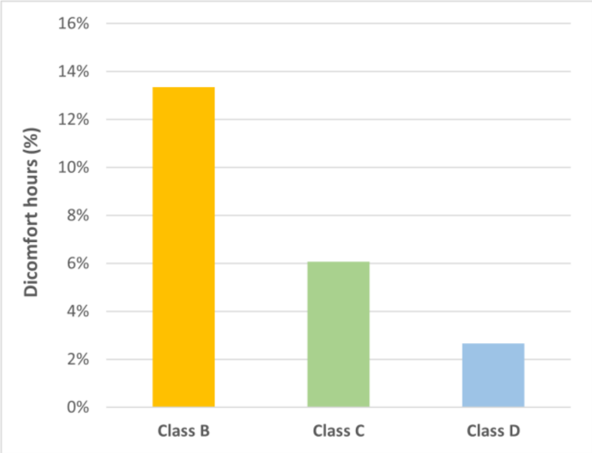
Thermal Performance	Class D	Unacceptable
Bandwidth	No. of discomfort hours	% of discomfort time
Class B	2470	52.61%
Class C	2141	45.60%
Class D	1929	41.09%
Total hours	6540	

Figure 110 Discomfort hours % for each class

Proposed

The new design of Ergometer room is modelled with better new roof with wooden truss having Rc value of 6.5 W/m2K. And the brick façade is added with interior insulation layer. The comfort temperature limit is set between 16-19ºC. The natural air change per hour in existing is assumed as 8 ac/h, provided cross ventilation through new window openings proposed. It is assumed that at temperature reaching 24ºC, the natural ventilation is possible in summer provided air speed of 0.2m/s. The comfort graph results reduction of total discomfort hours by 74%. Only 2.5% hours cross Class D limit. A bit overheating is experienced however, this can change depending on real-time adjustment with demand control ventilation. The heat recovery ventilation provides good thermal comfort for winters.





Thermal Performance	Class B	Acceptable
Bandwidth	No. of discomfort hours	% of discomfort time
Class B	550	12.95%
Class C	247	5.81%
Class D	109	2.57%
Total	906	

5.2.3 Daylight

Daylight evaluation is performed for Ergometer room. The two cases have different setup in the boat house. In existing case, the ergometer room is in the interior space without any façade with direct daylight. The glazing rather faces the indoor boat shed. There is slight entrance of natural light through roof skylight. Whereas the new ergometer facing the canal is south-west oriented with a WWR of 55% and roof skylight allows for partial north light to enter. There is around 90% increase in daylight access in the new design.

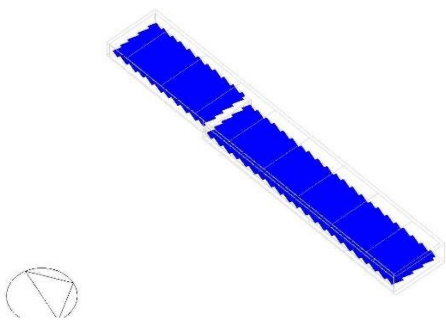


Figure 111 Ergometer - existing scenario - Daylight analysis

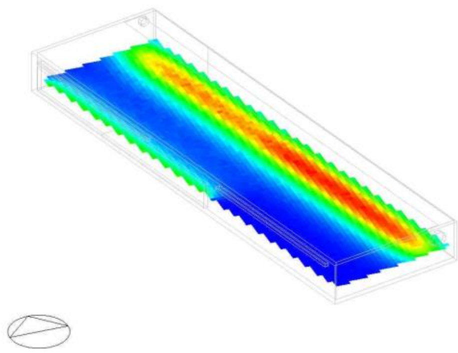
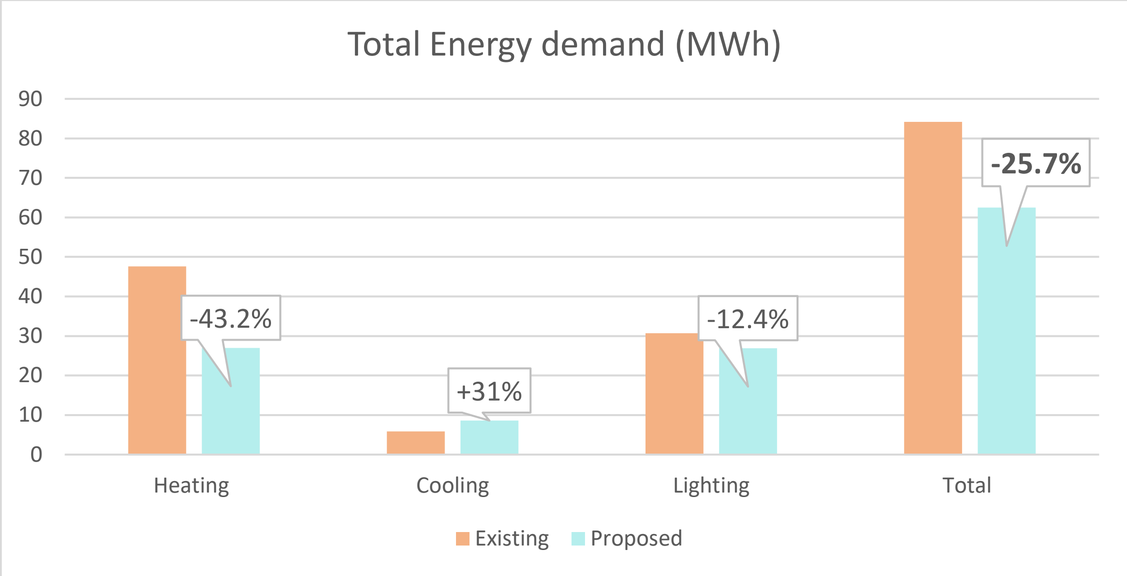


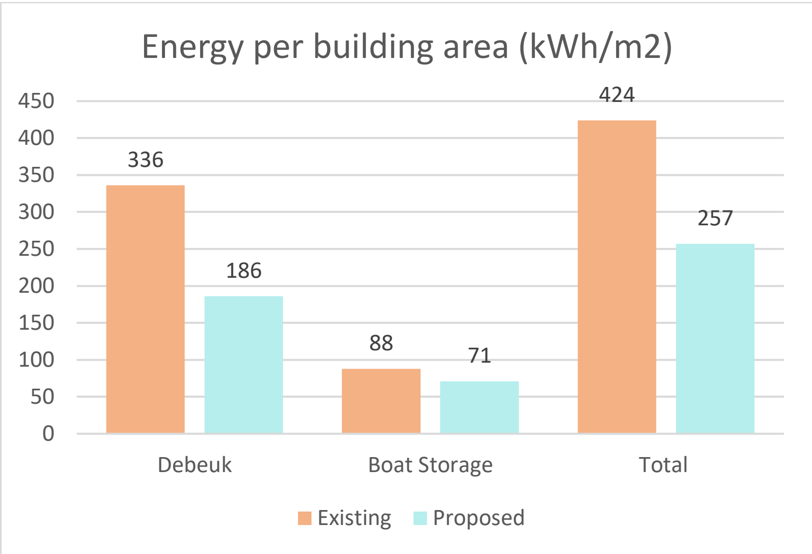
Figure 112 Ergometer - proposed scenario - Daylight analysis

5.3 Summary

The simulations for two building blocks to evaluate energy performance and comfort have been carried out individually. Three scenarios for De Beuk association building and two scenarios for boat storage. The total energy demand in De Beuk has reduced by 48%. On the other hand, in boat storage there is slight increase in energy demand 3.7% because of increased gross floor. However, the combined energy demand of the two buildings from proposed renovation shows 25.7% reduction compared to existing scenario.

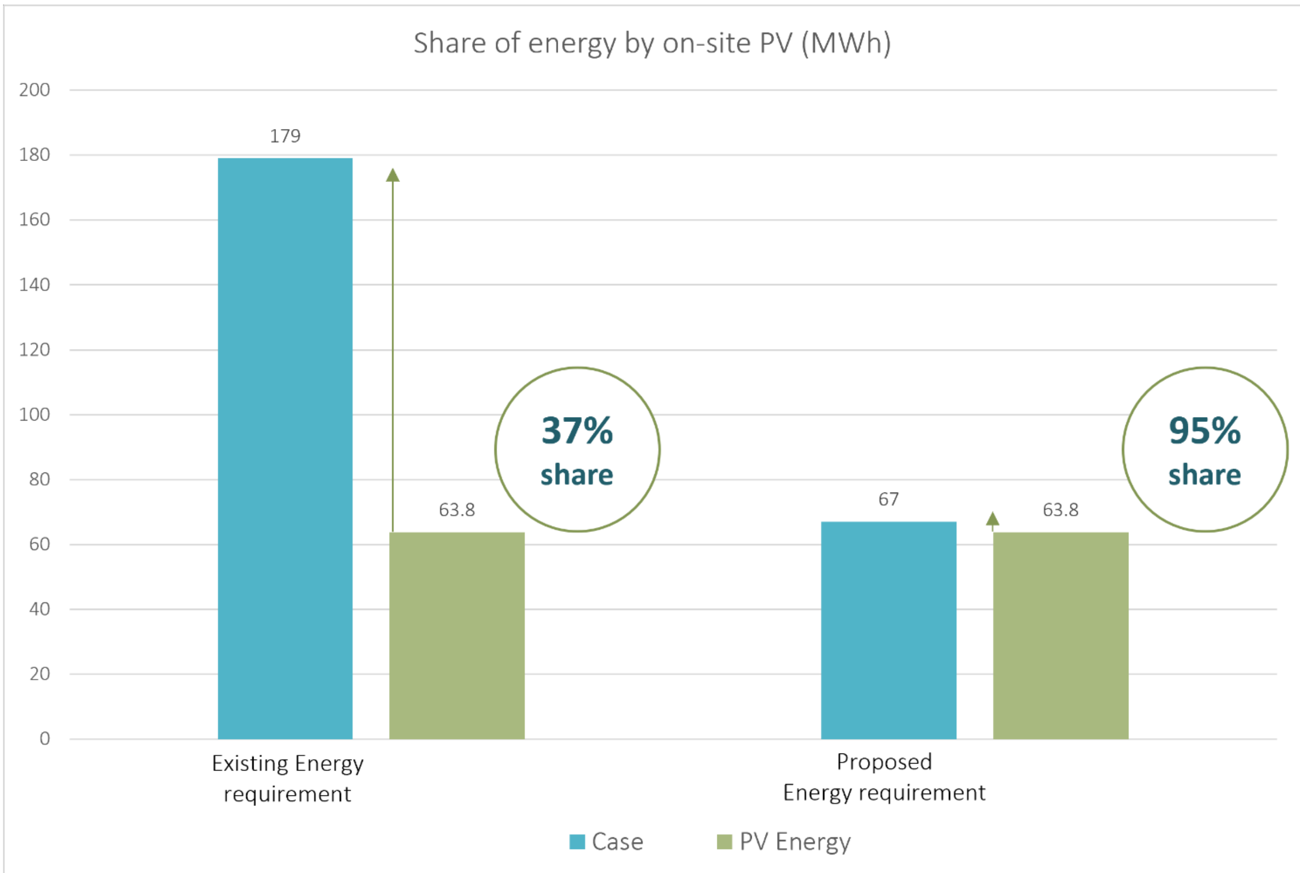


Major cause of reduction is due to refurbishment of façade, replacement of gas boiler heating to heat pump solution and heat recovery installation. Using high efficiency glazing and best practice LED lights, the lighting electricity demand is also reduced. The energy per building area for the whole site is reduced by **39.4%**, from 424 kWh/m2 to 252 kWh/m2.

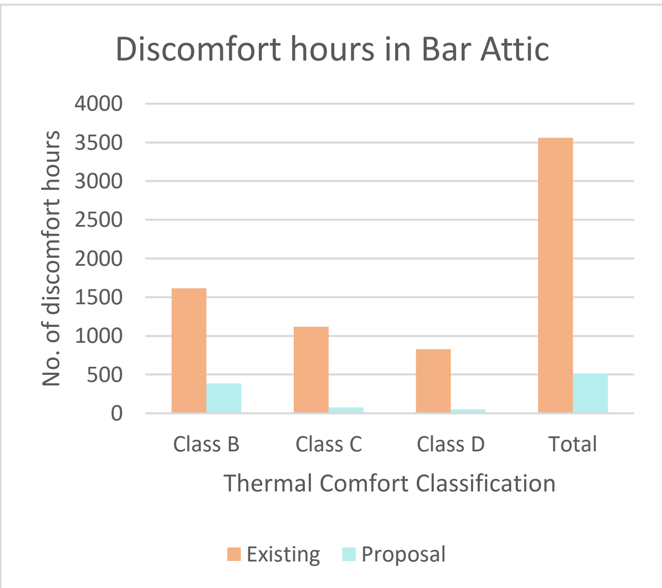


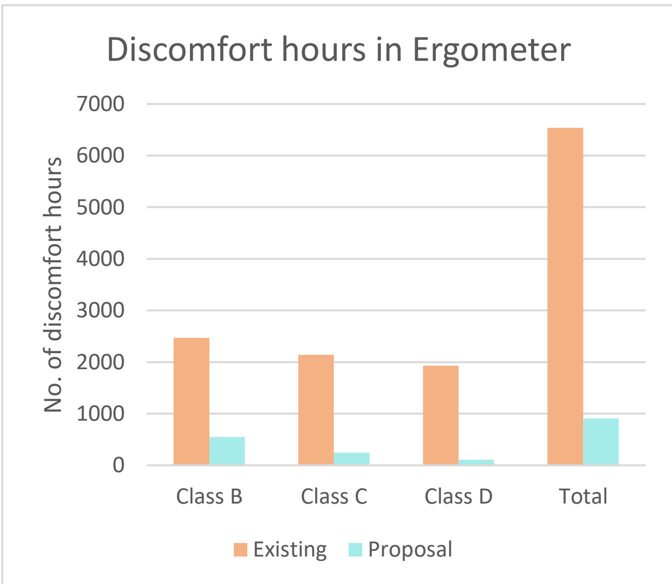
Moreover, using on-site PV, the building becomes 'energy producers' as well by almost reaching energy neutrality. Thus, it can be said that the proposed building has achieved **net-zero energy**.

A brief overview is shown below to analyse if only PV panels are added to existing structure versus the proposed building renovation with PV. In existing case, there is still 106MWh which uses grid electricity to run operational energy. Whereas a surplus of 13.5MWh of energy remains in proposed design, hence more profitable.

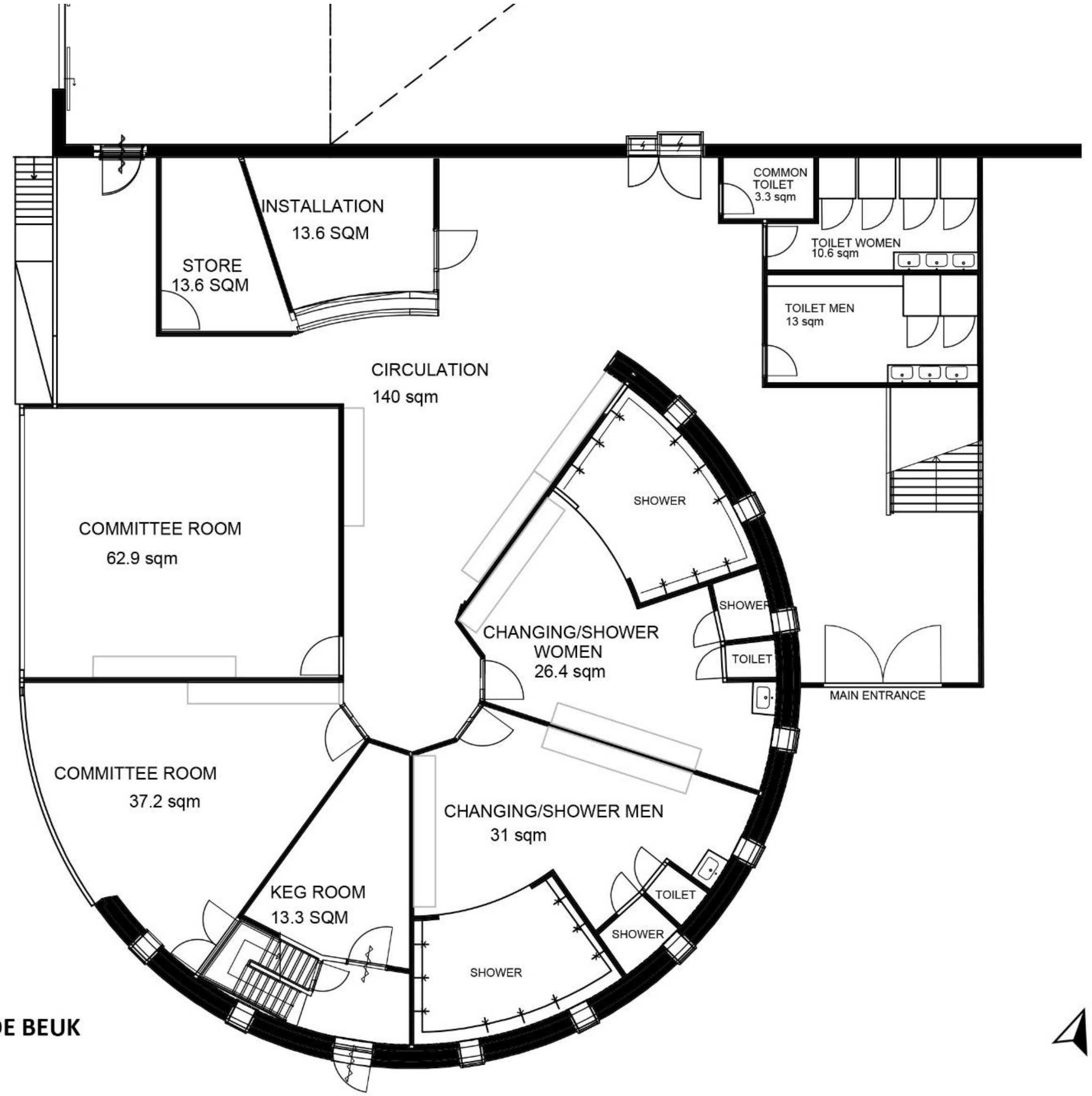


Discomfort hours are reduced specially during summer months which otherwise showed problems with overheating. The factors that contributed to better comfort is natural ventilation across the rooms, orientation of openings and optimization glazing percentage to avoid unnecessary heat gains in summers. Through renovation strategies for better thermal mass, the discomfort hours are reduced by 85% in bar attic and 75% in ergometer.



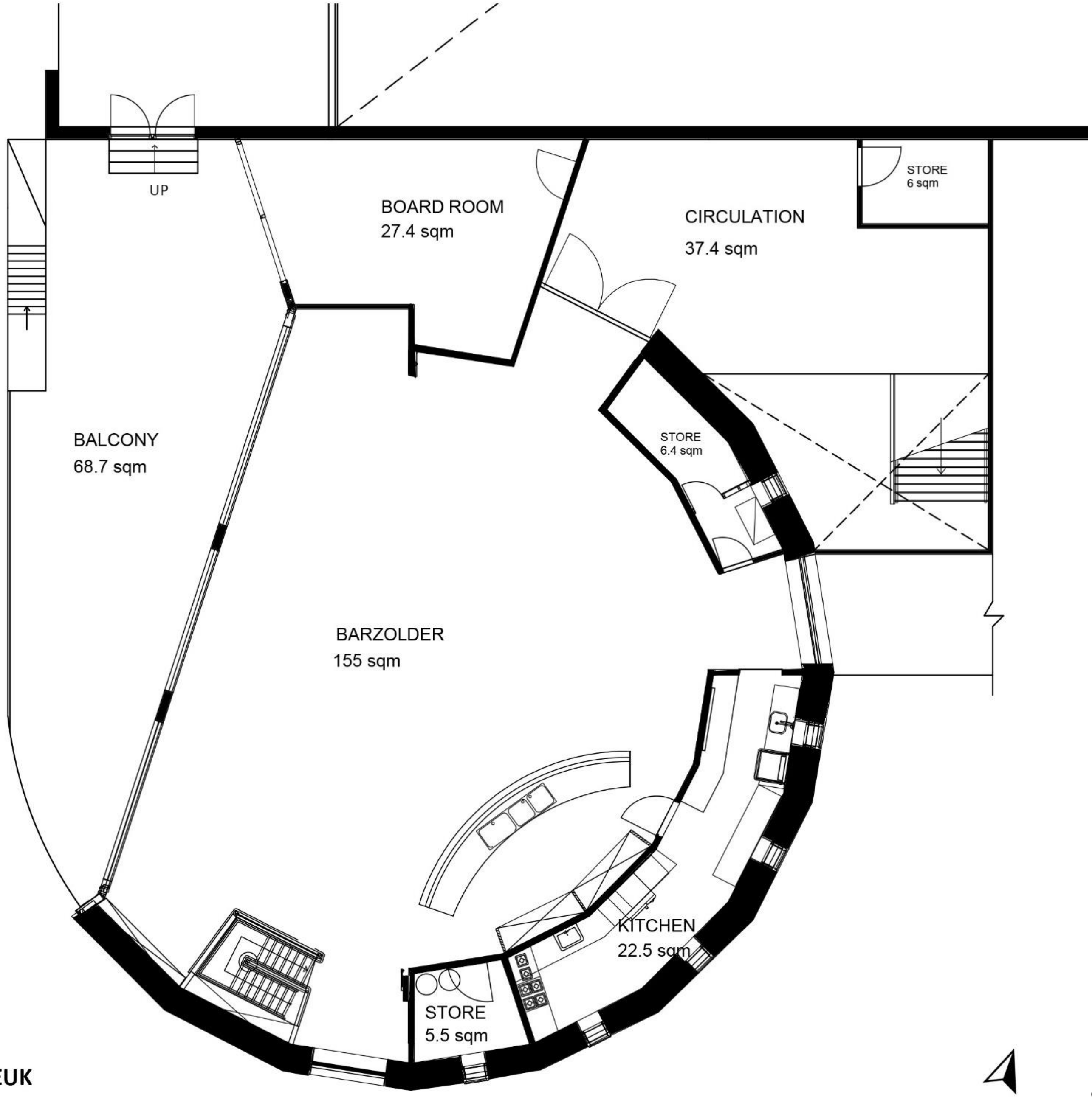


6. FINAL DESIGN

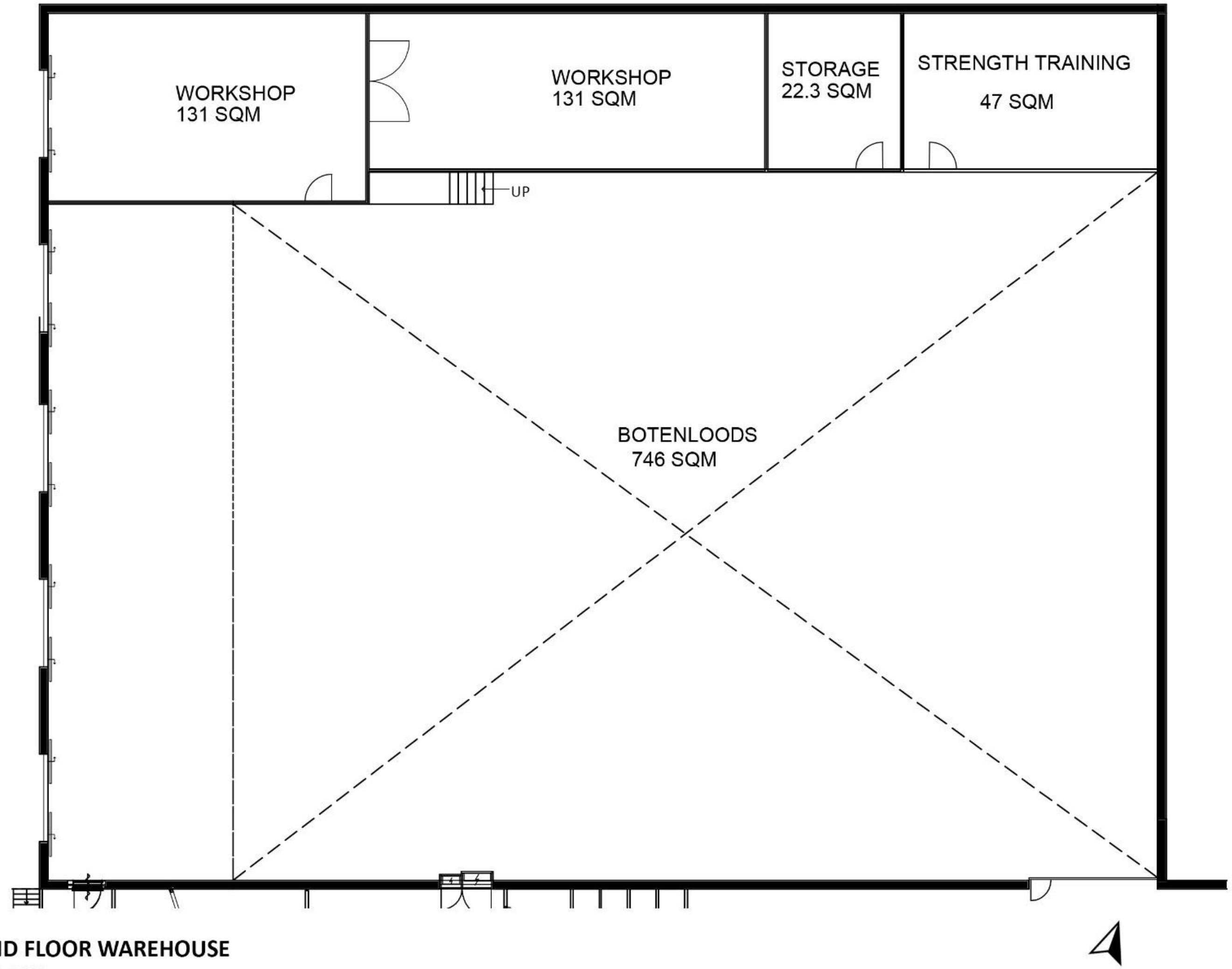


GROUND FLOOR DE BEUK

SCALE 1:150

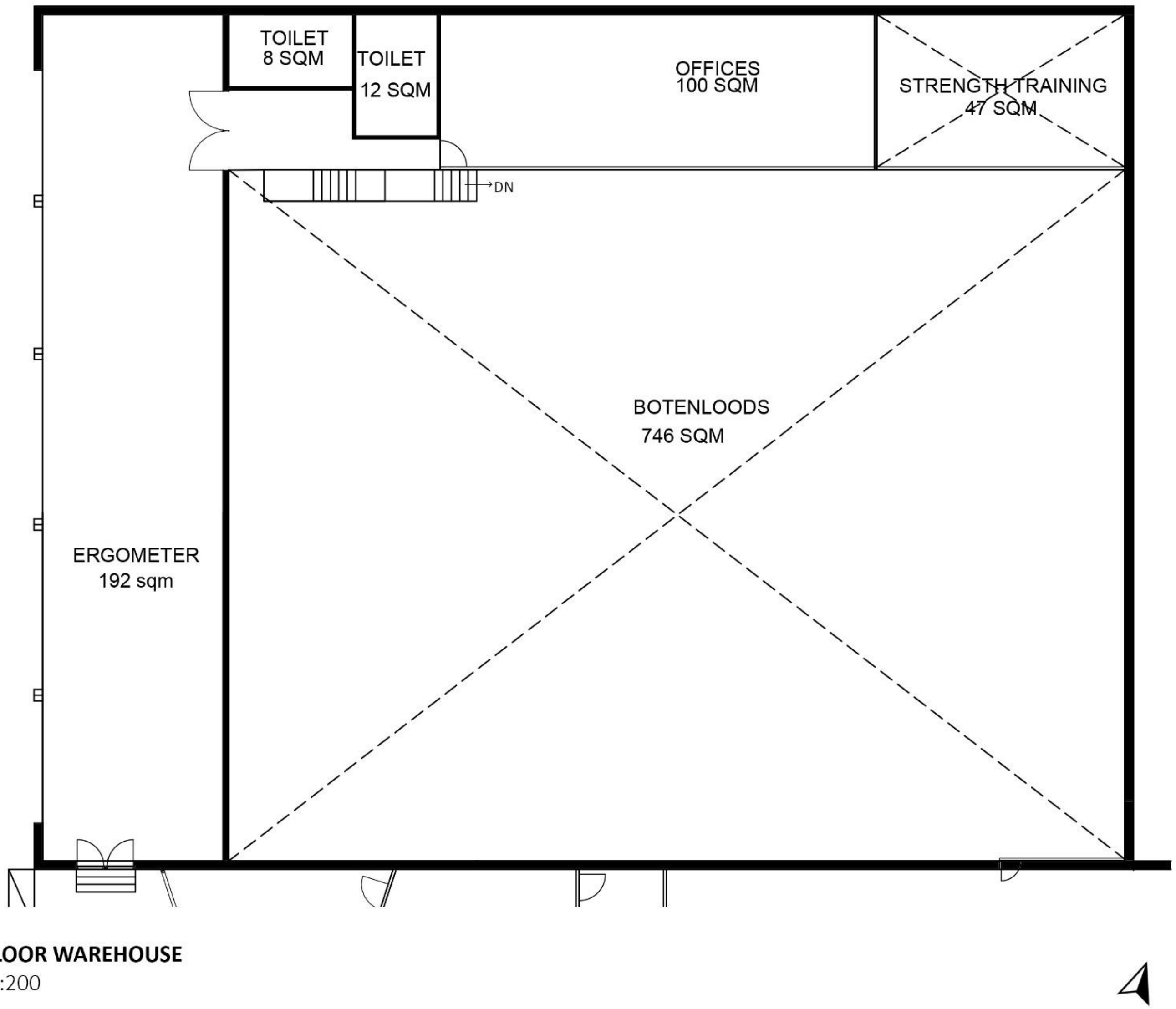


FIRST FLOOR DE BEUK
SCALE 1:150



GROUND FLOOR WAREHOUSE

SCALE 1:200



FIRST FLOOR WAREHOUSE
SCALE 1:200

View from canal

View from canal

View of Ergometer room

View from Ergometer room

View of Bar Attic

Front view

7. INVESTMENT AND PROFIT

In this section, an estimation is done to comprehend investment costs for renovation plan and thus reduction in future energy bills of Proteus Eretes. This analysis is performed to reflect upon the future-proof proposed renovation. However, certain cost items like cost of labour, installation, etc are not all included. This is only assumption of amounts and payback time with the use of PV energy in correspondence to energy demand in proposed design. Also, the analysis doesn't consider construction related prices for refurbishment.

In a five-year term, continuing the existing design with existing services the association would be paying a total of Euro 73780. This amount also includes 30% added gas tax which the Dutch government is applying. The number may even increase leading to higher bills. Although, applying renovation design for Proteus Eretes, the gas charges would be lifted along with government takes on electricity because of on-site energy production. There is almost savings of Euro 65000 if the proposed plan for renovation is implemented (table 16).

Table 22 Five year estimation of energy consumption bill.

	EXISTING				PROPOSAL			
Cost break-up	Cost (current)	30% added gas tax	Year	Cost (5 Year Estimation)	Cost (current)	30% added gas tax	Year	5 Year Estimation
Gas total (incl. govt. taxes)	5306	6174	5	30870	0	-	5	0
Electricity supply	2782	-	5	13910	0	-	5	0
Electricity grid management	1804	-	5	9020	1804	-	5	9020
Govt taxes Electrivity	3996	-	5	19980	0	-	5	0
Total (Euro)	**13889**	-		**73780**	**1804**	-		**9020**
					Savings (Euro)			**64760**

A rough investment for retrofitting building services and instalment of PV panels is provided in Table 15. All prices do not include cable cost and installation charges, but the base prices from manufacturing companies are used. Even though the technologies and products proposed can be expensive to purchase up front, however the cost difference is expected to be paid back over time through lower energy bills.

Table 23 Cost of building services and PV panels

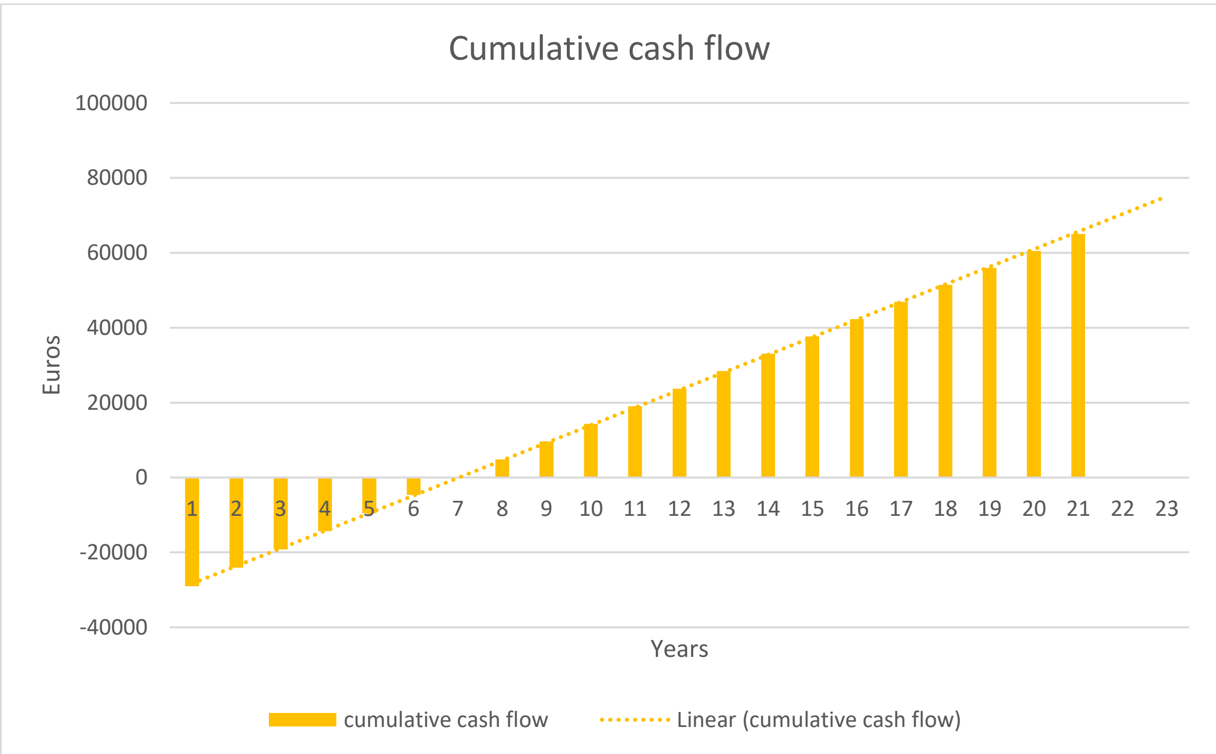
Panel cost	
Watt peak [Wp]	310
Cost/Wp	0.61
Cost per module	€ 189.10
Number of Modules	120
Cost of panels (Euros)	**€ 22000**
PV installation	**7000**
Total	**29000**
Additional costs	**5000**

Building services cost	**Rough estimated PRICE €**
Water heat exchanger	3000
Heat pump boiler unit (excl. installation)	5000
Heat recovery ventilation unit (excl. installation)	7000
Low temperature radiator	200
Solatubes	500
Total	**15700**

The cost of PV panels including installation is estimated as € 29000. Using the PV output from simulation results, payback period is calculated. The electricity cost Euro cents/kWh is considered from the current electricity bill. The payback period is 6 years. After this time frame, the association rather makes profit. These prices are subject to change depending on quantities and sizes which is not scope of this thesis.

Table 24 Input paramters for cumulative cashflow

Electricity cost (Euro cents/kWh)	Yearly output (kWh)	Yearly consumption (kWh)	PV Cost €	PV output reduction
0.07783	63000	51000	29000	0.45%



8. CONCLUSION

The research aimed to analyse problems associated in existing buildings that cause high energy consumption and poor indoor quality. Proposing climate design interventions in such a building aims to improve the energy performance and quality of indoors. The thesis answers the main research question with the case of Proteus Eretes, “What are the sustainable strategies that can be used in renovation projects to reach nearly zero energy (NZE) and high indoor environmental quality (IEQ) for user comfort?”

The literature study was built on two foundation criteria, transition of existing buildings towards nearly zero energy and high indoor environmental quality. The problems associated in existing buildings that cause high energy consumption, occupant discomfort, and poor indoor quality were identified. Since the topic was intricately concerned with real-life renovation plan of rowing accommodation D.S.R Proteus Eretes, the design revolved around the building’s occupancy, spatial requirements, and energy usage behaviour. From the beginning of the project till the end phase, each sub-question has been dealt sequentially to reflect on the main question.

The initial phase focussed on energy usage in the building that is affected by user experience of indoor comfort. On-site survey helped to create basic knowledge of Proteus Eretes indoor environment and locations of improvement in the building. Using thermal comfort software tool, understanding was made regarding the comfort classification to set design goal to have least percentage of people dissatisfied, specially in spaces like fitness rooms, ergometer room, and recreational spaces. The architectural redesigning of the rowing accommodation highly focussed on user interaction and user accessibility with each space. Design elements have been proposed that create unique sense to Proteus Eretes association. Through literature review, knowledge on integrated climate design strategies that combine passive design with active equipment technologies was gathered for renovation projects. Suitable choices for building envelope refurbishment, heating and ventilation retrofits, and use of renewable energy sources, were analysed for logical implication in the rowing club building.

Thermal mass systems that can be easily fitted in the existing building structure were investigated to reduce space heating demand. Changes made to façade openings by using high efficiency glazing also contributed to reducing solar heat gains and losses. With improving in window to wall ratio, enough daylight enters through the rooms. Additional mounting of solar tubes where reconstruction of windows is difficult, is also proposed for natural light in the spaces. Along with replacement of existing lights with best practice LED, large reduction in lighting consumption is observed. For pleasant environment specially in summers, windows have been designed in bar attic and ergometer room allowing cross ventilation. The issue with stale air at peak hours in changing rooms, toilets and bar attic has been resolved by proposing installation of heat recovery ventilation system with demand control sensors. The heat recovery system also reduced heating load by evenly distributing warm air during winter months. With the CO_2 sensors, the ventilation flow varies as per the amount of people in occupying the space. In this way, the system fan energy is also balanced. The proposed changes in bar attic and ergometer room are tested for ATG thermal comfort classification. The thermal comfort hours were affected by specifications like insulation levels, slight changes in window to wall percentage, increasing natural ventilation or changing HVAC setpoints. Finally, ***85%*** better overall environment is proposed.

Using heat pump instead of gas boiler proves large reduction in total energy consumption. Renewable heating energy source is ensured by interesting use of canal water by installing water heat exchanger. This technology is upcoming in Netherlands and the product is readily available in the market and can be easily installed. The roof of the boat storage is proposed to have almost 150 PV panels covering an of 300sqm. Not only this, but building integrated PV is also proposed for south-west-oriented façade of ground floor of De Beuk.

Calculations for ventilation requirement and energy demand have been carried out prior to simulation phase using Design Builder software. The proposed design was compared and validated against the existing situation in terms of energy performance, thermal comfort, and daylight access. The results were further developed in excel to measure primary energy consumption in existing building. Percentage reduction in heating, ventilation, lighting, domestic hot water has been noted for proposed design. There is ***25.7%*** reduction in energy demand in proposed design out of which heating and lighting demand contributing majorly. The overall *primary energy consumption drops down by **62.5%***. The calculations show a 95% energy of total energy requirement covered by PV generation. Hence, the renovation proposal for the rowing accommodation achieves the goal to become ***nearly zero energy building***.

Finally, rough cost estimation was performed regarding investment and profit that the association might ponder upon for the adopting the proposed renovation. The calculations might be subject to change as certain factors have been neglected for which, it is better to consult a specialist. Through the rough analysis it was observed that the initial investment for building service retrofits, PV installation and reconstruction might be high, although, the amount is paid back in a span of 6years, post this time the association rather makes profit at a constant rate.

In conclusion, the graduation research has been able to highlight all the relevant factors concerning the renovation of existing building towards *energy neutrality, high indoor quality, and user comfort* in *a symbiotic manner*.

9. LIMITATION

Focusing on climate design strategies is a manifold challenge. The research can become very broad with numerous interventions can be used to improve overall building performance. Therefore, to come to reasonable solutions, the choices were short listed based on the extent of changes required, simple energy efficient installation and to meet user needs in this renovation project.

A thorough analysis of existing building was performed for energy and comfort aspects. A more precise analysis for air quality and light intensity in the building could have been performed using measuring instrument like a CO_2 meter and lighting level meter. However, due to lack of tools, the assumption was made through surveys and site-visits that the air quality is poor and daylight is insufficient.

Since the graduation period took course in winter season, the user opinion about indoor environment might also be subjected to a cold weather condition. However, many people informed from past summer experience about the overheating problems.

During the design process, it was realised that changing the plan of the building can improve a lot in terms of indoor environment. The extent of renovation was limited to few locations for major improvement due to limited labour and expenses.

Due to time constraint, the detailed design for ventilation system i.e. demand control ventilation DCV not carried out. The outputs and fan energy consumption were manually calculated.

10. RECOMMENDATION

Based on the methodology considered during the thesis to solve a real-life renovation case and strategies explored, design guidelines have been formulated. This chapter highlights key recommendation for integration of climate design for renovation of buildings. These guidelines are applicable for renovation of rowing facilities and other buildings of similar typology.

- Defining goals based on occupant experience

Before diving into building analysis and renovation strategy development, it is important to inspect occupant experience of indoor environment and requirement for changes. This approach may include user interaction at various levels such as on-site surveys, observations, online forms, interviews with general users and specific user category. The subject for occupant consideration mainly focuses on two aspects, experience of indoor discomfort and interaction with architectural planning.

Assessment of indoor discomfort:

- Provides an understanding of occupants feel about indoor temperature
- Helps in identifying the main problems causing indoor discomfort. This can include inefficiency of heating and ventilation system, heat loss or heat gain due to building envelope, ineffective glazing system, over-crowding of spaces.
- Provides idea on the energy usage behaviour which is partly affected by indoor discomfort.

User Interaction with space:

- Provides idea on which spaces can be improved in terms of increasing area and improving the layout
- Helps in prioritizing the functionality of spaces as per the need of the users

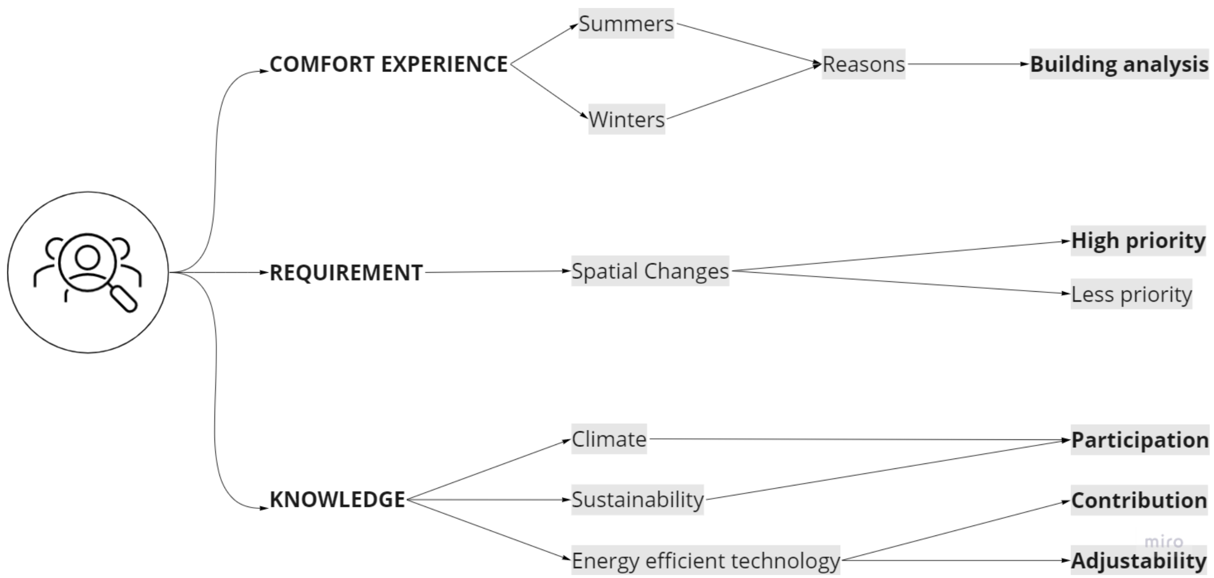


Figure 113 Defining goals based on occupant experience

At an early stage in the process, the above methodology with respect to end user requirement should be realised to define the design goal. The functionality of space along with the optimum cooling and heating design condition to provide high indoor environmental quality should be the prime focus.

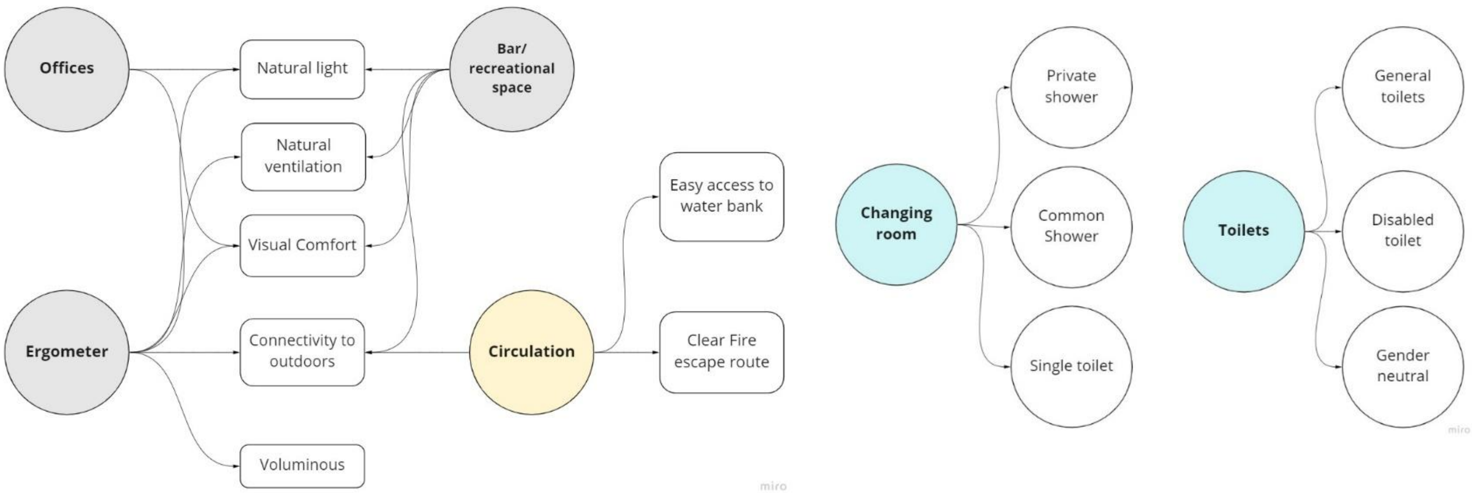
This is determined by summer and winter comfort condition that include respective operative temperature, minimum zone air speed, metabolic rate, and clothing value of occupants. The percentage of people dissatisfied in the existing condition of building outlines the reasons for indoor discomfort. The knowledge of thermal comfort experience gives idea on possible changes in building envelope, retrofitting heating and ventilation systems.

- **Defining criteria for architectural renovation and building service retrofits**

Various strategies for changing the spatial layout, façade and retrofitting building services were explored. The renovation of architectural layout might vary for different rowing accommodations. However, it is important to keep certain criteria fixed for re-designing the layout in terms of providing more space, provision of daylight, view to outdoors, connectivity with nature, orientation of rooms, easy circulation between different functional spaces. The space should be categorised as public space, semi-public space, or private space according to the usability. The focus points for renovation plan of rowing accommodation are as follows:

- The most active spaces like offices, ergometer room, bar cafes should have south orientation for more natural light.
- The ergometer room should have façade viewing the waters for better visual appeal and connectivity to outdoors. During rowing events, it should be easy for the spectators to access the water banks.
- In case of fire, a clear escape route within minimum evacuation time from each zone should ensured.
- The shower area should have one minimum private shower for those occupants who do not feel comfortable sharing shower.
- Main toilets should be separated from changing or shower rooms except a single toilet in changing room can be provided. A separate toilet for disabled people and/or gender-neutral people should be designed as well.

Figure 114 Bubble diagram for spatial editions



Building envelope:

The renovation of building envelope has potential for improving the quality of indoors and energy consumption in rowing clubs. Adhering to minimum requirements for thermal conductivity of façade, openings, floors and roof, the decisions are made specific to buildings.

- Use of double glazing with low-e coating preferably, or triple glazing with much lower U-value. The solar heat gain coefficient should lie between 0.4-0.63 for passive solar effect.
- Minimum 55% window to wall ratio should be considered for spaces like bar attic, offices, and ergometer room. This allows determined for better visual comfort, daylight provision and connectivity to outdoors.
- Natural ventilation through stack effect should be provided wherever possible. Operable windows in the glazing system also helps in natural air flow.

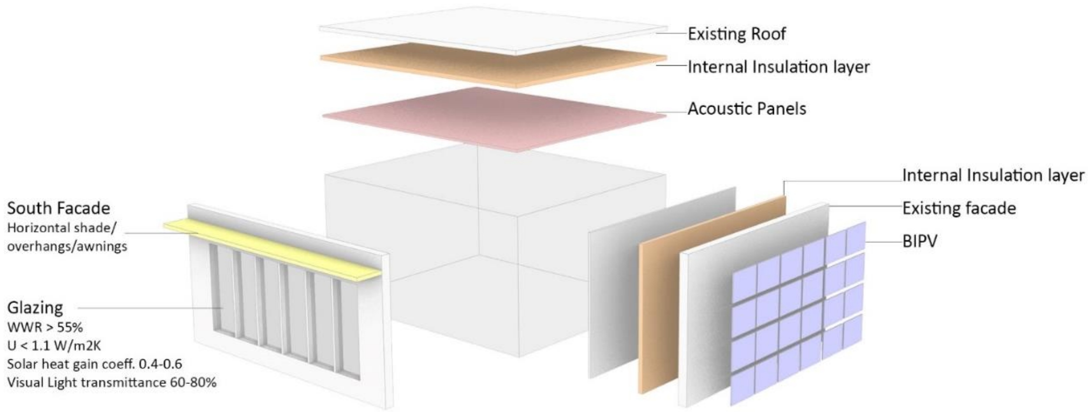


Figure 115 Recommendation for envelope

- Insulation strategy should consider the impact on internal floor area, extent of renovation of façade, thickness, thermal bridging. It is concluded from current thesis that providing a layer of internal insulation on façade and/or roof has reduced heating load without changing the appearance of façade.
- Acoustic panels should be provided in construction for sound proofing specially spaces such as bars.
- PV façade during refurbishment process impacts the aesthetics of the building while enhancing the energy efficiency. South façade with higher solar heat gain is suitable location for building integrated PV panels. It can also be achieved with shading elements.
- Additional green roof can be added for ambient temperature and rainwater buffer.

Building services –

- Immediate action for replacement of gas boiler with heat pump should be taken. There is 70% reduction in energy consumption observed which also cuts down energy bills by large amount.
- Heat recovery ventilation should be installed with demand control sensors. Using control sensors in such spaces with changing occupancy allows the ventilation supply to increase or decrease. This helps in energy savings while keeping comfortable indoor air.

- Shower water heat recovery system with heat exchanger can also be added if the connection of pipelines to hot water and heat exchanger is easily possible.

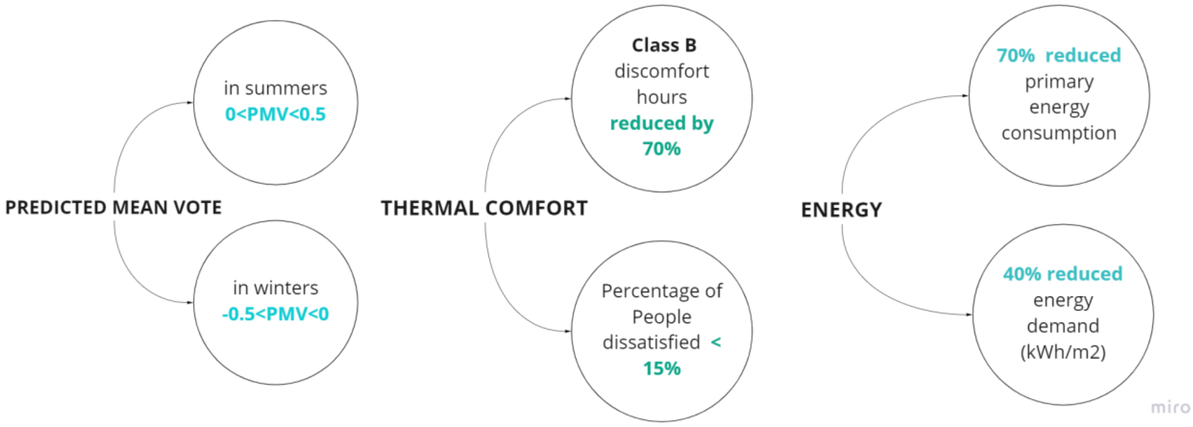


Figure 116 Benchmark for energy and comfort

- Maximizing the use of renewable energy technology

Water heat exchanger should be installed at the quay wall of rowing club. Not only it is renewable, but also simpler solution compared to ground source heat pump which requires more extraction space for ground and thus higher investment.

The boat storage warehouse in most rowing clubs provide suitable location for installation of PV panels. Depending on the primary energy requirement, the investment on PV panels should be done to achieve nearly zero energy. It is possible that with the complete renovation of the building, the energy demand reduces to great extent, which allows for surplus energy that helps association with financial profit by becoming energy producers for neighbouring electricity grid.

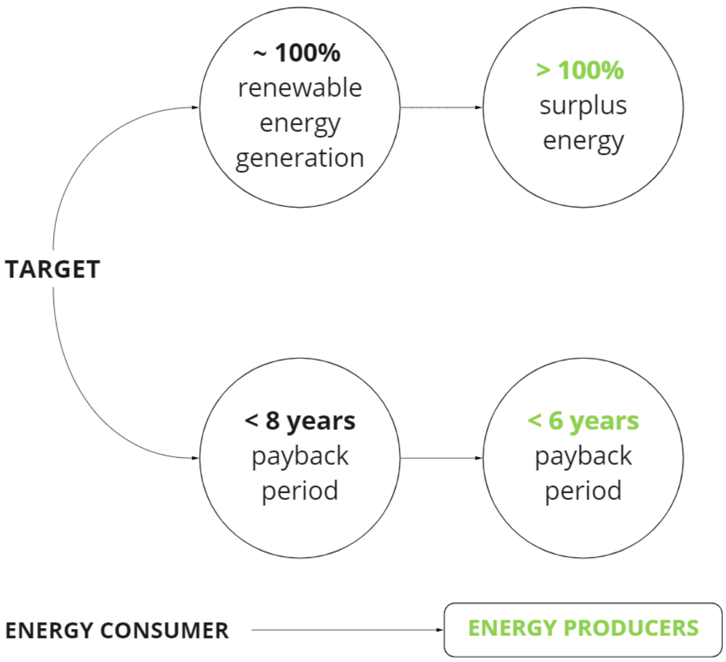


Figure 117 From eenrgy consumers to energy producers

11. REFLECTION

To meet EU's energy targets, the building sector is undergoing through immense research and methods to transition into nearly zero energy. The goals are not only set for new construction, but also for renovation of existing building stock. The degrading building fabric and outdated building systems in older construction contributes to high operational energy demand. Therefore, deep renovations that cut maximum energy consumption are of urgent importance. This poses a bigger challenge because existing structures have predefined users and functions. Therefore, incorporating nearly zero energy strategies in existing building draws attention to core technical, financial as well as social domains.

The research focussed on exploring sustainable strategies that can judiciously be applied for renovation projects to reach nearly zero energy target while enhancing indoor environmental quality for user comfort. The graduation thesis was developed around an ongoing case of rowing accommodation D.S.R Proteus Eretes. The building of rowing association was constructed in 1970, the structural condition of which has deteriorated with time leading to poor indoor quality and high energy consumption. Also, the growing occupancy of the association is not well accommodated by the current spatial planning of the building. The objective of the research was to devise a pragmatic solution to improve the condition of the building energy, indoor comfort, and functionality. During the graduation, I was able to *expand my horizon* in field of energy and climate and the relation of two in societal dynamics.

- Research methodology, design process, limitations, and results

A step-by-step methodology has been followed to achieve the goal of thesis in given time frame. As the topic is strongly concerned with the renovation of an existing building in Delft, the research approach took in consideration analysing the building at various levels. This involved survey performed on-site and online with the users of the building regarding the experience of indoor comfort at Proteus Eretes. This helped in clearly identifying locations of improvement in building. Simultaneously, knowledge regarding zero energy guidelines, factors affecting indoor air quality, thermal comfort, passive, and active strategies for refurbishment of old building towards energy neutrality were studied. The research immensely helped in understanding the major problems that generally occur in old buildings which leads to poor indoor environment, occupant discomfort and high energy consumption.

It was important to visit project site at different phases to relate the research-based solutions directly in terms of existing structural layout, HVAC layout and user behaviour. In this way, it was made sure that the design solutions are practical and innovative for the refurbishment of the building. Several comparative analyses were performed for design options developed for spatial layout, heating and ventilation schemes, façade refurbishment and retrofitting energy efficient system. The selection criteria for each aspect were formulated that helped in choosing the most unique, functional, and practical option.

The process also faced limitations in terms of extent of changes that can be done for renovation and expenses required to make those changes. However, the financial aspect was never in the scope of thesis, but it was important to derive solutions based on market research that are logical, sustainable, affordable and requires less labour. Each design strategy and limitation that came along was presented to the supervisors and Proteus Eretes's building committee to gather fruitful feedback. This resulted in an *effective integration of strategies that are climate responsive and sustainable for* the application in existing building.

Further assessment methods were followed to verify and validate the design options for energy performance, thermal comfort, and daylight. Different renovation scenarios were modelled in Design Builder software. The software really helped in validation of schemes and providing reliable results. Certain limitations that occurred in technical feasibility of the proposed intervention were also tackled in this phase by optimization approach within the software. This phase was very crucial in terms of performing correct simulations and calculations to reach a solid justification to the developed proposal.

The feedback from mentors throughout allowed me to think *out of the box solutions* for the project case and what it really means to end users. At each stage, the motivation I received from mentors pushed me towards not only achieving the objective but also *taking steps beyond the set goals*. It was kept in mind throughout, that a unique selling point of the proposal must be developed that can convince rowing association and stakeholders to adopt it for their plan of construction. Therefore, rough estimation in terms of investment and payback period of expenditure by using renewable and energy efficient technology was also performed especially for the building committee of Proteus Eretes.

- Relationship between research and design

The base of research study was formed on two performance indicators, nearly zero energy and indoor environmental quality. The guidelines for nZEB and factors affecting IEQ were studied initially. Later, a cohesive conclusion of the two factors was developed. This was followed by investigating integrated climate design strategies that can efficiently solve the issues of indoor air quality, thermal comfort, daylight, occupant's flexibility, and reduction in operational energy consumption. In a holistic manner, these strategies were brought together to meet the requirement of Proteus Eretes building.

The passive strategies that were explored included thermal performance of building envelope using energy efficient insulation and glazing system. The durability of different systems was correlated to the rowing accommodation to make choice for most relevant option. A lot of focus has been given to active equipment strategies regarding sustainable heating and ventilation retrofits. This included replacement of gas-fired heating system to heat pump and installation of heat recovery unit. Moreover, renewable energy sources for electricity generation and source for heat pump were also explored and effectively used in the design proposal. The assessment of design proposal not only highlighted measures to reduce energy consumption but also improving occupant comfort. This was done by thermal comfort ATG classification method used in the Netherlands to identify the percentage of people satisfied or dissatisfied with the experience of comfort in the building. Overall, the research and design process were carried out parallel to each other which led to the development of final design proposal.

- **Positioning of graduation topic in Building Technology track and Masters' program (MSc AUBS)**

The graduation thesis directly tackles the issue of energy and climate, which among others are the core of Building Technology track. The lessons on climate design, façade design, building physics, and zero energy design allows students to delve into sustainable strategies and use of energy efficient technology for buildings. However, it is highly important that the courses also focus on practical implication of the knowledge in real case studies such as Proteus Eretes that directly deal with end users and stakeholders. Under the guidance of Prof. Andy van den Dobblesteen and Prof. Atze Boerstra, the measures that were taken in this project adopted *logical reasoning and impact of building energy and indoor comfort related interventions on the end users*. The amalgamation of the zero-energy, indoor environmental quality, and user comfort for the renovation of existing structure was the main challenge that was solved through this project. The theme clearly aimed at bridging the gap between architecture and building technology.

More thesis topics related to sustainable renovation projects which allow students to directly deal with the building users and stakeholders should be included for Building Technology track. In this way, the *student is confident enough to overcome real life project complications and make an informed choice*. The role of student of building technology can become quite specific in terms of dealing with innovative strategies, building systems or micro level analysis of interventions. Therefore, the is important to devise such solutions from the very beginning of any building project to resonate with architectural evolution.

- **Relationship of graduation project with social, professional, and scientific domains**

On a wider scale, the graduation project intended to *bridge the gap* between building quality, energy use, and occupant health by studying and implementing scientifically confirmed climate design solutions that respond to energy neutrality and indoor quality.

The study aimed at putting forth problems associated to high energy consumption in existing buildings due to poor indoor environment and degrading building fabric. The design interventions took in account climate responsive strategies that are relevant for renovation of such building while meeting the needs of occupant.

Such a problem has been under research work for many residential, office or commercial buildings, however, sports facilities have not been investigated enough. In this category, the target audience are athletes whose health and performance in sports are affected by indoor environment in which they practice. The goal to achieve the nearly zero energy and indoor comfort in an existing building therefore must take in account the nature of activities performed by the end users which impacts the building energy usage in sports facilities.

The conclusion of the thesis influences and guides the rowing associations regarding the efficient use of renewable sources, such as canal waters as source for heating solutions and PV technology to transition towards energy neutrality or even become energy producers.

With a perception of looking at energy transition of existing built environment through a wider lens, provides solution to technical, financial, and social aspects in a holistic way. Refurbishment not just makes building functional as new but also helps in extending the lifespan by adding more value to the building than what is spent in the whole refurbishment process.

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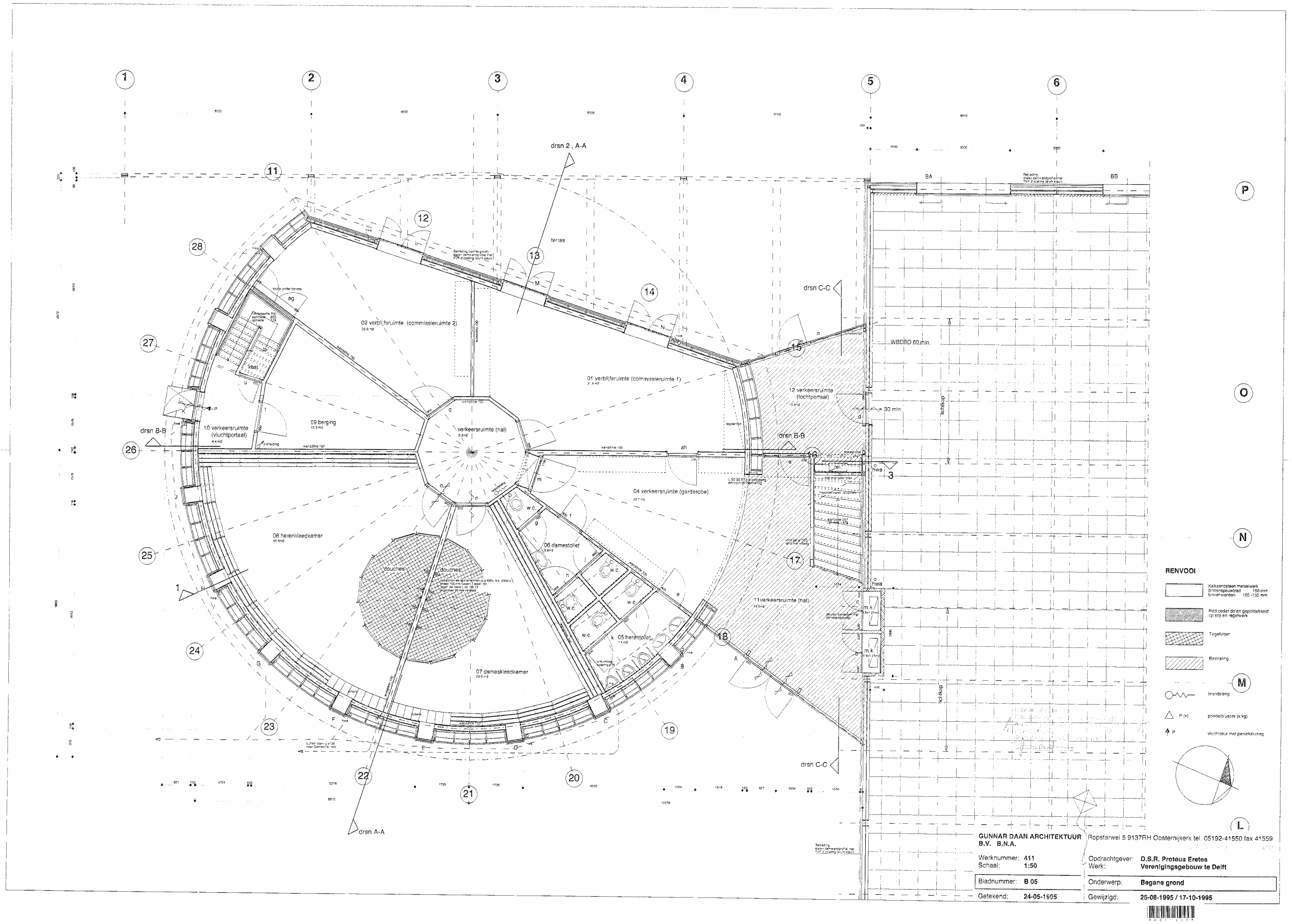
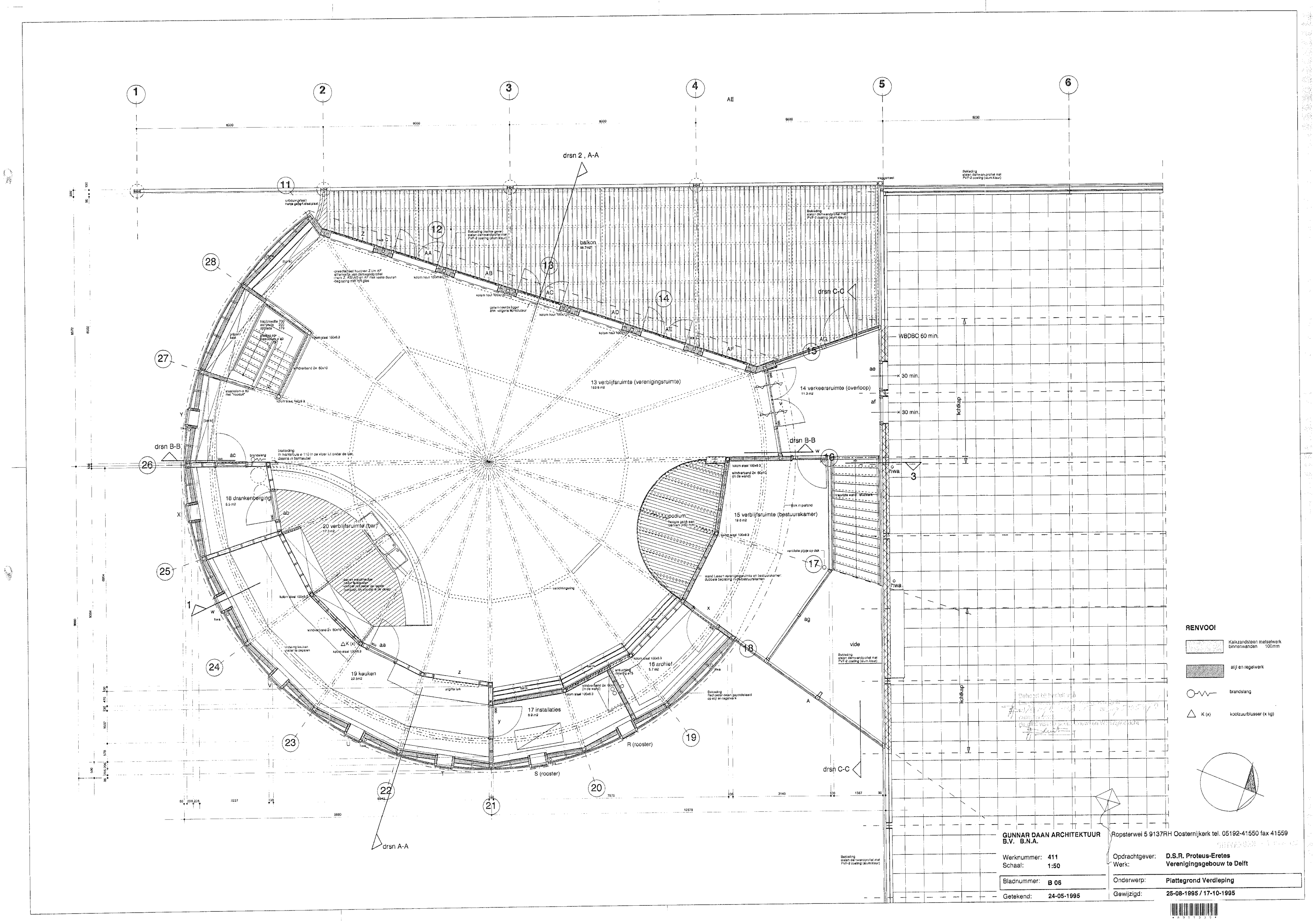
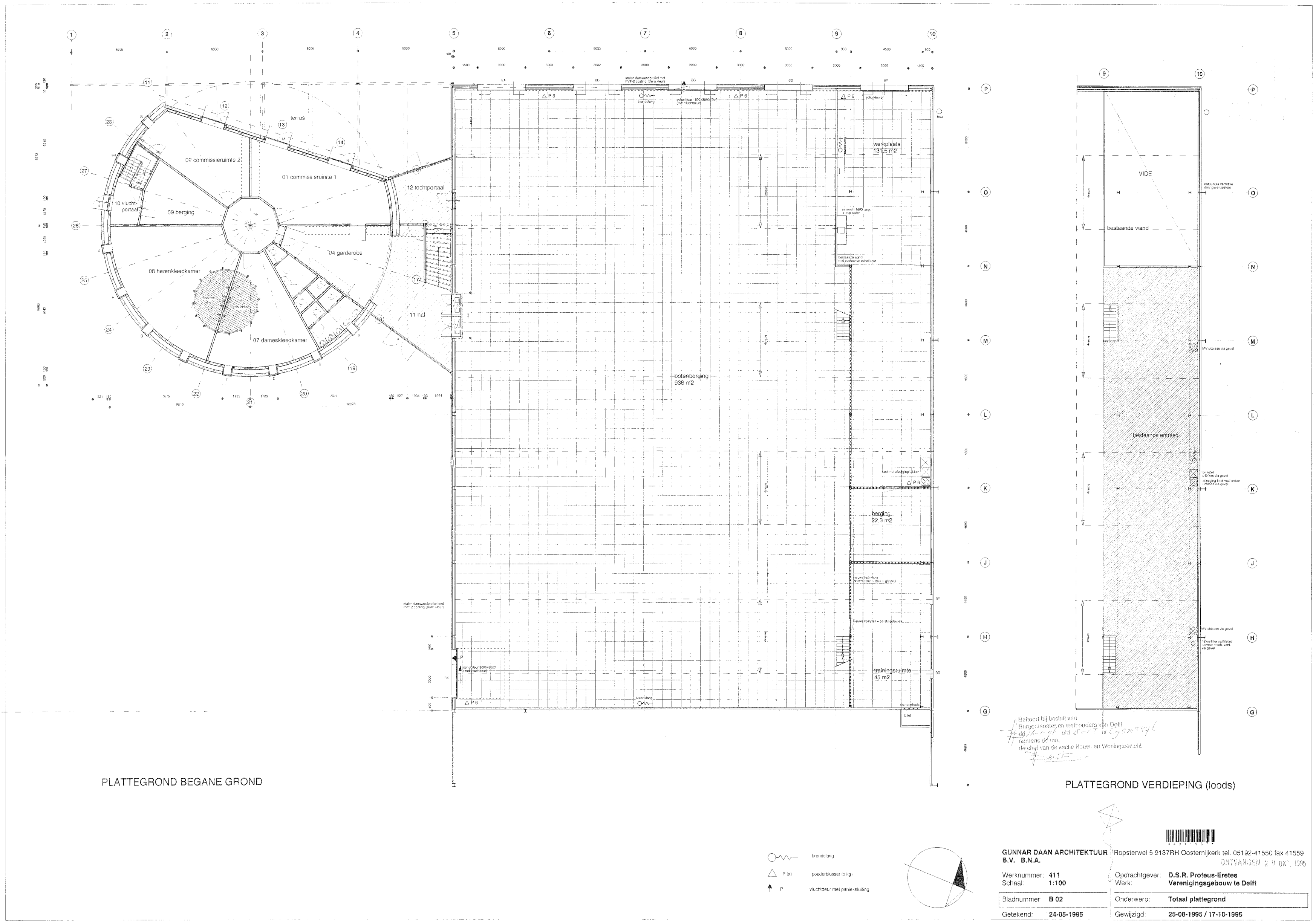
Appendix

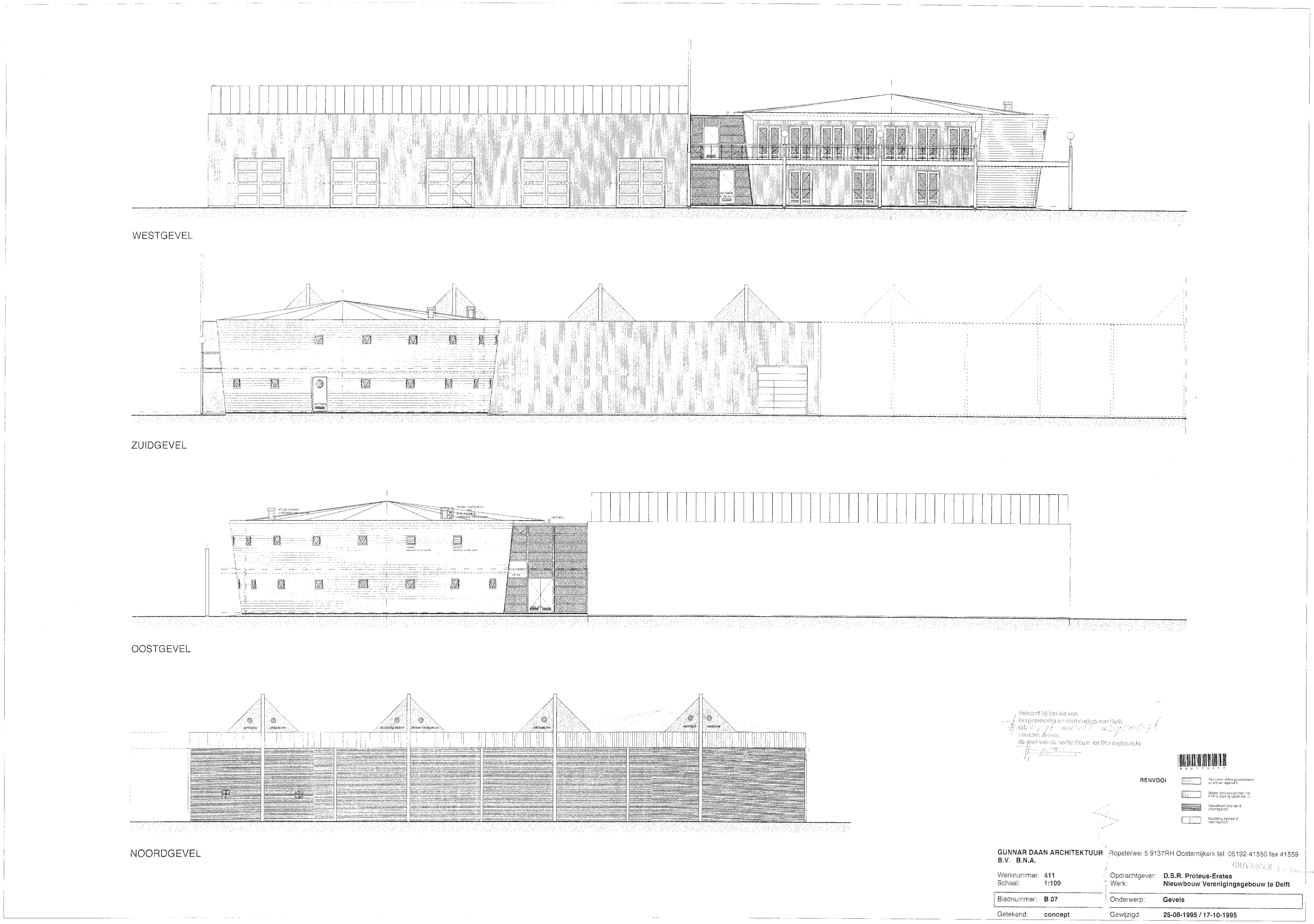
APPENDIX A: Existing Building Drawings

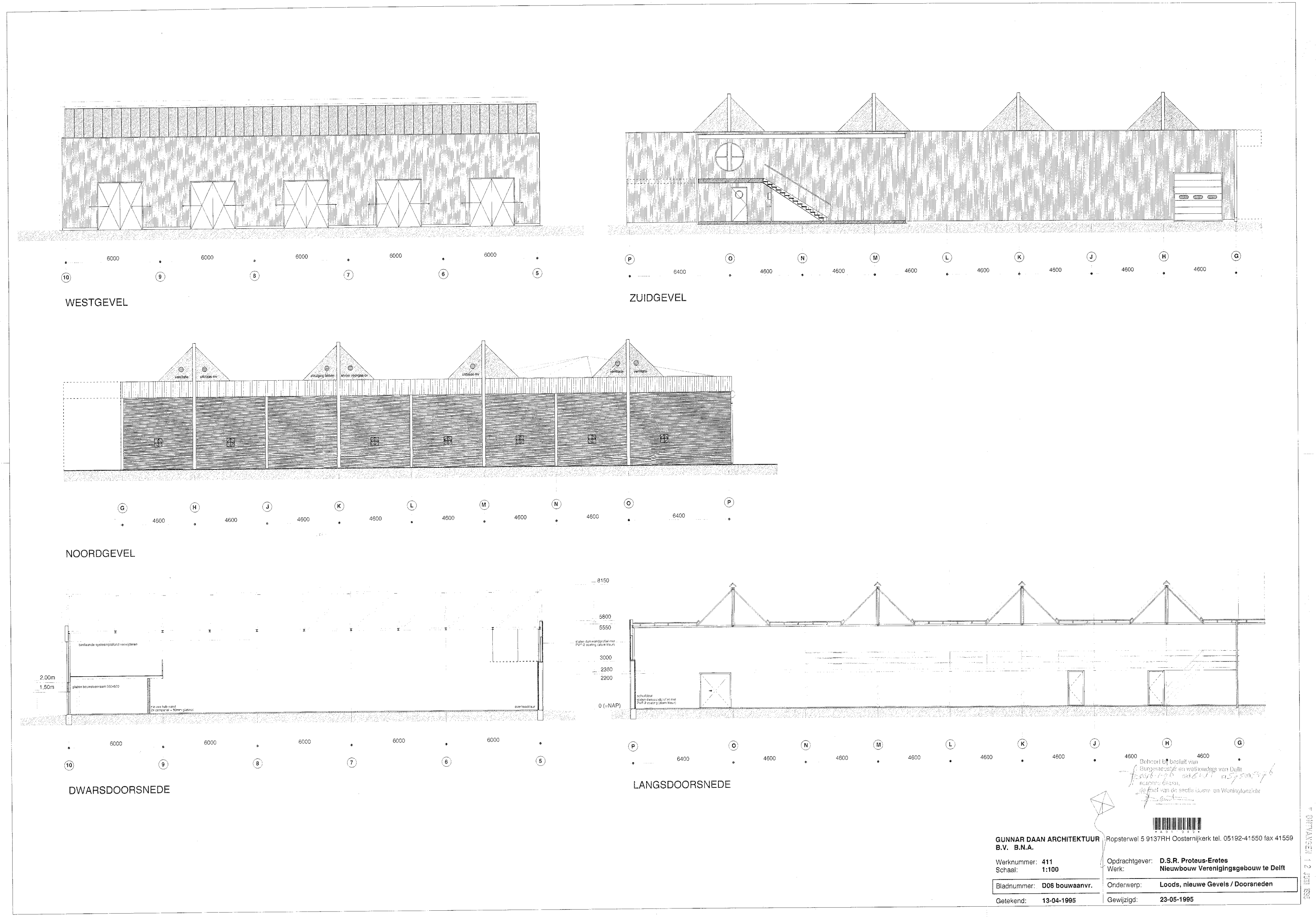


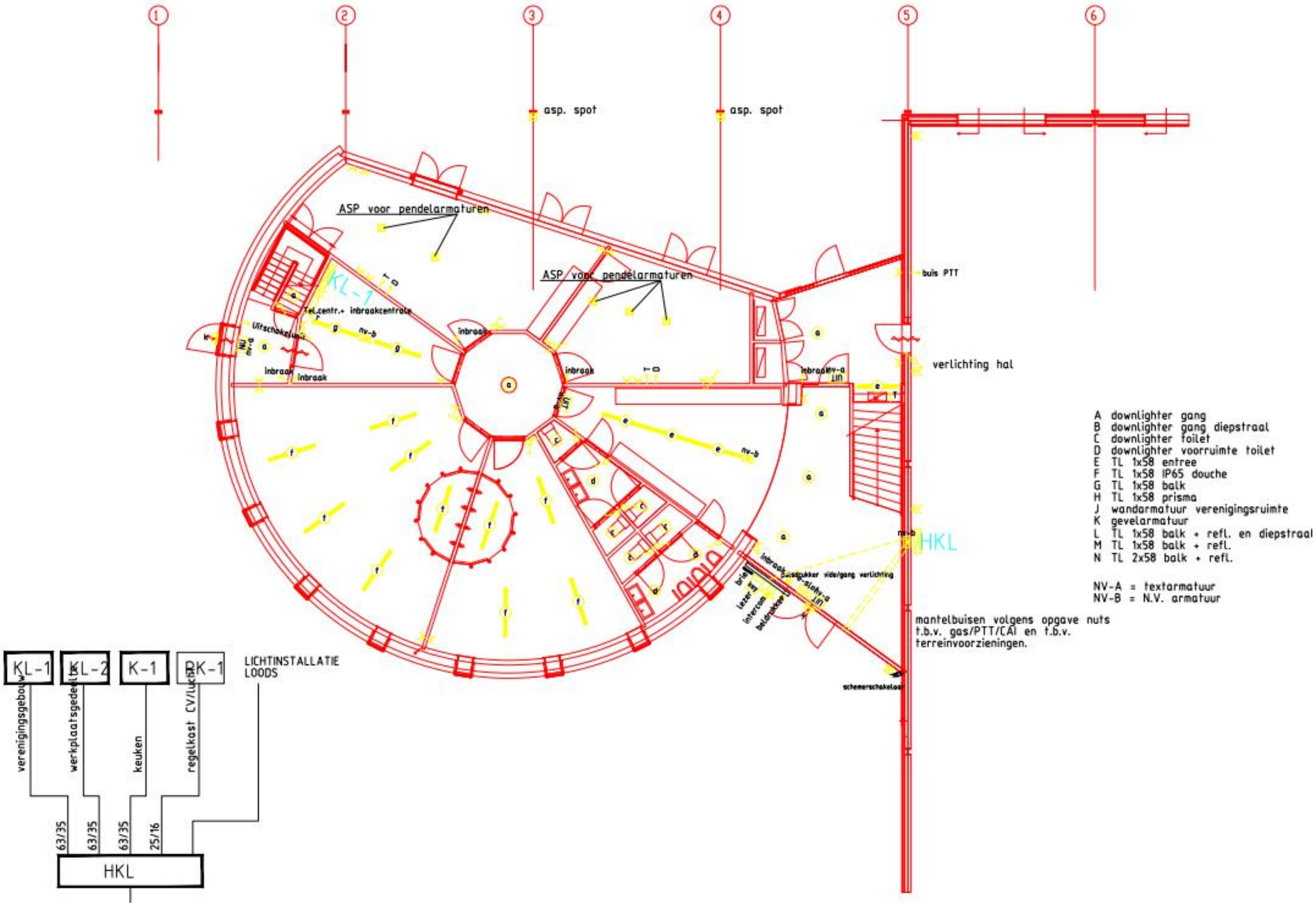

drsn 2 , A-A
balkon
drsn C-C
WBDBC 60 min.
30 min.
30 min.
13 verblijfsruimte (verenigingsruimte)
14 verkeersruimte (overloop)
drsn B-B
18 drankenbereiding
20 verblijfsruimte (bar)
podium
15 verblijfsruimte (bestuurskamer)
vide
19 keuken
17 installaties
18 archief
R (rooster)
S (rooster)
drsn A-A
RENVOOI
Kalkzandsteen metselwerk binnenwanden 100mm
stijl en regelwerk
brandslang
koolzuurblusser (x kg)
GUNNAR DAAN ARCHITEKTUUR B.V. B.N.A.
Ropsterwei 5 9137RH Oosternijkerk tel. 05192-41550 fax 41559
Werknummer: 411
Schaal: 1:50
Opdrachtgever: D.S.R. Proteus-Eretes
Werk: Verenigingsgebouw te Delft
Bladnummer: B 06
Onderwerp: Plattegrond Verdieping
Getekend: 24-05-1995
Gewijzigd: 25-08-1995 / 17-10-1995


podium 400mm hoog
GUNNAR DAAN ARCHITEKTUUR B.V. B.N.A.
Ropsterwei 5 9137RH Oosternijkerk tel. 05192-41550 fax 41559
Werknummer: 411
Schaal: 1 : 20
Opdrachtgever: D.S.R. Proteus-Eretes
Werk: Verenigingsgebouw te Delft
Bladnummer: D 09 bouwaanvr.
Onderwerp: Doorsnede A-A
Getekend: 23-05-1995
Gewijzigd: -

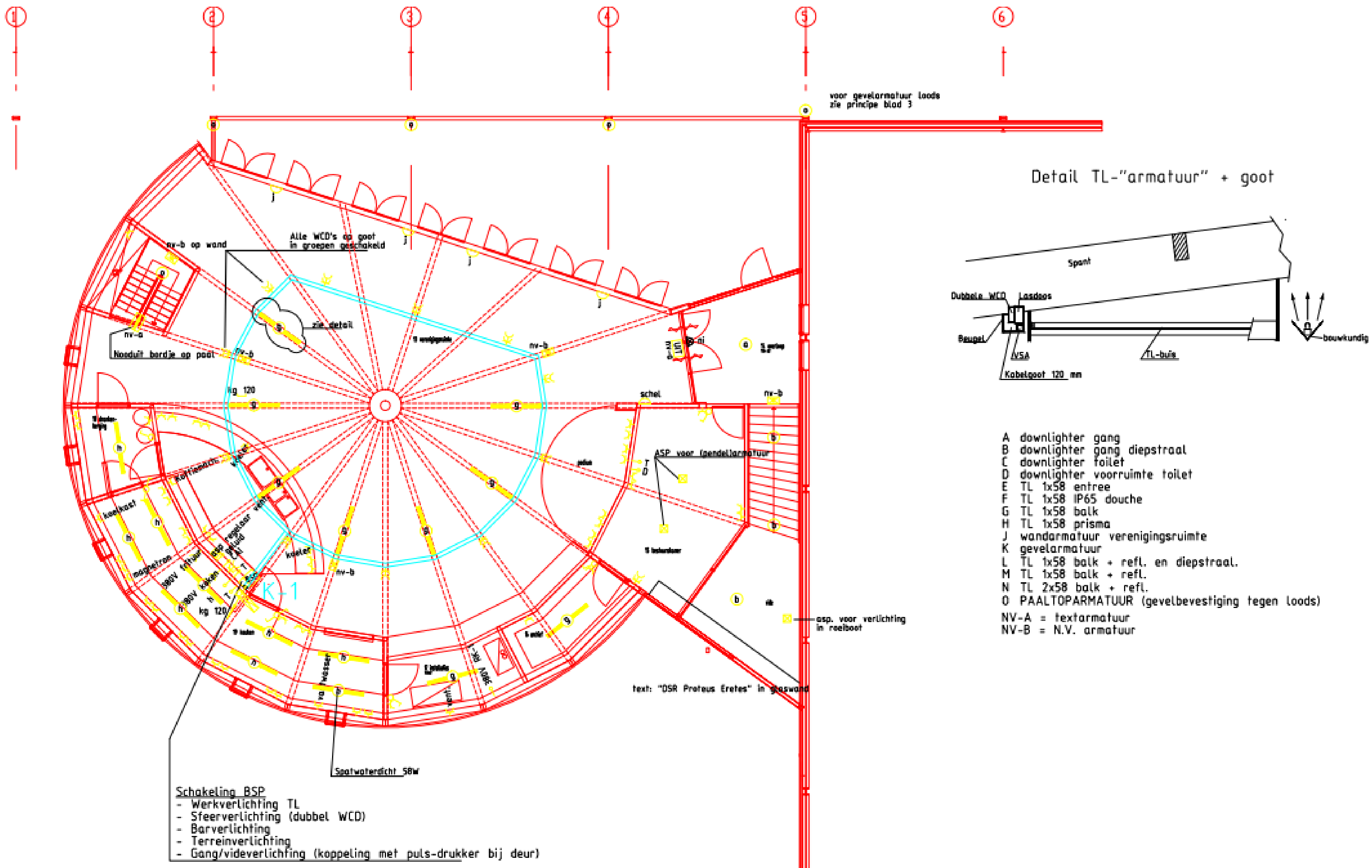

terras
02 commissieruimte 2
01 commissieruimte 1
12 tochtportaal
10 vlucht-portaal
09 berging
04 garderobe
08 herenkleedkamer
11 hal
07 dameskleedkamer
werkplaats
131.5 m2
botenberging
936 m2
berging
22.3 m2
trainingsruimte
45 m2
VIDE
bestaande wand
bestaande entresol
PLATTEGROND BEGANE GROND
PLATTEGROND VERDIEPING (loods)
brandslang
poederblusser (x kg)
vluchtdeur met paniekslviting
GUNNAR DAAN ARCHITEKTUUR
B.V. B.N.A.
Ropsterwal 5 9137RH Oosternijkerk tel. 05192-41550 fax 41559
ONTVANGEN 2 0 OKT. 1995
Werknummer: 411
Schaal: 1:100
Opdrachtgever: D.S.R. Proteus-Eretes
Werk: Verenigingsgebouw te Delft
Bladnummer: B 02
Onderwerp: Totaal plattegrond
Getekend: 24-05-1995
Gewijzigd: 25-08-1995 / 17-10-1995


WESTGEVEL
ZUIDGEVEL
OOSTGEVEL
NOORDGEVEL
RENVOOI
Staten damwandprofiel met PVF-2 coating (alum.kleur)
Metselwerk bestaand (noordgevel)
Beplating bestaand (noordgevel)
GUNNAR DAAN ARCHITEKTUUR B.V. B.N.A.
Ropsterwei 5 9137RH Oosternijkerk tel. 05192-41550 fax 41559
Werknummer: 411
Schaal: 1:100
Opdrachtgever: D.S.R. Proteus-Eretes
Werk: Nieuwbouw Verenigingsgebouw te Delft
Bladnummer: B 07
Onderwerp: Gevels
Getekend: concept
Gewijzigd: 25-08-1995 / 17-10-1995


WESTGEVEL
ZUIDGEVEL
NOORDGEVEL
DWARSDOORSNEDE
LANGSDOORSNEDE
6000
6400
4600
8150
5800
5550
3000
2380
2200
0 (=NAP)
2.00m
1.50m
Behoort bij besluit van
Burgemeester en wethouders van Delft
GUNNAR DAAN ARCHITEKTUUR
B.V. B.N.A.
Ropsterwei 5 9137RH Oosternijkerk tel. 05192-41550 fax 41559
Werknummer: 411
Schaal: 1:100
Opdrachtgever: D.S.R. Proteus-Eretes
Werk: Nieuwbouw Verenigingsgebouw te Delft
Bladnummer: D06 bouwaanvr.
Onderwerp: Loods, nieuwe Gevels / Doorsneden
Getekend: 13-04-1995
Gewijzigd: 23-05-1995



asp. spot
asp. spot
ASP voor pendelarmaturen
ASP voor pendelarmaturen
KL-1
Tel.centr.+ inbraakcentrale
buis PTT
verlichting hal
HKL
A downlighter gang
B downlighter gang diepstraal
C downlighter toilet
D downlighter voorruimte toilet
E TL 1x58 entree
F TL 1x58 IP65 douche
G TL 1x58 balk
H TL 1x58 prisma
J wandarmatuur verenigingsruimte
K gevelarmatuur
L TL 1x58 balk + refl. en diepstraal
M TL 1x58 balk + refl.
N TL 2x58 balk + refl.
NV-A = textarmatuur
NV-B = N.V. armatuur
mantelbuisen volgens opgave nuts
t.b.v. gas/PTT/CAI en t.b.v.
terreinvoorzieningen.
schemerschakelaar
KL-1
KL-2
K-1
RK-1
LICHTINSTALLATIE
LOODS
verenigingsgebouw
werkplaatsgebouw
keuken
regelkast CV/lucht
63/35
63/35
63/35
25/16
HKL


voor gevelarmatuur loods
zie principe blad 3
Detail TL-"armatuur" + goot
Spant
Dubbele WCD
Lasdoos
Beugel
VSA
TL-buis
bouwkundig
Kabelgoot 120 mm
Alle WCD's op goot
in groepen geschakeld
nv-b op wand
zie detail
Noodunit bordje op paal
lig 120
schel
ASP voor (pendel)armatuur
asp. voor verlichting
in roelboot
text: "DSR Proteus Eretes" in glaswand
Spatwaterdicht 58W
K-1
A downlighter gang
B downlighter gang diepstraal
C downlighter toilet
D downlighter voorruimte toilet
E TL 1x58 entree
F TL 1x58 IP65 douche
G TL 1x58 balk
H TL 1x58 prisma
J wandarmatuur verenigingsruimte
K gevelarmatuur
L TL 1x58 balk + refl. en diepstraal.
M TL 1x58 balk + refl.
N TL 2x58 balk + refl.
O PAALTOPARMATUUR (gevelbevestiging tegen loods)
NV-A = textarmatuur
NV-B = N.V. armatuur
Schakeling BSP
- Werkverlichting TL
- Sfeerverlichting (dubbel WCD)
- Barverlichting
- Terreinverlichting
- Gang/videverlichting (koppeling met puls-drukker bij deur)

APPENDIX B: Existing Building Drawings

Electricity Bill

ENGIE Nederland Retail B.V. Postbus 10087
8000 GB Zwolle
www.engie.nl

Bij vragen www.engie.nl/klantenservice

Klantnummer	K01829283
Factuurnummer	F029600664
Factuurdatum	**07-02-2022**
Gebruikersnaam MijnENGIE	M.H. Miedema
Aansluitgegevens	Rotterdamseweg 362 2628 AT DELFT

Postbus 10087, 8000 GB Zwolle

Delftse Studenten Roeivereniging Proteus-Eretes
Rotterdamseweg 362-A
2628 AT DELFT

Heeft u vragen over uw factuur, kijk dan eens op
www.engie.nl/klantenservice

Jaarafrekening 04-02-2021 t/m 03-02-2022

	Inclusief btw
Leveringskosten elektriciteit	2.782,20
Netbeheerkosten elektriciteit	1.804,39
Overheidsheffingen elektriciteit	3.996,44
Totaal elektriciteit	**8.583,03**
Leveringskosten gas	1.715,45
Netbeheerkosten gas	696,51
Overheidsheffingen gas	2.894,15
Totaal gas	**5.306,11**
Totale energiekosten	**13.889,14**
Totaal in rekening gebrachte termijnbedrag(en)	-13.387,00

Door u te betalen (incl. € 87,14 btw) € **502,14**

Dit bedrag wordt op 21-02-2022 van rekening NL28 **** 580 afgeschreven onder machtigingsreferentienummer MDT0002125384.

Nieuw termijnbedrag

Elektriciteit (Rotterdamseweg 362, 2628 AT, DELFT)	632,00
Gas (Rotterdamseweg 362, 2628 AT, DELFT)	459,00

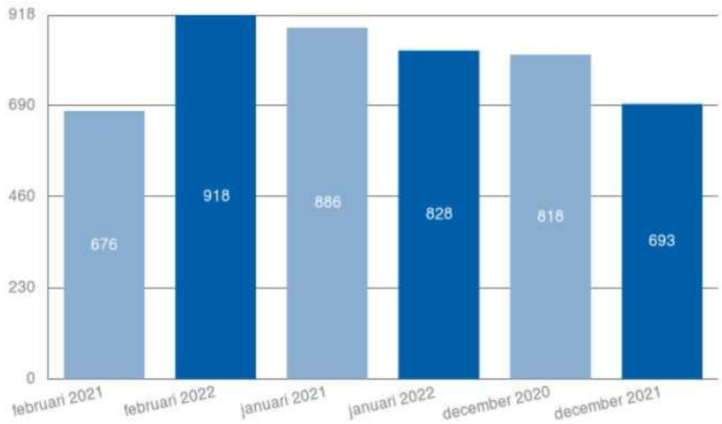
Uw nieuwe termijnbedrag (incl. btw) € **1.091,00**

Gaat een maand na de factuurdatum in. Wij brengen dit termijnbedrag apart in rekening. **Uw termijnbedrag**

Gas Consumption

Gasverbruik in m3

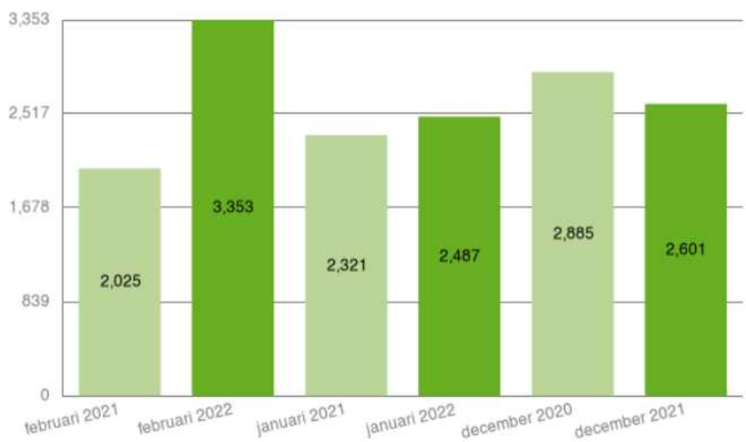
In onderstaande grafiek zie je hoeveel gas je de afgelopen 3 maanden hebt verbruikt en wat het verschil is met diezelfde maanden vorig jaar.



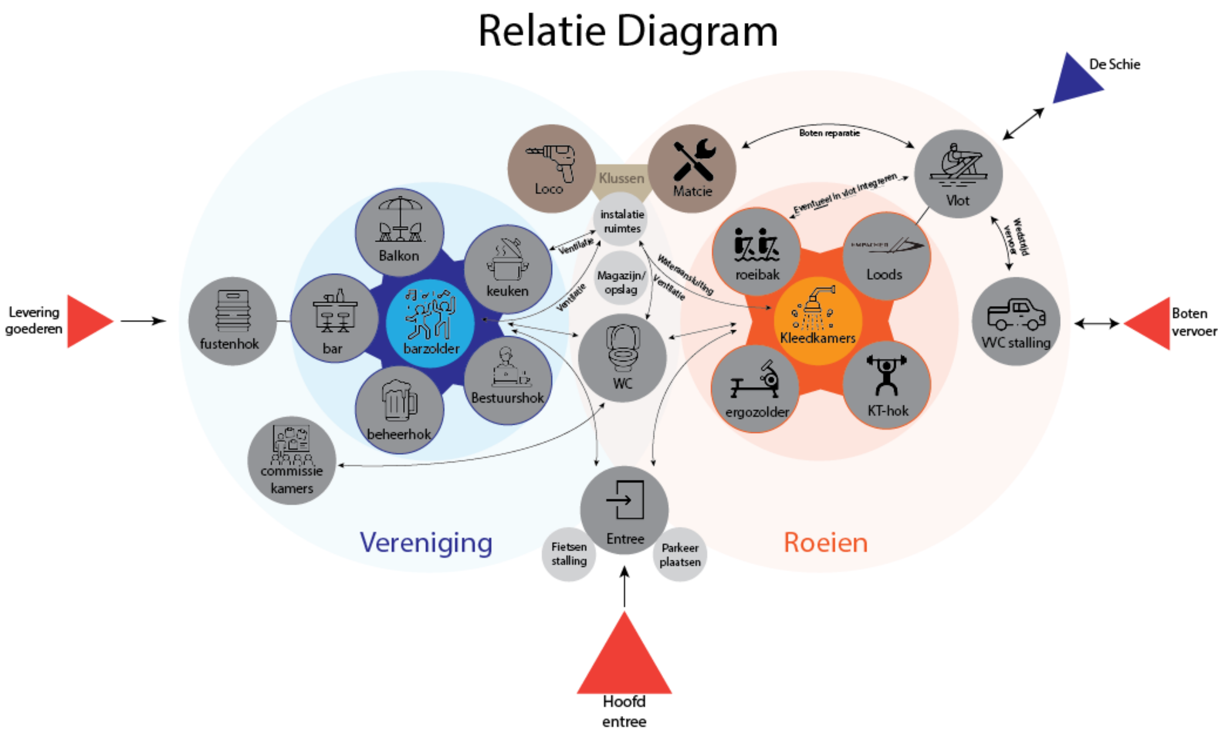
Power Consumption

Stroomverbruik in kWh

Bekijk in onderstaande grafiek hoeveel stroom je de afgelopen 3 maanden hebt verbruikt en wat het verschil is met diezelfde maanden vorig jaar.



Zoning Relation Diagram – Aanbouw Proteus Eretes



APPENDIX C: User Survey

Indoor environment experience inside Proteus Eretes Building

1. Which are the spaces in the rowing club building you find most comfortable to be in, to sit, work and relax? And why?

25 responses

OPEK to work, because is has nice lighting and spacious. Boardroom because it has the best facilities to work and has airconditioning. Barzolder to relax because of the ambiance and connection to the balcony.

The balcony, it provides a nice view of the vlot and has sun.

Uhm... As of right now not so many places. The couches upstairs are allright but there's not really a great place to sit, work or relax like there is on campus.

The "barzolder" has a very nice atmosphere to chat during the day

The OPEK for it's comfortable seating. At the bar for the nice height and gezelligheid if people are around.

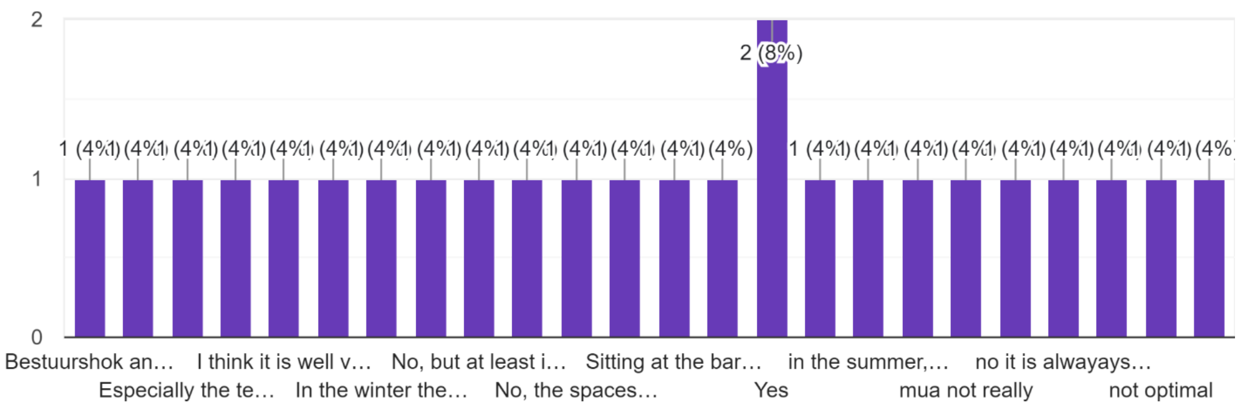
I like to sit in the OPEK, because the temperature is relatively nice compared to the LCK and KCK. Although, there is not much daylight

The OPEK, enough light and a room that can easily warm up

To socialize, I like to sit at the bar, drinking coffee during the day. Surrounding the coffee machine is the

2. Do you think your 'comfortable space of work' is well ventilated and provides thermal comfort?

25 responses



3. Which areas become uncomfortable during peak occupancy hours?

25 responses

Dressingrooms, the meetingrooms are not that sound proof so thats annoying when you are in a meeting and the halls are full. Also the barzolder is very hot and noisy when its busy.

changing rooms

The ergozolder is really uncomfortable when a lot of people are working out there. The barzolder is also pretty uncomfortable when it's filled up with people.

The changing rooms

Barzolder, keuken

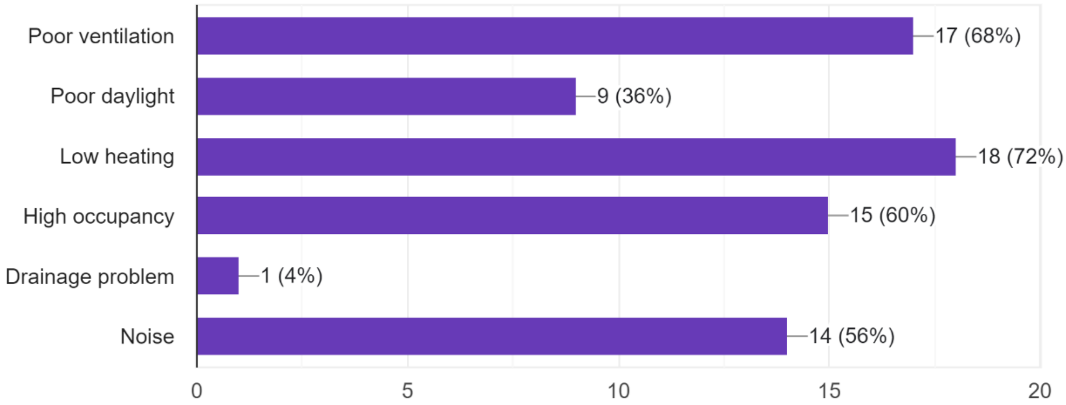
The barzolder and kitchen

The hall and ergometerroom

I find the dressing rooms often times uncomfortable during peak hours, mainly when it's hot outside. In those times, you feel crammed with bad ventilation. I do not like that. The barzolder can get very noisy and

4. What do you think causes indoor discomfort in the rowing club building? Select multiple answers below.

25 responses



5. Any specific remarks about the indoor environment in mid winters and mid summers?

25 responses

Peak winters are cold, but you can dress to that. That goes for nightly activities and sports. Summers are just crazily warm.

During the summer ventilation can be a problem in the ergometer room, but mostly the changing rooms are very noisy and damp

It is very cold in the winter in almost all areas, and in the summer it is very warm at the barzolder if a lot of people are around for drinks or a party.

It is very cold in the winter during winter and pretty hot in summer, especially the ergozolder.

In peak winter it is always cold because the heating is off because it isn't working or it is too expensive for a few people. The daylight is also very minimal. In the summer there is a lot more comfort, more sunlight and no heating problem

Cold when cold, hot when hot.

Too hot i summer almost unbearable at times. In winter it can be cold but not extremely problematic

6. When you are uncomfortable, what do you do? Are there specific actions you take to restore comfort?

7 responses

Grab my jacket and put it back on whenever it's cold. I'd rather sit somewhere where there's daylight.

more clothes in winter and more ventilation in summer

try to open windows

At large parties: cool down in the downstairs area, or even outside.

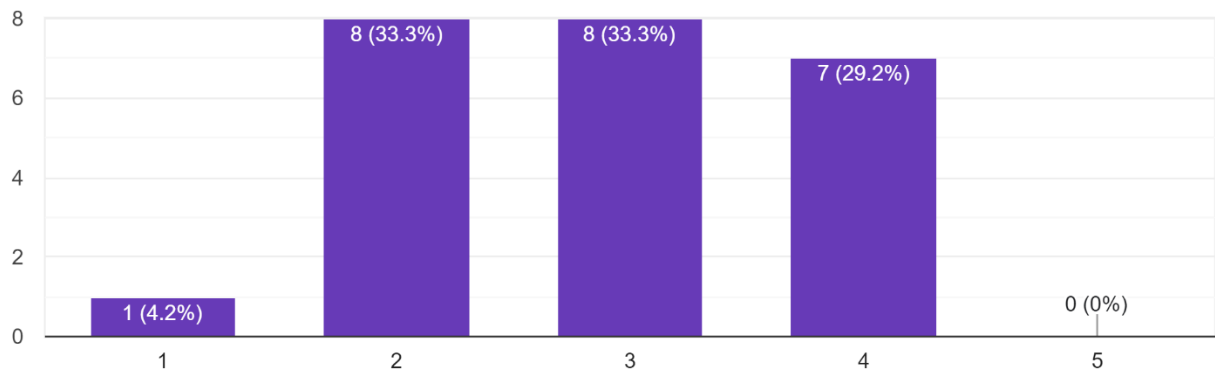
When its cold: put on more clothes. This is not really working if you are staying for a long time

Turn on the heater when it's cold or when it's warm, move to a different area to cool off.

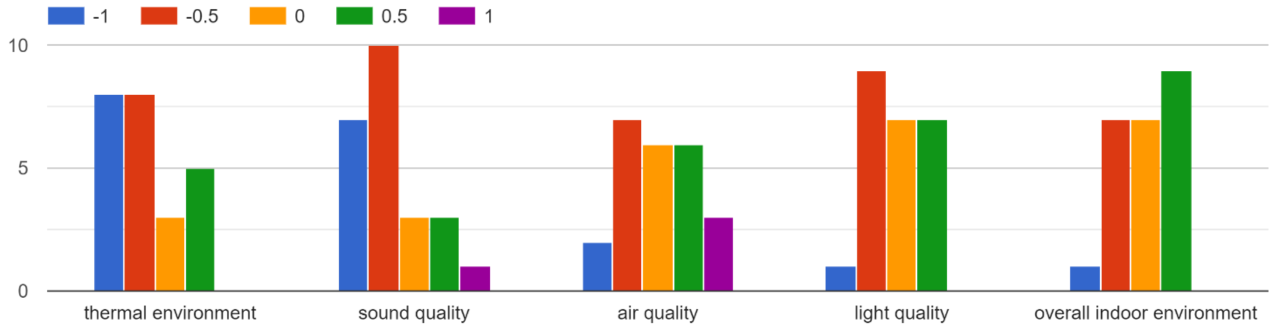
put ergs outside, try to switch all heaters on

7. Are you satisfied with the natural light in your space of work?

24 responses



8. How do you assess the thermal environment/sound quality/air quality/quality of indoor environment at the moment? Rate on scale of -1 to 1.



9. Do you have any ideas to improve the current indoor environment situation?

7 responses

Improve amount of daylight and isolation for keeping warmth in.

fix the insulation and the ventilation

not really

sound dampening!

Insulate the place, install proper ventilation

better ventilation and better insulation

Add isolation to the barzolder, both sound and heat, add an airconditioning or way better ventilation to the ergozolder, add better ventilation to the barzolder that can be switched on and off, add better ventilation to the changing rooms that can be switched on and off, provide better heating to the KCK, OPEK, LCK,

10. Would you prefer low-tech or high-tech solution? Can you give an example if any?

8 responses

High-tech, I row at Proteus, but I study Medicine and Mathematics, my expertise isn't tech solutions, but I guess that isolation is quite expensive, although not so high-tech??

high quality but low price as we are student association, also high tech is nice but only if it is easy to use seeing only volunteers

high tech as it is more building for the future

I prefer something we can build and fix ourselves, professional repair is usually expensive

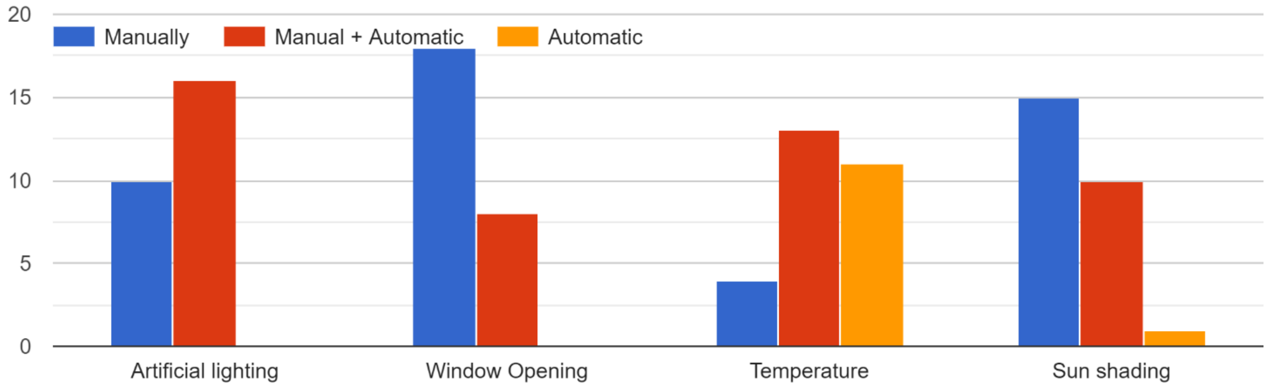
low tech. Just keep it simple, 'high tech' stuff is not going to get the maintenance it needs at a student (rowing) club, and will just break.

No opinion, since I don't know much about it

both are fine, no preference

I think it can be done with low tech, most important to me is that the knowledge about the systems can be passed on each year with great ease, and that it is easily switched on or off. High tech could help tho, but

11. How do you wish to control indoor environment?



12. Are there other problems you would like to mention regarding indoor environmental quality?

14 responses

I really like a lot of daylight in working rooms

Nope

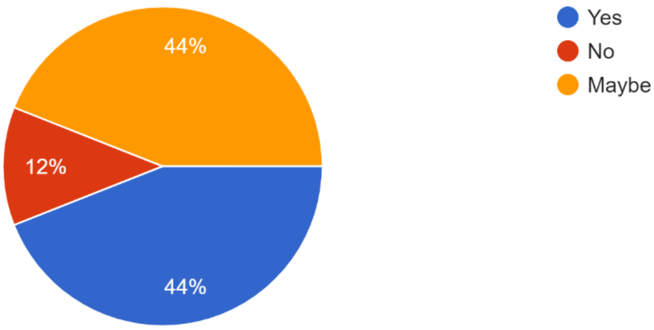
-

To be very fair, I think this questionnaire is not representative of the building we have currently. In my opinion, it shows that you only look at the problem with your study background, and not with the mind of a member of our club. I would suggest spending a few days working, sporting and enjoying a drink at our club, to connect better with the club and have more of an idea of what the building is actually like.
Furthermore, you can also ask the board what they and previous boards think of the building, as they are the ones that spend most time there. This is in my opinion best done in real life, as they can show you what is going wrong.
I would like to mention that it is very nice that you created this form, and ask for our honest opinion.
Though, i would preferably receive this form with a bit more club specific questions.

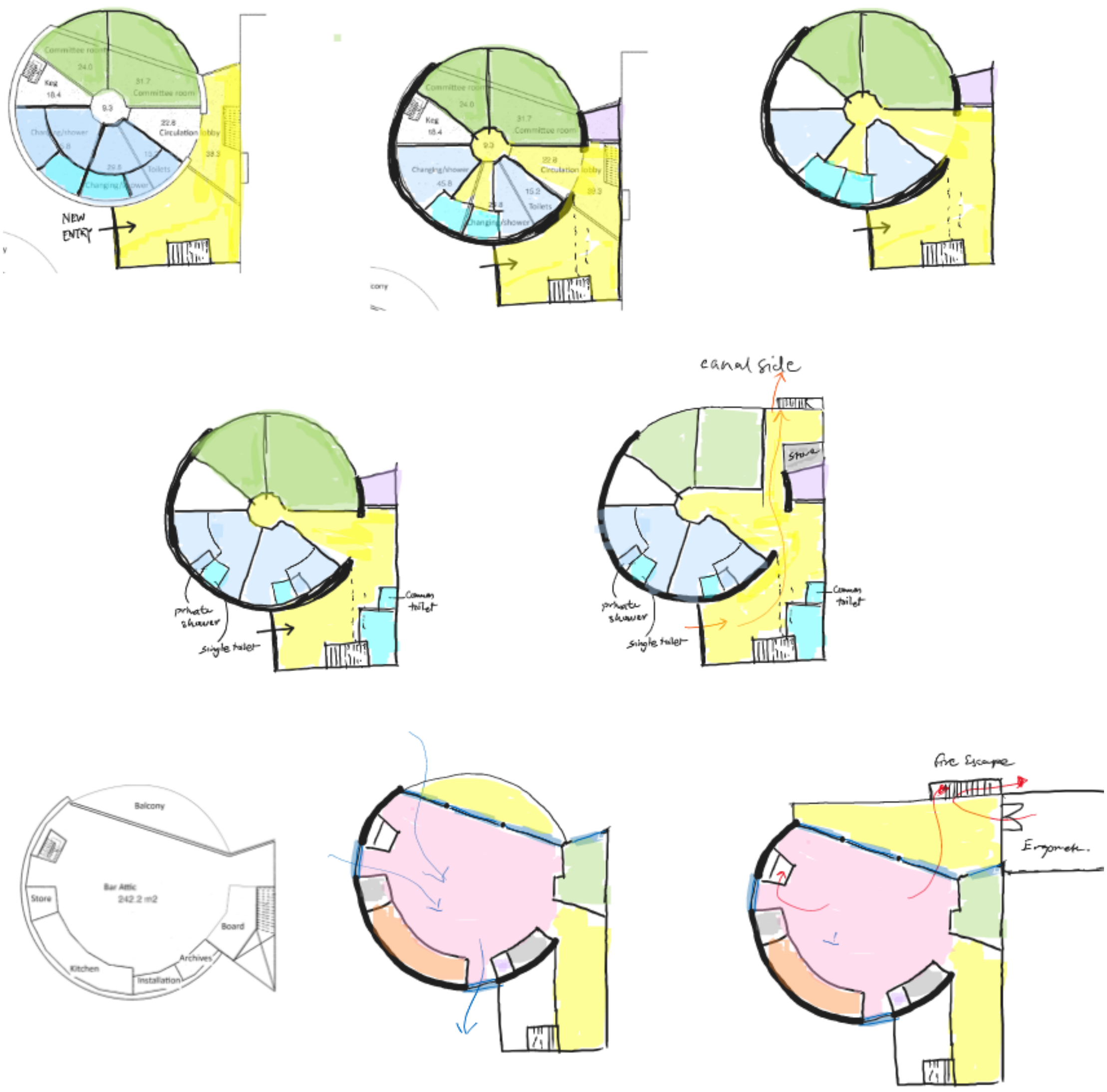
The main problems are capacity to be honest. The member count has doubled since the building was built, causing everything to be overly full. The other main problem is that the building is horribly isolated, ventilation is inadequate and cannot be operated easily, and heating is just underpowered.

12. Do you think you would profit from being given advice on your behavior in relation to heating, ventilating and lighting?

25 responses



APPENDIX D: Design Evolution Sketches



APPENDIX E: Product Details - Renovation installation

Water Heat Exchanger by MEFA (Mefa, n.d.)

data sheet

MEFA ***water*** 1235 - register design

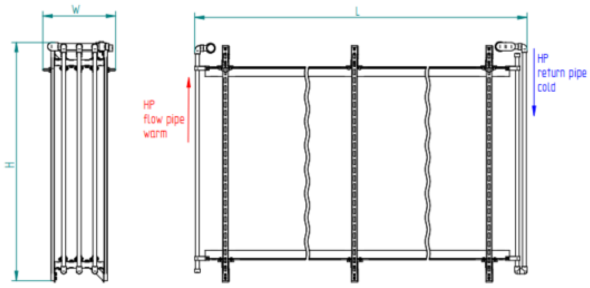
The water heat exchanger MEFA ***water*** consists of uncovered and full-surface through flowen heat exchangers, a stainless steel frame (V2A) and tubing. It is delivered fully assembled.

Ideal areas of aplication are:

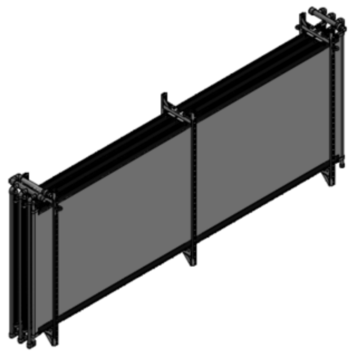
- Active energy source for brine / water heat pumps, both for heating and cooling
- Heat sink for passive cooling of objects with appropriate temperature conditions
- Heat recovery from surface water, waste water, greywater and process liquids

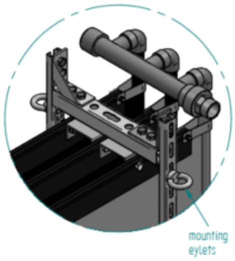
MEFA water 1235 – register design								
description	part number	output high current	output low current	dimensions	connection	recommended volume flow rate V(t)	weight empty/full	brine content
MEFA water 2x1235	E8019794	HP – 6 kW source – 4,7 kW	HP – 4,2 kW source – 3,3 kW	L 3.6m x H 1.55m x W 0.36 m	HP: 2 x 1 1/4" OD	HP: 1.5 m³/h; 25 l/min	58 kg / 85 kg	30 L
MEFA water 3x1235	E8019795	HP – 10 kW source – 7,5 kW	HP – 7 kW source – 5,5 kW	L 3.6m x H 1.55m x W 0.46 m	HP: 2 x 1 1/4" OD	HP: 2.4 m³/h; 40 l/min	83 kg / 124 kg	41 L
MEFA water 4x1235	E8019796	HP – 13 kW source – 9 kW	HP – 10 kW source – 7,5 kW	L 3.6m x H 1.55m x W 0.57 m	HP: 2 x 1 1/4" OD	HP: 3.2 m³/h; 53 l/min	115 kg / 167 kg	52 L
MEFA water 5x1235	E8019782	HP – 16 kW source – 11,5 kW	HP – 12,5 kW source – 8,5 kW	L 3.6m x H 1.55m x W 0.67 m	HP: 2 x 1 1/4" OD	HP: 4.1 m³/h; 68 l/min	130 kg / 195 kg	65 L
MEFA water 12x1235	E8019756	HP – 30 kW souce – 21 kW	HP – 23 kW souce – 16 kW	L 3.6m x H 1.55m x W 1.28 m	HP: 2 x 2" OD	HP: 7.9 m³/h; 130 l/min	252 kg / 408 kg	156 L

different models on request



sample: MEFA water 3x1235





The following points must be observed during preparation and assembly:

- MEFA planning and operating instructions
- Recommendet operating preasure 1.5bar; maximum operating preasure 2.5bar
- Temperature range from -20°C to +55°C
- The heat exchanger mus be completely submerged in the water, secured in position and connected with flexible tubes
- The heat exchanger should be protected against flotsam or other extrenal damage
- All installation work must be carried out professionally and carefully

Properties and charakteristics:

- Possibility to set up in cascade, connected in parallel
- Can be used in flowing mediums and water
- Completely pre-assembled, easy to set up an connect
- Less susceptible to contamination
- Easy to maintain
- Good material resistance by use of PP and stainless steel

MEFA
energy systems
www.mefa-energy-systems.de
74635 Kupferzell

data sheet: E-50-0112-20
as of: 19.10.2020

MEFA ***water*** 0650 - register design

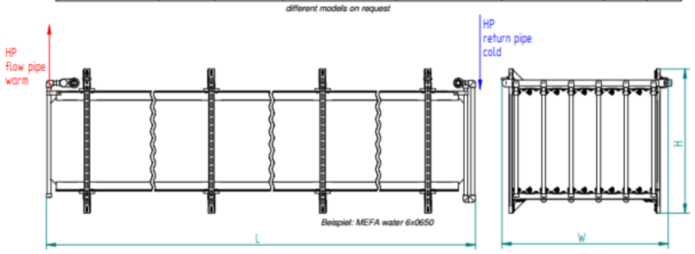
The water heat exchanger MEFA ***water*** consists of uncovered and full-surface through flowen heat exchangers, a stainless steel frame (V2A) and tubing. It is delivered fully assembled.

Ideal areas of aplication are:

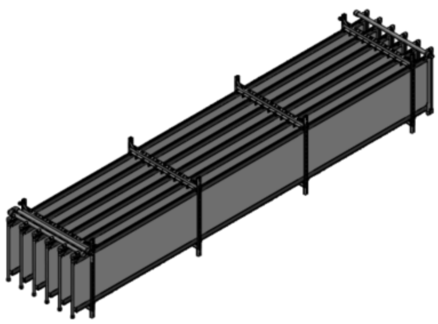
- Active energy source for brine / water heat pumps, both for heating and cooling
- Heat sink for passive cooling of objects with appropriate temperature conditions
- Heat recovery from surface water, waste water, greywater and process liquids

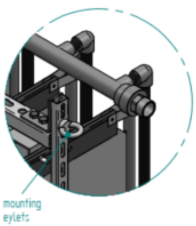
description	part number	output	dimencion	connection	recommended volume flow rate V(t)	weight empty/full	brine content
MEFA water 3x0650	E8019763	HP = 6 kW source = 4,7 kW	L 3.6m x H 0.95m x W 0.6 m	HP: 2 x 1 1/4" AG	HP: 1.5 m³/h; 25 l/min	97 kg / 127 kg	30 L
MEFA water 4x0650	E8019757	HP = 8 kW source = 6,2 kW	L 3.6m x H 0.95m x W 0.7 m	HP: 2 x 1 1/4" AG	HP: 2.0 m³/h; 34 l/min	119 kg / 158 kg	39 L
MEFA water 5x0650	E8019762	HP = 10 kW source = 7,5 kW	L 3.6m x H 0.95m x W 0.8 m	HP: 2 x 1 1/4" AG	HP: 2.6 m³/h; 42 l/min	146 kg / 195 kg	49 L
MEFA water 6x0650	E8019761	HP = 13 kW source = 10 kW	L 3.6m x H 0.95m x W 1.0 m	HP: 2 x 1 1/4" AG	HP: 3.2 m³/h; 53 l/min	173 kg / 231 kg	58 L
MEFA water 8x0650	E8019760	HP = 16 kW source = 12,5 kW	L 3.6m x H 0.95m x W 1.1 m	HP: 2 x 1 1/4" AG	HP: 4.1 m³/h; 68 l/min	219 kg / 295 kg	76 L
MEFA water 10x0650	E8019759	HP = 20 kW souce = 16 kW	L 3.6m x H 0.95m x W 1.3 m	HP: 2 x 1 1/4" AG	HP: 5.2 m³/h; 87 l/min	271 kg / 366 kg	95 L
MEFA water 15x0650	E8019758	HP = 30 kW source = 23 kW	L 3.6m x H 0.95m x W 2.1 m	HP: 2 x 2" AG	HP: 7.6 m³/h; 128 l/min	345 kg / 487 kg	142 L

different models on request



Beispiel: MEFA water 6x0650





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- MEFA planning and operating instructions
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Properties and charakteristics:

- Possibility to set up in cascade, connected in parallel
- Can be used in flowing mediums and water
- Completely pre-assembled, easy to set up an connect
- Less susceptible to contamination
- Easy to maintain
- Good material resistance by use of PP and stainless steel

MEFA
energy systems
www.mefa-energy-systems.de
74635 Kupferzell

data sheet: E-50-0123-20
as of: 27.07.2020

Solatube product sheet. (Solatube, n.d.)

Technical Specifications Ø 74 cm

	Light output in lumens***	Recommended maximum tube length*	U-value complete set**	G-value**	LTA/value**	Sound Insulation** Dn,e,w (C Ctr)	Upward pressure / downward pressure****	Gust Load
Ø 74 cm	-	max. 20 m	-	-	-	65 (- 2;-7) Db	UL 3352/ DL 7182	SB 1350

* Solatube Lumen Output Tabels 4.1 - 7/05
** Research Grontmij (Sweco), Peutz en ITC-CNR
*** Half-year average based on research by Grontmij (Sweco) en Lichtconsult.nl
**** tested with the EN 1873 method by British Board of Agrément.

Measurements

The U-value measurements are carried out with a dedicated hotbox specifically built for the test. This enabled the measurements to be carried out with the daylight systems mounted in a vertical position. The measurements were carried out in accordance with EN-ISO 12567 for windows and doors. The optical measurements were carried out spectrally in accordance with EN 410 using the spectral range of 250-2500 nm. A 2.5 kW HMI light source was used. The measurements were carried out for an angle of incidence of 45 degrees to determine the g-value.

Technical Specifications Ø 35 cm

	Light output in lumens***	Recommended maximum tube length*	U-value complete set**	G-value**	LTA/value**	Sound Insulation** Dn,e,w (C Ctr)	Upward pressure / downward pressure****	Gust Load
Ø 35 cm	2884	max. 9 m	U=1,3 W/m2K	g=62%	57%	65 (- 2;-5) Db	UL 3352/ DL 7182	SB 1350
Ø 35 cm ECO	2330	max. 9 m	U=0,7 W/m2K	g=47%	46%	66 Db	UL 3352/ DL 7182	SB 1350

* Solatube Lumen Output Tabels 4.1 - 7/05
** Research Grontmij (Sweco), Peutz en ITC-CNR
*** Half-year average based on research by Grontmij (Sweco) en Lichtconsult.nl
**** tested with the EN 1873 method by British Board of Agrément.

Measurements

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APPENDIX F: Ventilation Calculation affected by Activity level

Ventilation requirement in existing building

Factors considered for ventilation calculation											
	Area m2	**Height m**	**Outdoor air flow rate per sqm (l/s-m2)**	**Outdoor air flow rate per person (l/s-m2)**	**min. m2 per person**	**m2 per person**	**ACH**	**No. of people (normally)**	**Activity level (low)**	**No. of people (peak)**	**Activity level (high)**
Committee rooms (3 rooms)	75	2.8	0.3	2.5	2	7.8	2	18	1.1	27	1.1
Bar Attic	155	3.4	0.7	4.9	1.5	7.8	6	20	1.2	70	3.6
Circulation de beuk	62	2.8	0.3	2.5			2	4	1.2	6	1.2
Ergometer	208	2.8	1.5	7	1.6	13	8	15	4	30	4

Ventilation requirement				
	DE BEUK			**BOAT STORAGE**
Normal occupancy	**Committee rooms (all)**	**Bar Attic**	**Circulation debeuk**	**Ergometer**
	m3/hr	m3/hr	m3/hr	m3/hr
Minimum air flow rate required ASHRAE method	67	743	103	1431
Air flow rate by ACH	420	3162	347	4659
Air flow rate by activity level, Outdoor CO2 conc.	673	1224	257	2550
High occupancy	**Committee rooms (all)**	**Bar Attic**	**Circulation debeuk**	**Ergometer**
	m3/hr	m3/hr	m3/hr	m3/hr
Air flow rate by activity level, Outdoor CO2 conc.	1010	8568	257	4080
Total	**9344**			**4080**
Grand total	**13424**			

Ventilation in Bar Attic during normal occupancy hours (Airmaster, n.d.)

VENTILATION CALCULATOR

Print

Project informtion

Project name:

Room:

Customer:

Calculaction prerequisites

Room type:	Other rooms
Ventilation standard:	EN15251
Category:	2
Building classification:	Low
Area [m²]:	155 m²
Ceiling height [m]:	3.4 m
Persons:	30
Activity level:	1.2 met
Outdoor CO_2 concentration [ppm]:	500 ppm

Calculation results

Required airflow:	1224 m³/h

Bemærk!

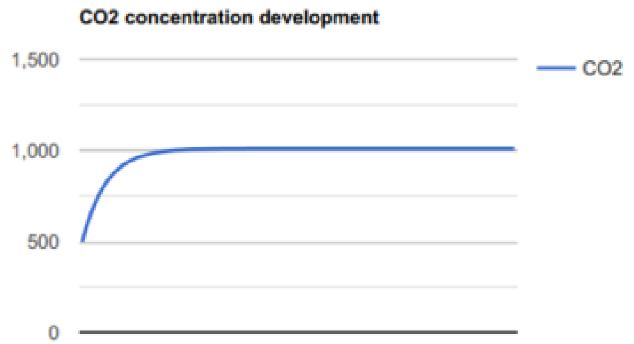
På grund af rummets størrelse anbefaler vi at du kontakter os for at finde den mest optimale løsning

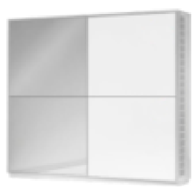
Airmaster suggests

+/-

Suggestion 1

Air handling unit:	1 x AM 1200 H / AM 1200 V
Maximum airflow:	1200 m³/h [max. 35 dB(A)]
Air change rate at max airflow:	2.3 h^{-1}
Max CO_2 concentration [static concentration]:	1010 ppm





Ventilation at Bar Attic at peak occupancy hours (Airmaster, n.d.)

VENTILATION CALCULATOR

Print

Project informtion

Project name:

Room:

Customer:

Calculaction prerequisites

Room type:	Other rooms
Ventilation standard:	EN15251
Category:	2
Building classification:	Low
Area [m²]:	155 m²
Ceiling height [m]:	3.4 m
Persons:	70
Activity level:	3.6 met
Outdoor CO_2 concentration [ppm]:	500 ppm

Calculation results

Required airflow:	8568 m³/h

APPENDIX G: Design Builder Simulation Results

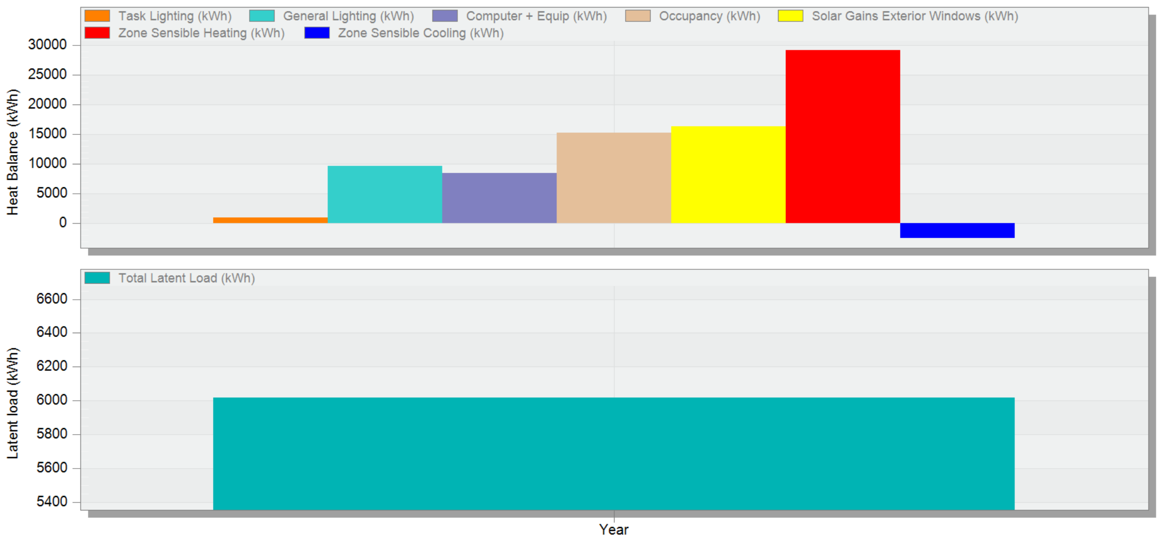
De Beuk Existing

Internal Gains + solar - Debeuk, Debeuk

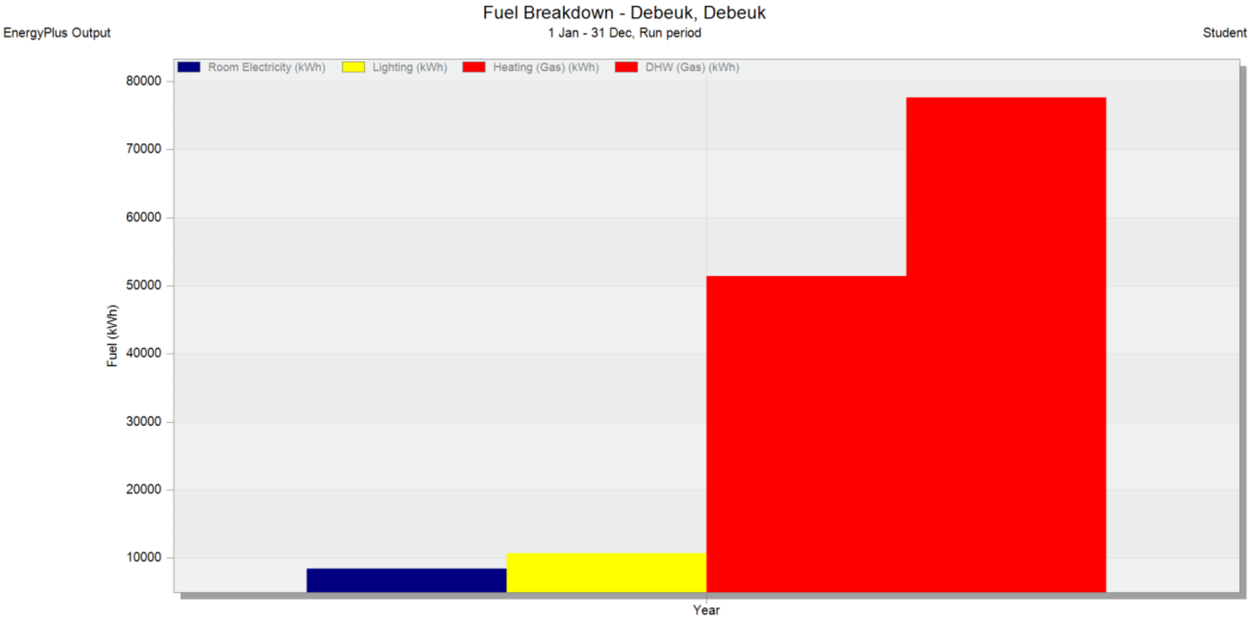
EnergyPlus Output

1 Jan - 31 Dec, Run period

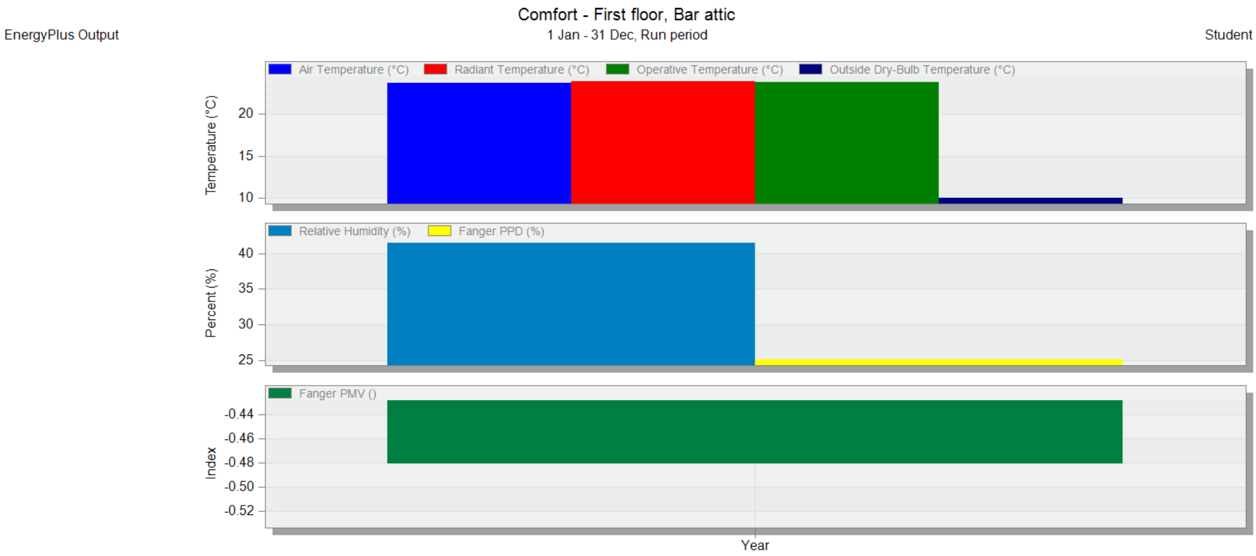
Student



Task Lighting (kWh)	1052.74
General Lighting (kWh)	9633.65
Computer + Equip (kWh)	8474.03
Occupancy (kWh)	15271.60
Solar Gains Exterior Windows (kWh)	16341.30
Zone Sensible Heating (kWh)	29217.99
Zone Sensible Cooling (kWh)	-2472.51
Total Latent Load (kWh)	6017.62

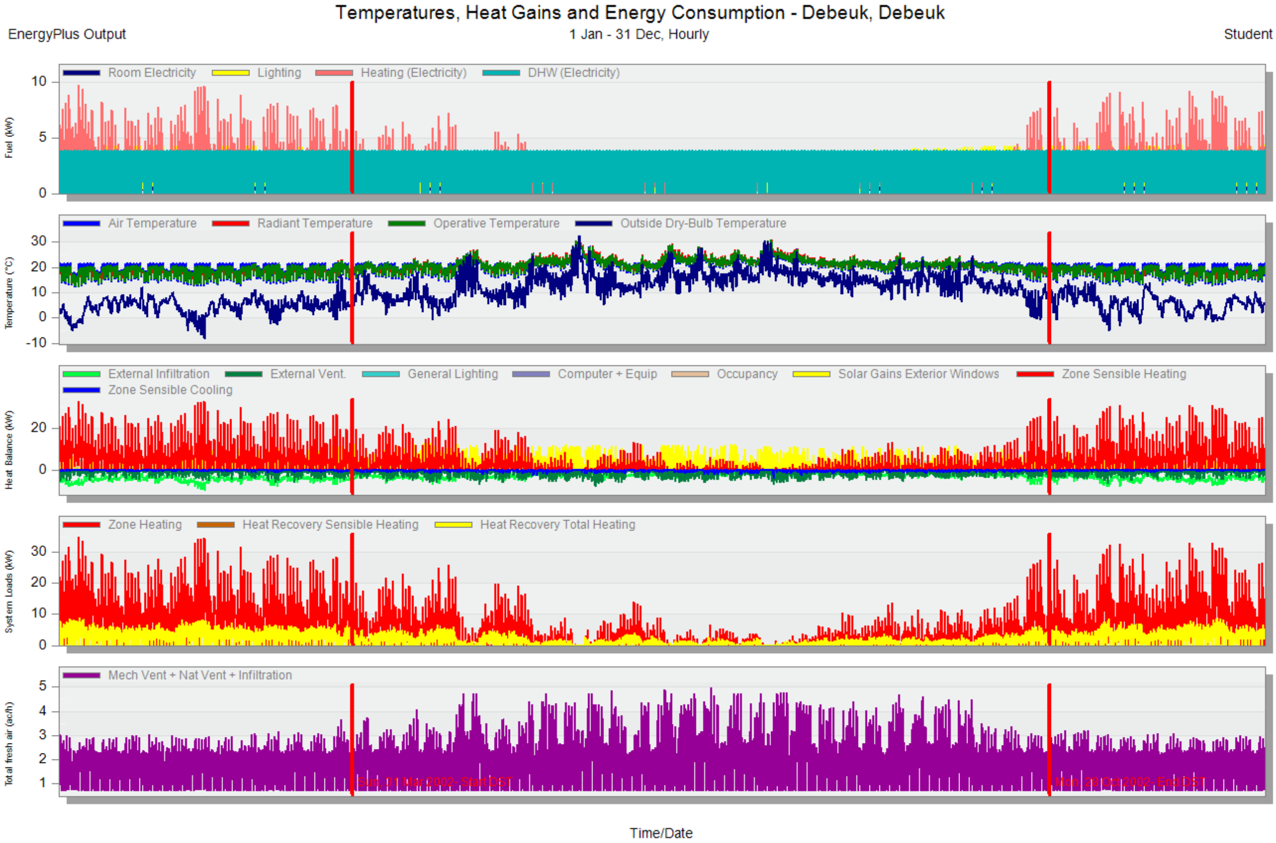


Room Electricity (kWh)	8474.03
Lighting (kWh)	10686.39
Heating (Gas) (kWh)	51425.91
DHW (Gas) (kWh)	77633.65

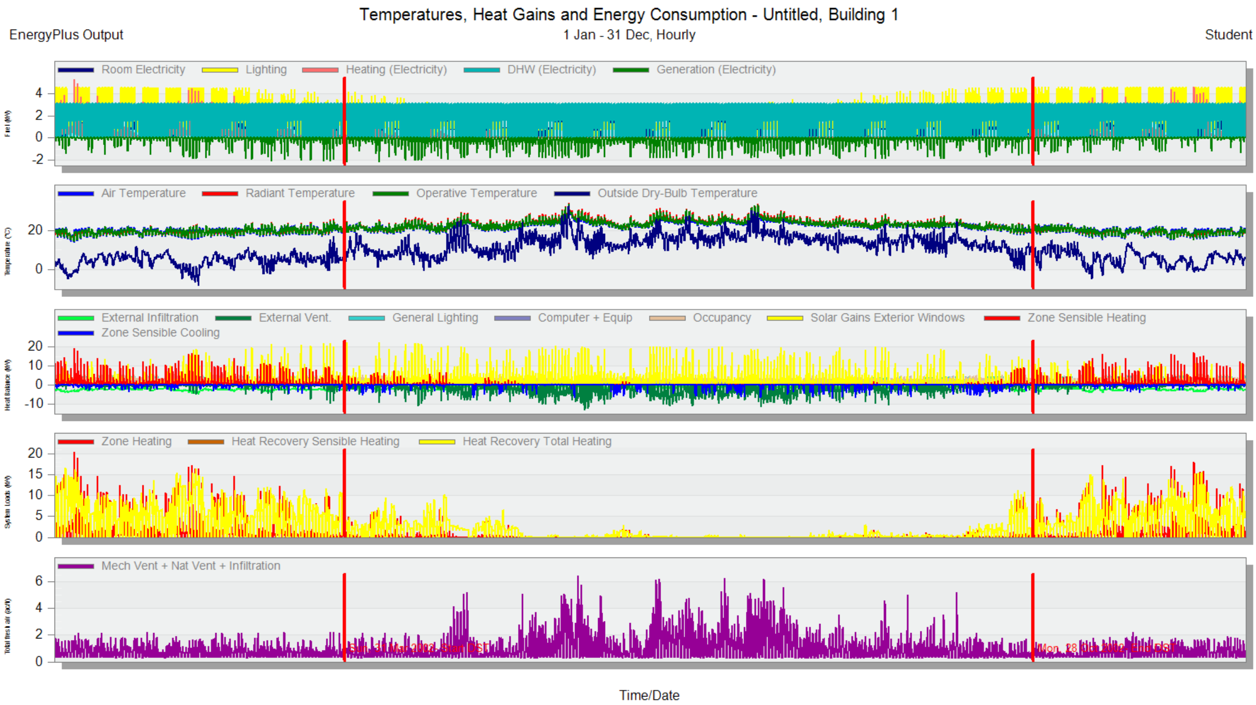


Air Temperature (°C)	23.73
Radiant Temperature (°C)	23.86
Operative Temperature (°C)	23.80
Outside Dry-Bulb Temperature (°C)	10.03
Relative Humidity (%)	41.41
Fanger PPD (%)	25.18
Fanger PMV ()	-0.48

De beuk – Existing with heat recovery system and heat pump



De Beuk – Proposal

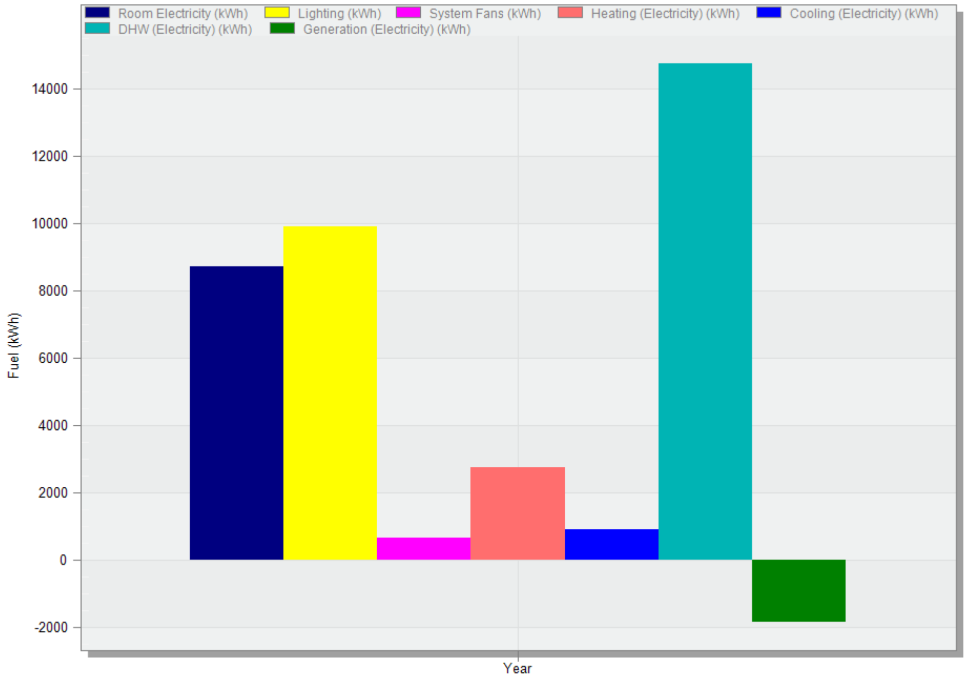


EnergyPlus Output

Fuel Breakdown - Untitled, Building 1

1 Jan - 31 Dec, Run period

Student



Room Electricity (kWh)	8718.20
Lighting (kWh)	9914.12
System Fans (kWh)	671.17
Heating (Electricity) (kWh)	2759.67
Cooling (Electricity) (kWh)	899.21
DHW (Electricity) (kWh)	14751.21
Generation (Electricity) (kWh)	-1838.04

EnergyPlus Output

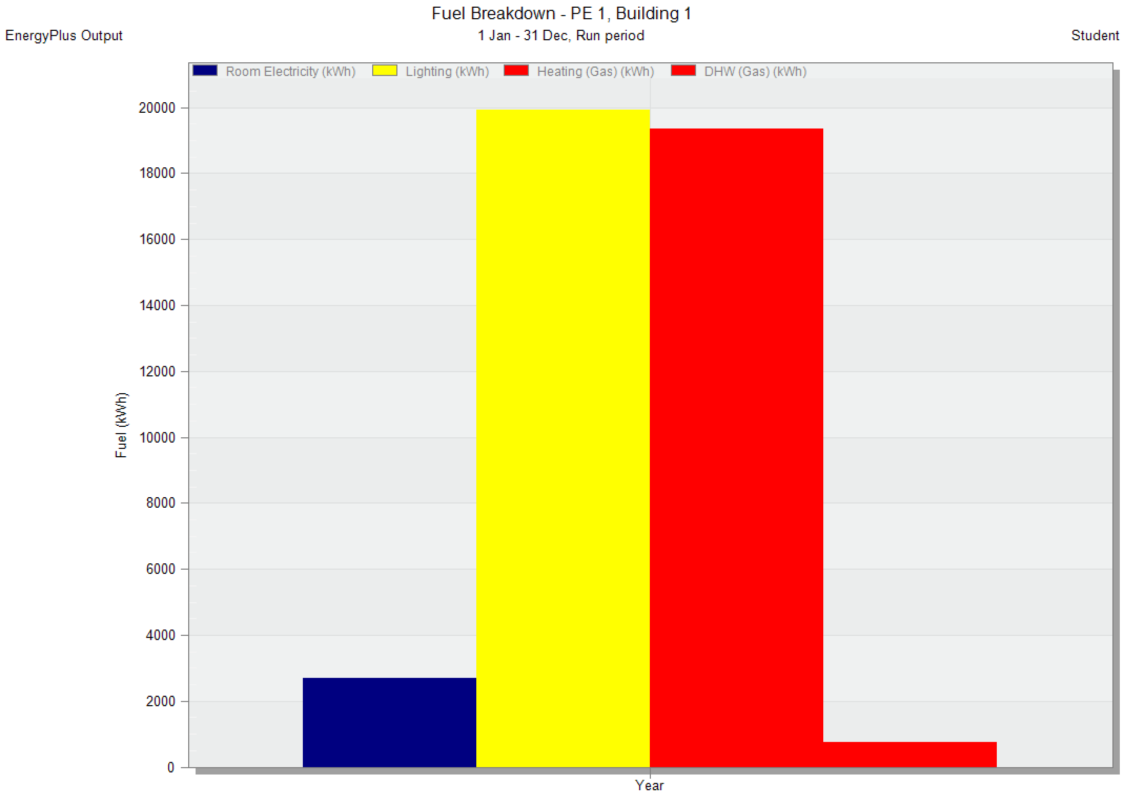
Comfort - First floor, Bar attic

1 Jan - 31 Dec, Run period

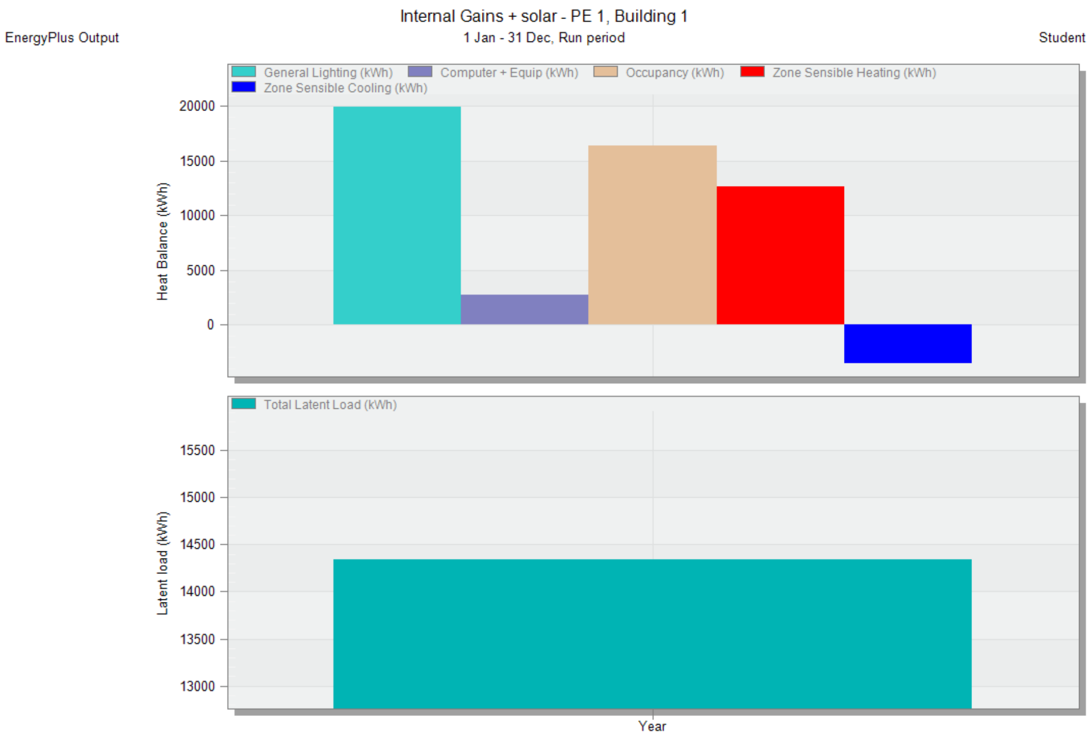
Student

Air Temperature (°C)	22.73
Radiant Temperature (°C)	22.76
Operative Temperature (°C)	22.74
Outside Dry-Bulb Temperature (°C)	10.03
Relative Humidity (%)	40.48
Fanger PPD (%)	30.51
Discomfort hrs (all clothing) (hrs)	386.75
Fanger PMV ()	-0.91

Boat storage Existing

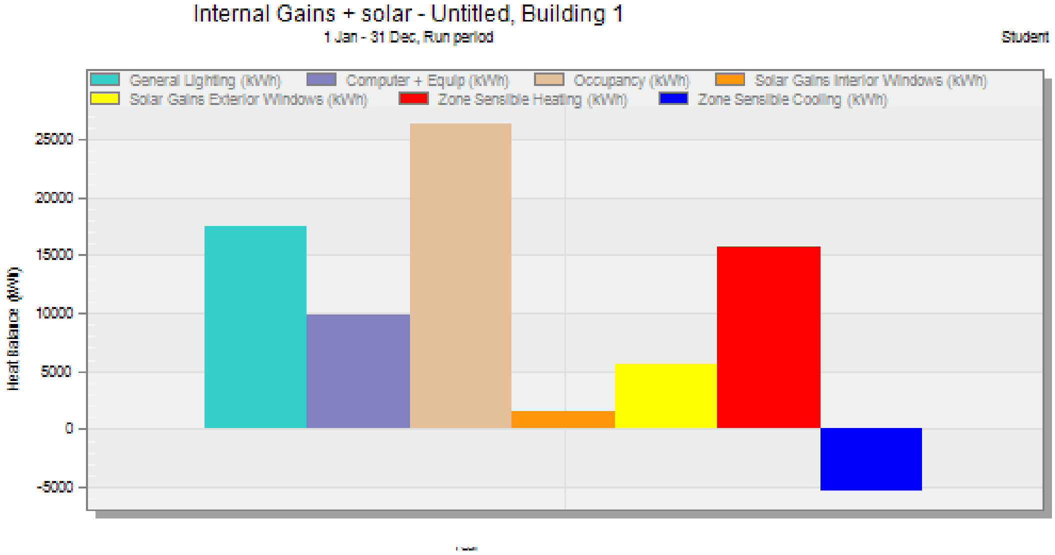


Room Electricity (kWh)	2703.73
Lighting (kWh)	19936.50
Heating (Gas) (kWh)	19357.96
DHW (Gas) (kWh)	740.20

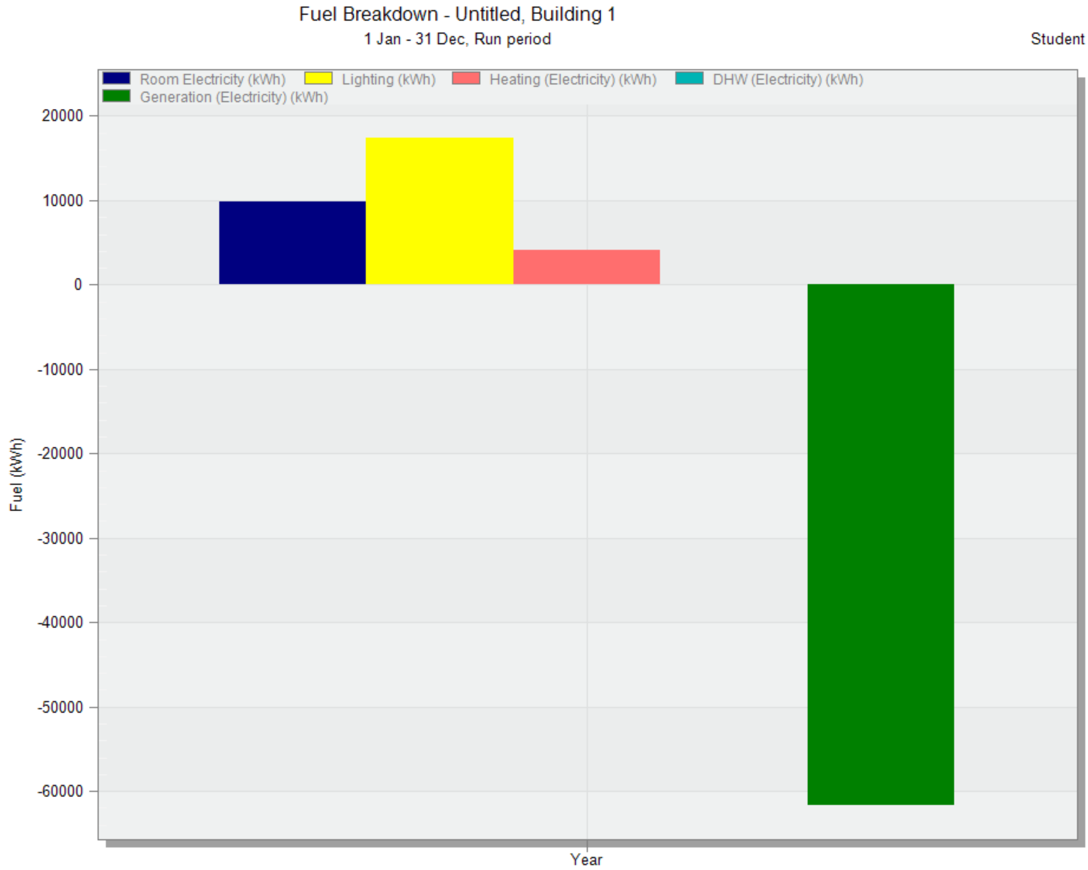


General Lighting (kWh)	19936.50
Computer + Equip (kWh)	2703.73
Occupancy (kWh)	16420.15
Zone Sensible Heating (kWh)	12659.44
Zone Sensible Cooling (kWh)	-3519.32
Total Latent Load (kWh)	14340.97

Boat storage Proposal



General Lighting (kWh)	17436.69
Computer + Equip (kWh)	9792.94
Occupancy (kWh)	26239.80
Solar Gains Interior Windows (kWh)	1600.08
Solar Gains Exterior Windows (kWh)	5626.71
Zone Sensible Heating (kWh)	15675.79
Zone Sensible Cooling (kWh)	-5268.54
Total Latent Load (kWh)	27093.40



Room Electricity (kWh)	9792.94
Lighting (kWh)	17436.69
Heating (Electricity) (kWh)	4065.61
DHW (Electricity) (kWh)	115.47
Generation (Electricity) (kWh)	-61684.10

APPENDIX G: Payback Period calculation using PV-energy output

electricity cost (Euro cents/kWh)	yearly output (kWh)	Yearly consumption (kWh)	PV Cost	pv output reduction
0.07783	63500	51000	29000	0.45%

years	Net Cash flow	Yearly output	cumulative cash flow
0	-34038		-34038
1	6693.38	86000	-27344.62
2	6663.25979	85613	-20681.36021
3	6633.275121	85227.7415	-14048.08509
4	6603.425383	84844.21666	-7444.659706
5	6573.709969	84462.41769	-870.9497375
6	**6544.128274**	**84082.33681**	**5673.178536**
7	6514.679697	83703.96629	12187.85823
8	6485.363638	83327.29844	18673.22187
9	6456.179502	82952.3256	25129.40137
10	6427.126694	82579.04014	31556.52807
11	6398.204624	82207.43446	37954.73269
12	6369.412703	81837.501	44324.14539
13	6340.750346	81469.23225	50664.89574
14	6312.216969	81102.6207	56977.11271
15	6283.811993	80737.65891	63260.9247
16	6255.534839	80374.33944	69516.45954
17	6227.384932	80012.65492	75743.84447
18	6199.3617	79652.59797	81943.20617
19	6171.464572	79294.16128	88114.67074
20	6143.692982	78937.33755	94258.36373