RUGGEDISED
Designing smart, resilient cities for all

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Executive summary

One of the main objectives in Task 2.2 of the RUGGEDISED-programme was to connect several buildings to a Smart Thermal Grid (STG), in order to facilitate the exchange of heating and cooling between buildings and make better use of the existing Aquifer Thermal Energy Storage at the Ahoy entertainment complex.

By creating a backbone between Ahoy and the Rotterdam Ahoy Convention Center (RACC) a more robust and reliable system can be built, which is more in balance, and cooling and heating can be exchanged between the system if needed. The increased cooling demand in the area resulting from the refurbishment and further isolation of halls 2 to 6 and the construction of the new conference center, has been realized in an efficient manner without requiring additional cooling capacity (chillers) in comparison to the old situation. Furthermore two solutions were suggested to balance the system even more. Using the heat from a wastewater treatment facility and a large heat exchanger in the tarmac at the parking lots of Ahoy. By utilizing this heat, less district heating is needed and, in that way, a more standalone energy system is created.

It has not been possible to realize the Thermal Smart Grid (TSG) to its full potential. Meaning the extension towards a new build hotel and several buildings in the surrounding Zuidplein area (like the swimming pool building) we have explored. The main reason is that a profitable business case for these connections could not be made. We have concluded that expanding the TSG is not financially feasible on this location, due to relative long distances of the required pipeline route and more important the availability of alternatives, meaning the realization of new connections to the sustainable TSG is relatively expensive in comparison to alternatives.

Presence of cheap and sustainable district heating at this location

- The expansion with sustainable sources will result in lower district heating consumption, but because of the relatively low purchasing costs of high-temperature district heating and operating cost, the low-temperature sources don't contribute to a positive business case for the TSG;
- The presence of the relatively cheap and sustainable district heating alternative is an attractive heat source for potential users with a lot of high temperature heat demand (e.g., hotel).

Relatively large distance to potential users

- Distance between connections is the most important factor for the costs of expanding the TSG. Due to the distance between developments in the area and market conditions in which potential users mainly decide on price, expanding the sustainable TSG is more expensive than alternatives.

The fact that the TSG is not financially feasible at this location does not mean that TSG will not be financially successful in other densified urban locations without an existing alternative (district heating) system. The TSG has proven to be successful in terms of efficient exchange of heating and cold.

Contents

1. Introduction

Before presenting the methods and results of the varying proposals that have been studied, a short summary of the chronological events in the Heart of South will be given, to provide the necessary context, especially in the light of shifting responsibilities between the RUGGEDISED partners.

1.1 Development of the Thermal Smart Grid in the Hart van Zuid area

One of the main objectives in Task 2.2 of the RUGGEDISED-programme is to connect several buildings to a Smart Thermal Grid (STG), in order to facilitate the exchange of heating and cooling between buildings and make better use of the existing Aquifer Thermal Energy Storage at the Ahoy entertainment complex.

The realisation of the STG, and all Smart Solutions which are part of it, were the responsibility of Ballast Nedam, as specified in the Grant Agreement. Early in the project (at the end of 2016), investigations regarding the exact demarcation of the ownership structure for the cold-heat storage (geothermal heating and cooling) in Ahoy were carried out by Ballast Nedam[1]. During this period (November 2016 - April 2017) there were still too many uncertainties regarding the STG. The major uncertainty at the time was the proposed length of the grid, which was much longer than initially assumed during the preparation of the RUGGEDISED project. The team was involved in discussions with the development director of Ballast Nedam. After the preliminary analysis (January 2017) the team found that the business case was under pressure. It was uncertain whether the future dwellings, the swimming pool, theatre, the shopping centre a hotel & cinema will be connected to the grid, which would be beneficial for the business case.

Simultaneously, Nuon (now Vattenfall), who has been awarded the monopoly for delivering high temperature district heating for new buildings in the South of Rotterdam (including Heart of South) carried out an impact analysis of the consequences for business case of the district heating supply. With the business case under pressure and a possible clash with the monopoly of Nuon, there was no ground to take an investment decision. By the summer of 2017, the construction of the swimming pool started. This meant that the RUGGEDISED-partners were not able to integrate the STG into the building design. Instead, the Swimming Pool would be connected to the central district heating system of Vattenfall.

1.1.1 Transfer to Eneco

After the failure to keep the new swimming pool as a customer for the STG, the RUGGEDISED partners from Rotterdam started discussions regarding the responsibilities of different partners with view on the implementation of the smart solutions and tasks. In order to speed up the development of the STG, the partners discussed transferring the developing tasks (task 2.2) from Ballast Nedam to the energy company partner Eneco. This change of responsibilities would also allow to start the development of the STG based on an alternative layout, without swimming pool and theatre, but still including the Ahoy entertainment complex, the new conference centre and possibly a hotel and a cinema.

Eneco took control of the business case and, together with its subcontractor Energie Totaal Projecten (ETP), designed a system for the Ahoy entertainment complex and the new conference centre with a business case that was attractive enough for Gemeente Rotterdam and Ballast Nedam to participate in. The change of responsibility was codified in a head of terms in May 2019 and the Second Amendment to the RUGGEDISED Grant Agreement.

1.1.2 Expanding the TSG

Simultaneously with the development of the STG for Ahoy and the conference centre, Eneco, ETP and the second subtractor DWA, started on the first designs for the Smart Solutions R1 (Geothermal heat-cold storage and heat pumps), R2 (Thermal energy from waste streams), R3 (Surface water heat-cold collection) and R4 (Pavement heat-cold collector), to be connected to the Smart Thermal Grid. In the following year, Eneco and ETP held meetings with the relevant stakeholders to get in touch for information and possibilities

[1] Ballast Nedam as partner RUGGEDISED works together with building contractor Heijmans within the Public Private Partnership for the redevelopment of Hart van Zuid. Heijmans as such is not a partner of RUGGEDISED, but many of the tasks attributed to Ballast Nedam were executed by employees of Heijmans.

for the sewage systems, pavement collector and thermal energy from surface water source. The analysis of the potential of these different possibilities are further discussed in the reports on deliverables D2.8 and D2.10.

In addition, Eneco had held extensive discussions with the developer of the hotel and cinema for the expansion of the STG. The hotel developer has decided not to connect to the STG mainly because of cost considerations, a large high temperature heat demand and available alternatives in the area. Eneco is having further discussions with the cinema who has a preference to connect to the STG because of a far larger cold demand and high sustainability ambition.

1.2 Existing situation

The existing cooling system at Ahoy entertainment centre consisted of an aquifer thermal energy storage (ATES) and two chillers, of which one was broken, and of which one was approaching the end of its life cycle. The urban renewal program of the Heart of South area foresaw two major developments around Ahoy. The existing halls 2 to 6 were refurbished and further insulated. The second development was the construction of a new Ahoy Conference Center (RACC) next to the existing buildings. These developments meant an increase in cooling demand at the existing buildings, which meant that the two chillers at Ahoy would need replacing. The new ICC would be furbished with two new chillers and working autonomously.

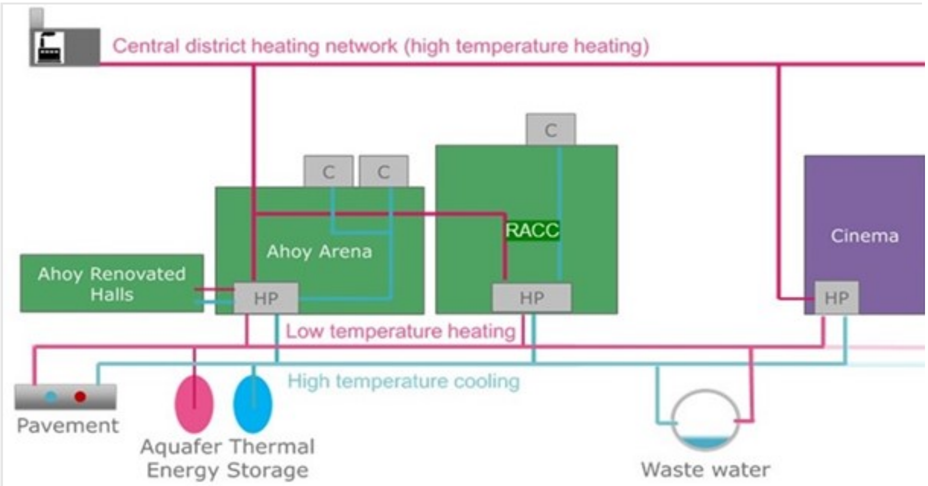


Figure 1-1 Existing situation for the cooling system at Ahoy

The reference situation fell short both in terms of total cooling power and in terms of cooling power for the separate buildings.

Table 1-1 Cooling power in the reference situation

Building	Cooling demand (peak*) in kW	Cooling available in kW
Ahoy existing 1	2500	ATES** + 2200 (broken)
Ahoy existing 2-6	2287	None
ICC	2833	2400
Total	7.620	Between 4.600 and 6.150

* Maximum capacity of the internal distribution system per building
** Depending on season, maximum 1550

2. Methods and results

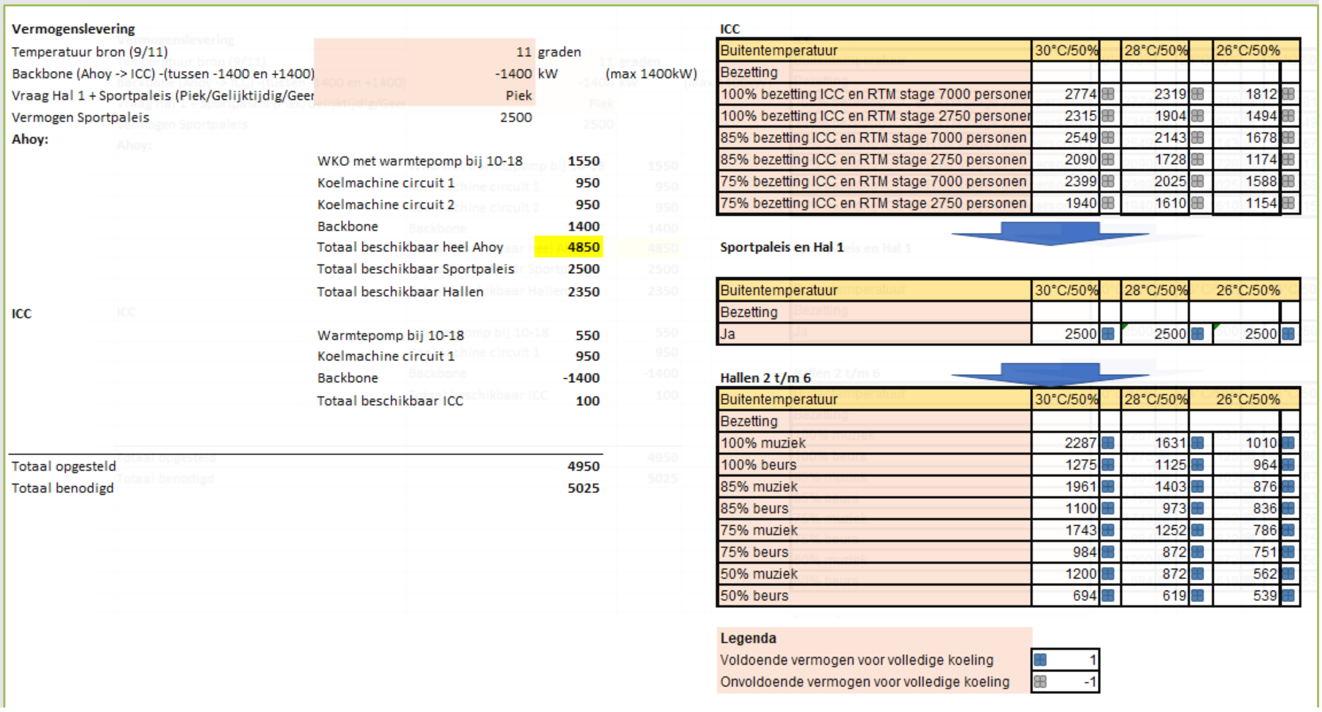
2.1 Design

In order to see what can be gained by implementing a thermal distribution system between the buildings, a proper assessment needed to be made what were the actual demands of the separate buildings.
This was an important step to gain the trust of the end customers, who need to be assured that their energy supply will be secure. In order to do this, it is necessary to speak the language of the end user and their needs. For the Ahoy entertainment centre the main driver is the attendance of events. In order for them to understand what the Smart Thermal Grid would do, it was necessary to translate the amount of cooling available to air conditions for a certain number of visitors for a certain outside temperature. Project Partner Ballast Nedam provided a breakdown what the new conference is expected to demand in cooling for a given number of visitors and a given outside temperature (ranging from 26 degrees to 30 degrees). The table below shows the results. The yellow cells indicate the amount of energy that would have been provided in the business-as-usual / non-Ruggedised situation.

Outside temperature	30ºC / 50%	28ºC / 50%	26ºC / 50%
occupation			
100% occupation ICC + RTM stage 7000 visitors	2774	2319	1812
100% occupation ICC + RTM stage 2750 visitors	2315	1904	1494
85% occupation ICC + RTM stage 7000 visitors	2549	2143	1678
85% occupation ICC + RTM stage 2750 visitors	2090	1728	1174
75% occupation ICC + RTM stage 7000 visitors	2399	2025	1588
75% occupation ICC + RTM stage 2750 visitors	1940	1610	1154

Figure 2-1 Power in kW needed to cool the conference centre based on outside temperature and visitor numbers

This breakdown was scaled up for all different buildings of the Ahoy complex. These numbers were juxtaposed to the available power planned for the Thermal Smart Grid. In the end the choice was made for a system based on a temperature in the ATES of 11 degrees, two heat pumps of 550 kW and three chillers (two at the existing Ahoy and one at the new congres centre) of 950 kW each. The optimal amount exchange of cooling between Ahoy and the new conference centre was set at 1400 kW. With this amount, a fully packed conference centre can get enough cooling up until an outside temperature of 30 degrees. In the 'business as usual'-scenario, only cooling until 26 degrees would have been possible. This added benefit convinced the end users to commit to and invest in the project.



Vermogenslevering

Temperatuur bron (9/11)		11	graden
Backbone (Ahoy -> ICC) -(tussen -1400 en +1400)		-1400	kW (max 1400kW)
Vraag Hal 1 + Sportpaleis (Piek/Gelijktijdig/Geen		Piek	
Vermogen Sportpaleis		2500	
Ahoy:			
	WKO met warmtepomp bij 10-18	**1550**	
	Koelmachine circuit 1	**950**	
	Koelmachine circuit 2	**950**	
	Backbone	**1400**	
	Totaal beschikbaar heel Ahoy	**4850**	
	Totaal beschikbaar Sportpaleis	**2500**	
	Totaal beschikbaar Hallen	**2350**	
ICC			
	Warmtepomp bij 10-18	**550**	
	Koelmachine circuit 1	**950**	
	Backbone	**-1400**	
	Totaal beschikbaar ICC	**100**	
Totaal opgesteld		**4950**	
Totaal benodigd		**5025**	

ICC

Buitentemperatuur	30°C/50%	28°C/50%	26°C/50%
Bezetting			
100% bezetting ICC en RTM stage 7000 personen	2774	2319	1812
100% bezetting ICC en RTM stage 2750 personen	2315	1904	1494
85% bezetting ICC en RTM stage 7000 personen	2549	2143	1678
85% bezetting ICC en RTM stage 2750 personen	2090	1728	1174
75% bezetting ICC en RTM stage 7000 personen	2399	2025	1588
75% bezetting ICC en RTM stage 2750 personen	1940	1610	1154

Sportpaleis en Hal 1

Buitentemperatuur	30°C/50%	28°C/50%	26°C/50%
Bezetting			
Ja	2500	2500	2500

Hallen 2 t/m 6

Buitentemperatuur	30°C/50%	28°C/50%	26°C/50%
Bezetting			
100% muziek	2287	1631	1010
100% beurs	1275	1125	964
85% muziek	1961	1403	876
85% beurs	1100	973	836
75% muziek	1743	1252	786
75% beurs	984	872	751
50% muziek	1200	872	562
50% beurs	694	619	539

Legenda

Voldoende vermogen voor volledige koeling	1
Onvoldoende vermogen voor volledige koeling	-1

Figure 2-2 Screenshot of the spreadsheet used to assess the impact of a thermal distribution system. On the right in this overview the heating power needed in with different occupations. On the left the heating power available by the system in presented through the chillers and ATES and Backbone. Combined it showes that the total power needed equals the heat generation

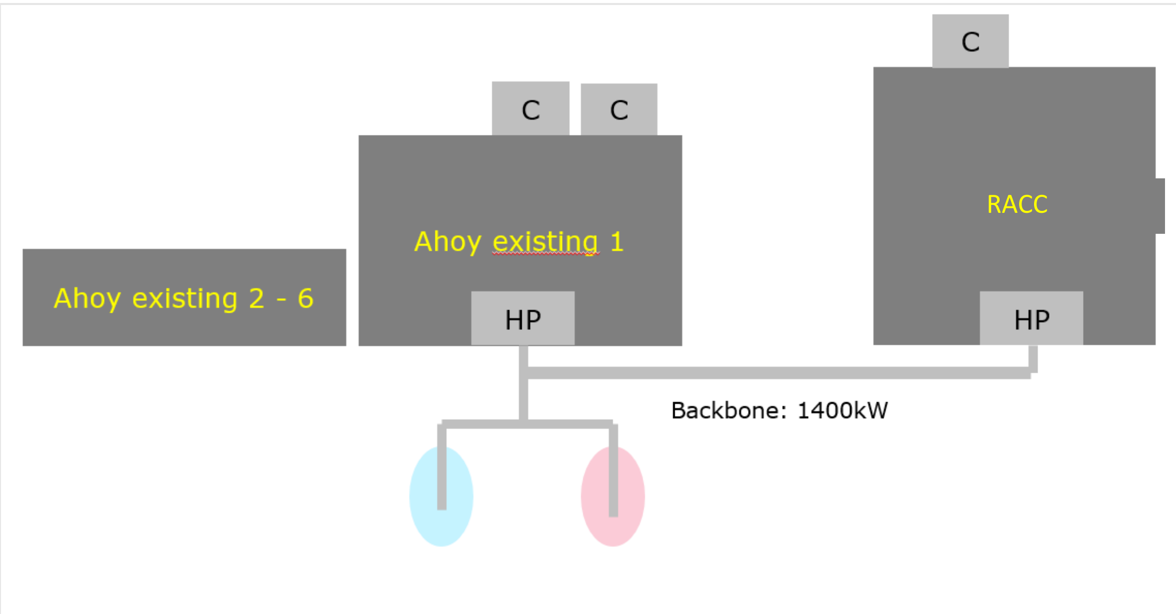


Figure 2-3 Proposed solution

Table 2-1 Cooling power in the RUGGEDISED situation

Building	Cooling demand (peak*) in kW	Cooling available
Ahoy existing 1	2500	ATES** + 2200 kW (broken)

Ahoy existing 2-6	2287	None
ICC	2833	2400
Total	7.620	4.950

* Maximum capacity of the internal distribution system per building
** Depending on season, maximum 1550

The Aquifer is used as baseload for the cooling demand. If this is no longer sufficient the Chillers on the roof of Ahoy and/or RACC will provide the extra needed cooling power.

Table 2-1 can also be constructed for the heating demand, during heating configuration the system also used base load components and components in peak demand.

Base load Heat pump: 2x 740 kW
Peak load District heating: 2x 1000 kW
Total available: 3480 kW
Total needed(expected: 2513 kW

Furthermore the Aquifer is used to store energy which can be used to power the Heat pump, and provide passive to the building. This system of energy exchange must be balanced (within each year). In other words the heat that has be taken out must be injected again. If the heating is not balanced the Heating pump cannot run as often as possible, in this situation the district heating will be used to provide heat. However, the system becomes less “stand-alone” and becomes less sustainable. Therefore it is decided to include regenerative solutions to the backbone, an explanation is given below.

2.2 Construction

Construction was started on the backbone in the summer of 2018, in order to finalise it before the groundworks of the Conference Centre were laid. The contracts between Ahoy, Eneco and the Rotterdam municipality were signed on November 2019. After the signing of the contracts, work started on revitalising the ATES, which needed safety and efficiency upgrades.

The second major investment was replacing the natural-gas powered heat pump with two electric heat pumps at Ahoy, as part of the new all-electric set-up and replacing the chillers. This step was finished in March 2020.

Figure 2-4 The cooling system at Ahoy (picture: Willem van Voorst Vader / Eneco)

The third and final phase was the placement of the heat pump and the new chiller at the conference centre. This phase also foresaw the finishing of backbone between the buildings. Here the project suffered a minor setback as Ahoy was turned into a temporary hospital during the COVID-19 outbreak in the spring of 2020. Since part of the backbone was planned to run through the basement of the Ahoy complex, works to connect the two systems had to be postponed. These works were wrapped up in September 2020.

2.3 ATES and Backbone

ATES is and aquifer storage system in which water of different temperatures is stored. “warm” water of 12-14 degrees as the input for heating pump during the winter to produce heating for buildings or hot tap water. The rest product of the heating pump is “cold” water which is stored in the “cold” well of the aquifer. This “cold” water is used during the summer to cool buildings, the heat from this building is transported and stored in the “warm” aquifer, and thus closing the loop. The backbone is used to transport this valuable water (warm or cold) to the desired technical area in which the heat pump is located. Multiple of these individual systems can be attached to this backbone. As the temperature of the backbone is similar to the ground and it surroundings, the heat loss is negligible and not interfering with the efficiency of the system. Due to the permission received from the government the Aquifer must be in balance (input of energy must be zero over an entire year).

2.4 Regeneration solutions

The current users connected to the backbone are using more heating than cooling. Because more heat is used in the buildings, the resulting “cold” is transferred into the ATES system. This creates an imbalance in the system which is officially not allowed regarding the permission received from the government. To balance the ATES, it is needed to capture heat. There are two ways by which the heat in the backbone is captured:

1. Residual heat from the wastewater treatment

A double heat exchanger is placed between the water of pumping station and the backbone. In this way it is possible to transfer heat the system, and thereby capturing valuable heat to balance the system.

2. Heat from a pavement collector which is placed in the lane to the parking spots of Ahoy.

The sun heating up this lane at Ahoy, will also heat up liquid in the tarmac tubes in the asphalt. Using a heat exchanger this heat can be transferred to the backbone resulting in more balance between heat and cooling in the system.

Currently, (Q2 2022) the detailed engineering on the project is started and construction expected to finish at the end of this year.

Energy efficiency/Sustainability2021 was the first full year of operating the newly installed system. Due to COVID last year the delivery and consumption of heat and cold were not normal. Therefore, the sustainability data is not representative for the initial projected design and looking forward, it is expected that delivery and consumption of heat and cold will change the coming years compared to 2021. However in the initial year, the results where the following (all numbers are excluding district heating).

The seasonal performance factor (SPF) is calculated by adding the heating and cooling the system has produced and dividing it by the total energy input (in this case this is electricity). In the graph underneath the inputs can be found, in which VDK1 and VDK2 are electricity measurements.

	Total [kWh]	VDK1 [kWh]	VDK2 [kWh]	Heating [GJ]	Cooling [GJ]	SPF
Realized	261257	171600	89657	1928	744	2,84

Ahoy and RACC is a large conference center, which has a unique energy demand (therefore a comparison to another project is not relevant). This means that during events a peak in heating or cooling is expected. The peak power compared to the base load is therefore large. The heat pump and Aquifer provide a base load power. The district heating and Chillers are installed when peak demand is required. During COVID many of the events where cancelled and therefore the delivery and consumptions are not representative. It is expected that the seasonal performance factor will increase when the system is fully operational.

The heat pumps included in the project are generated by electricity instead of gas-powered heat pump. This means that when the electricity is generated from renewable energy the system is becomes renewable, which was not possible with gas powered heat pumps.

Including regeneration solutions to the Backbone and ATES, the performance is reduced by a small amount. This is due to the extra electricity used by the transfer pumps as is used to transfer heat into the system. But overall, the efficiency is increased. Without the regeneration solutions District heating is used balance the system. In other words, district heating is used a source of energy instead of the heat pump (and ATES). By adding energy into the system using the regeneration solutions proposed, it is expected that 400 GJ of district heating is no longer needed. Making the system a whole more sustainable and more self-sufficient.

3. Business Case

The Backbone and generation facilities are owned and operated by Eneco.The initial investment for the CAPEX is done by Eneco, but also the operating costs and maintenance costs are on the balance of Eneco. To construct a viable Business Case for Eneco an installation Fee is asked from the participating parties. This means that Eneco is able to operate the system while achieving a “healthy” profit.

Optimization in the energy use of the installation are also very important. An efficient system uses less electricity and thus the operating costs are lower. This is why the system is closely monitored to address any alteration which make this possible.

It is possible for additional projects to join the Backbone of Eneco which can be provide sustainably energy for heating and cooling. By creating a portfolio of projects with different heat and cooling demands, the system can be further optimized and be utilized to its maximum capabilities.

Through attaching different project to the backbone a more robust system is built in which less back-up power is needed, because the other project can fill in the gap if needed.

4. Recommendations

The process described above was a co-creation between the end user (Ahoy), the building owner (municipality of Rotterdam), the building company (Ballast Nedam) and the investor/energy company (Eneco). In order to scale up this solution in other parts of the city and the country, the process needs to be streamlined and standardized.

However, it is already clear that the following steps need to be taken in every scenario:

- Assess the potential of heat sources in the local environment like the ATES. Also test the important environmental conditions like the temperature of the heat source and the available cooling.
- Assess the cooling needs of the building, in terms which the end users can understand.
- Model the energy streams and show clearly how the exchange influences the performances of the system. Make sure that the model shows results which the end users can relate to, and which can give them additional comfort.
- Role of the government is to make policy for real estate owners, developers, energy companies and users which are active in the area towards connecting to a collective system.
- Partner achievement is realized by regular consultation with the project partners, real estate owners and users in the area and be open for each other’s interests.

5. Risk Register

Risk	What is the risk	Level of risk[2]	Solutions to overcome the risk
No viable business case	No viable business case because of the operational costs (maintenance and/or electricity costs) are higher than the income.	2	Look for valuation of other benefits generated by the waste streams heat collection, like upscaling to other pumping stations and see this as a learning process.
Difficulties with building (permit)	There is a risk that it will take a long time before construction can start. At the moment there is a shortage for building materials. There are also delays in building permits.	3	Already early in the process preparing for buying materials.

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[2] Risk level: 1 = high risk, 2 = medium risk, 3 = Low risk