Designing smart, resilient cities for all

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Executive summary

This report provides insight in one of the thirteen Smart Solutions that are implemented in the Heart of South area in the City of Rotterdam. These innovative solutions are part of the RUGGEDISED program, which is subsidised by the European Union, and aims to test, implement and accelerate the Smart City model across Europe. Smart Cities include places were traditional networks and services are made more efficient with the use of digital technologies, for the benefit of its people. The smart solution this document further elaborates on are pavement collectors (R4).

First is explained what the solution includes. In short, the system consists of tubes within the asphalt (the collectors). Cold water flows through the tubes and are heated in the summer. This heated water is stored in the seasonable aquafer thermal energy storage (ATES) and used again in winter to defrost the road surface. During wintertime it is used the other way round, and cooling is harvested to be stored in the ATES

Thereafter, is elaborated on the implementation process. First a suitable location to place the collectors had to be found. A location is chosen with as much sun available and as close to the technical room as possible. Another important part of the implementation process is asset management. There resulted to be little parties capable of implementing this system. Currently, the collectors are implemented.

Furthermore, is explained how this solution contributes to the Smart Thermal Grid (STG) in Heart of South. A STG enables heat and cold exchange between buildings and relies on renewable energy sources. Together with other solutions, like heat and cold from sewage water (R2), the heat and cold that is extracted from the pavement collectors' feeds into the STG.

Thereafter, insight is given into the business case: the financial concept and the expected impact and costs. In this particular location it was quite hard to realise this solution with a feasible business case, let alone a profitable one. The energy sources connected to STG are competing with District Heating and compression chillers on the roof of Ahoy (already present) which convert the outside air into cold air to cool the buildings. Therefor the energy from the asphalt collector is competing to the energy produced to the energy of the District heating and these chillers.

In the last chapter is concluded that pavement collectors are commercially and technically viable in Heart of South. Also, several recommendations to partners are given, like giving importance to finding an adequate location for the system, as this impacts the economic yield.

Contents

1. Introduction

RUGGEDISED is a Smart City project funded under the European Union's Horizon 2020 research and innovation program. The European Commission defines a smart city as: "A place where the traditional networks and services are made more efficient with the use of digital and telecommunication technologies, for the benefit of its inhabitants and businesses". The goal of the project is to test, implement and accelerate the Smart City model across Europe.

1.1 Lighthouse cities

The current period in which we live, is characterised by rapid technological development, strong globalisation of (social and economic) activities, a need to protect our living environment and to ensure social stability. In the European-funded Smart City project RUGGEDISED, the three lighthouse cities of Rotterdam, Umea, and Glasgow work together with a number of partners from academic, business and consultancy backgrounds to develop and test solutions to exploit and explore sustainable urban development opportunities offered by smart solutions.

The three overall aims of RUGGEDISED are:

- Improving citizens' quality of life by offering a clean, safe, attractive, inclusive and affordable living environment.
- Reducing the environmental impacts of activities, amongst others by achieving a significant reduction of CO_2 emissions, a major increase in the investment and usage of renewable energy sources and an increase in the deployment of electric vehicles.
- Creating a stimulating environment for sustainable economic development, by generating more sustainable jobs, stimulating community involvement in smart solutions (as consumers and as producers) and to boost start-up and existing companies to exploit the opportunities of the green digital economy and Internet of Things.

Within Rotterdam the main focus is on Smart Energy systems, with the goal to reduce import of energy from outside the area and produce as much as possible energy within the area itself.
Two grids are designed, one Smart Thermal Grid (STG) and one Smart Electric Grid (SEG). Only the STG was realised as shown in the drawing below.

Figure 1: An overview of the Heart of South implementations

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1.2 Smart thermal grid in Rotterdam

The City of Rotterdam played an important role in the RUGGEDISED project. Rotterdam is the Netherlands second-largest metropolis and is characterised by its diverse, multi-ethnic community and Europe's busiest port. The City of Rotterdam introduced the Heart of South, the city centre of the South side of Rotterdam, as their lighthouse district. Through RUGGEDISED the area is undergoing a transition, consisting of renovating event centre Ahoy and building new facilities like a shopping mall and a cinema.

Figure 2: Map of the city of Rotterdam

Figure 3: An overview of the Heart of South area and the Ahoy complex.

One of the main goals of the project in Heart of South is to connect several buildings in the area to the STG, which is based on renewable energy sources and facilitates the exchange of heating and cooling between buildings. The establishment of the STG – in combination with city heating - made the Ahoy area natural gas free in 2019, which leads to CO_2 reduction.

In total thirteen innovative solutions are implemented in the area, from which several solutions contribute to the establishment of the STG. The solutions are highly related; for example, some solutions focus on extracting energy, while other solutions focus on the storage of that energy.

This deliverable elaborates on one of the solutions that contributes to feeding energy into the grid, the extraction of heat and cold from asphalt, (R4), is displayed in the yellow circle in figure 4. It is a proven technology, but never before used as a renewable energy source for, and connected to, a STG, ea. 5th generation network.

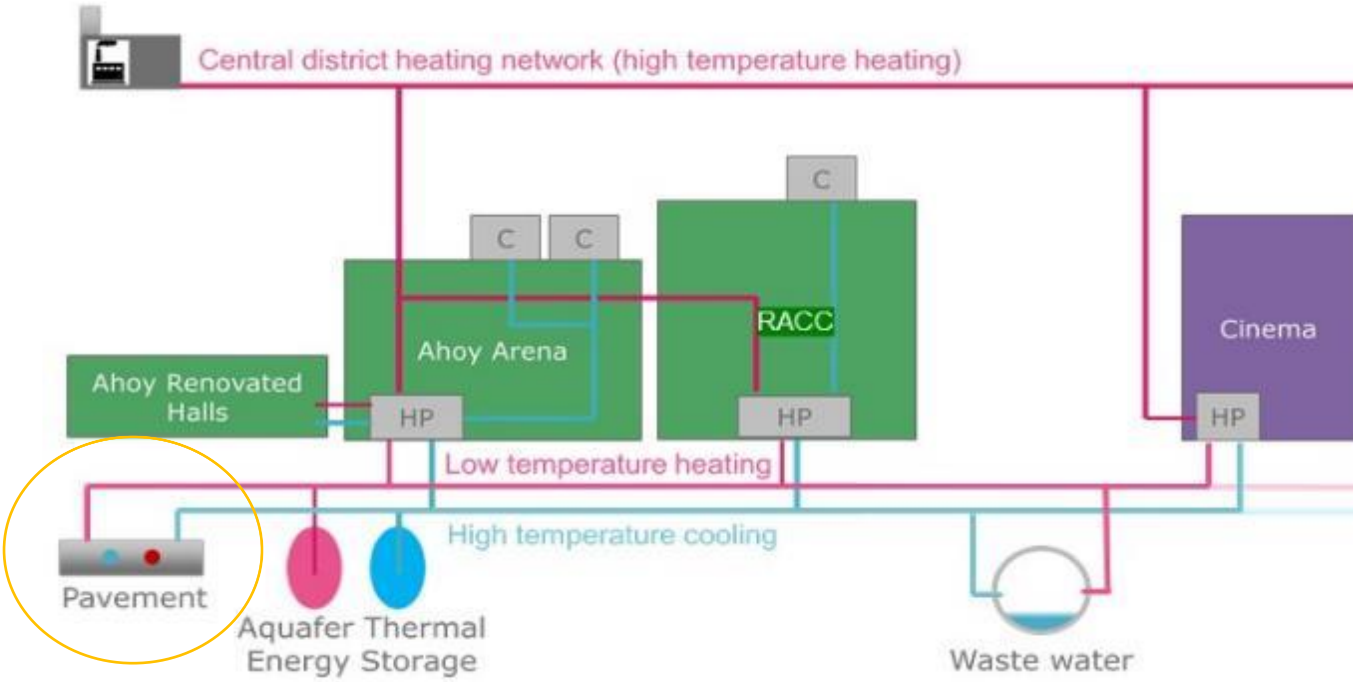

Figure 4: A schematic overview of the buildings that are connected to the STG in Heart of South.
STG is the whole system
C: compression chillers
HP: Heat pumps

Collecting heat or cold to produce thermal energy, is one of the solutions which is part of the STG.
The STG is designed to deliver heating or cooling to the different halls of Ahoy, Rotterdam Ahoy Convention Centre (RACC) and the newly to be build Cinema, according to specific demand needed. The whole complex is equipped with sensors, which are operated from a central portal to heat or cool a certain hall. This means that not the whole complex needs to be heated or cooled.
Currently, the Ahoy area uses a hybrid heat and cooling system, in which a district heating system and the STG are combined. The STG is fed with 4 different energy sources, district heating and heat pumps/compression chillers for regenerating the base temperature, a pavement collector and the wastewater collector to deliver the base load. All excess heating or cooling is stored in the seasonal Aquifer Thermal Energy Storages (ATES).
This energy source is situated in the main access road (Ahoyweg) for the parking area of Ahoy. The installation in the asphalt is directly connected to the technical installations in the installation room of Ahoy. The installation room of Ahoy is located directly next to the Ahoyweg.

Figure 5: An overview of the Ahoy complex, RACC and cinema. All buildings connected by the main backbone (R1) and 2nd backbone to the cinema. R4 is situated next to the installation room of Ahoy (ATES)

2. Pavement collectors

Pavement collectors consist of tubes that are integrated in the asphalt layer. In summer time, the collectors recover warmth from asphaltic concrete; temperature can be between 60 to 65 °C in this season. This is done by pumping cold water through the tubes, which is heated by the high temperatures of the asphalt. This heated water is stored in the ATES. In wintertime, water warmer than the asphalt is pumped through the tubes. The heat of the water exchanges with the asphalt, which results in the asphalt temperature staying above 0°C. In this way, snow and ice is melted and the pavement is frost free. At the same time the water within the tubes is cooled down and the cold is harvested to send back in the ATES. The stored cold is used during summer time to cool the Ahoy buildings. The total area of the heat/cold pavement is 500 m².

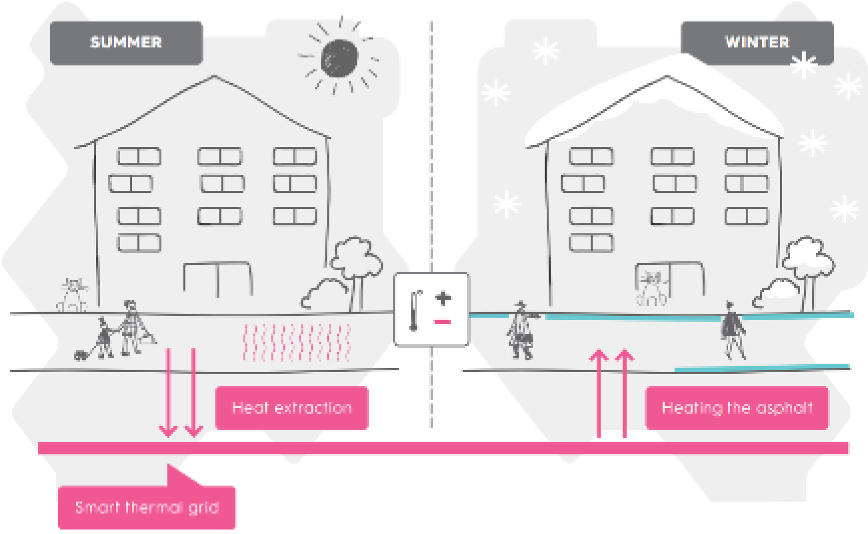

Figure 6: Schematic overview of the functioning of pavement collectors.

3. Implementation

3.1 Designing the system

In the first phase of the implementation proces, Eneco (energy company), Heijmans (a construction company) and the Municipality of Rotterdam together searched for the most adequate location for the heat collector in the pavement. There were four possible options, which are shown in figure 7. In this search attention is paid to finding a spot with little shadow, were it is unlikely that heavy objects stand still for a long time (as weight can damage the piping), where no short-term renovations were planned (as this implies that the asphalt and the collectors in it will be removed) and that is close to the technical space (which includes the circulation pump and the heat exchanger). Option 4 resulted to be the best fit.

Figure 7: Possible locations for the pavement collector.

After a couple of months of preparation, it became clear that this project had to comply with tendering rules. There were little contractors specialized in this innovation and therefore only three parties were invited. After specifying the technical and financial requirements, resulted that none of the parties wanted to execute the task for several reasons. For example, one party didn't have the right knowledge for the engineering, another one stated that the budget wasn't sufficient enough. At the same time, the regulation concerning one on one agreements changed, which implied that the project team could close the tender and continue with a one-on-one agreement with one of the parties.

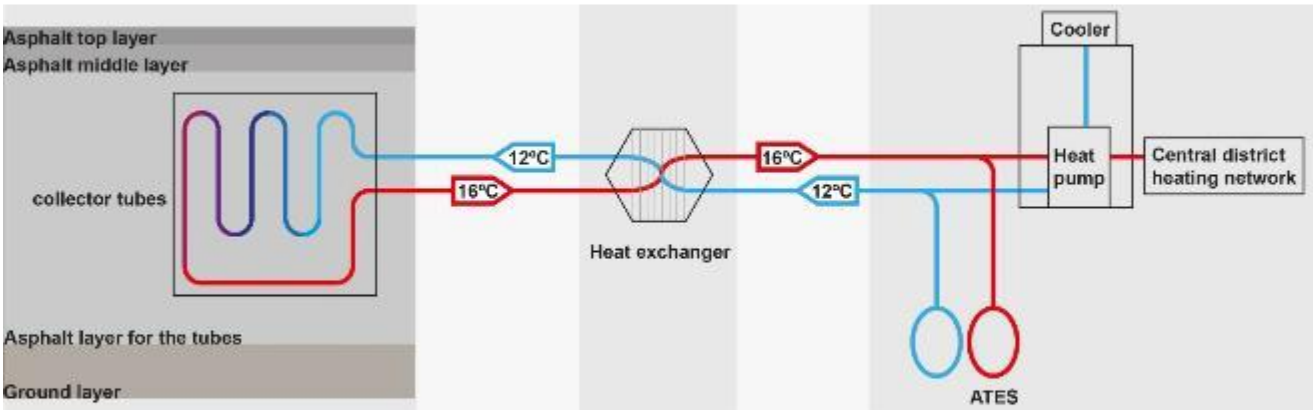

Figure 8: schematic overview of the system.

Pavement collectors are part of the STG as they extracted heat and cold feeds into the grid.

The selected contractor, Dura Vermeer, started the engineering of the system, to be able to implement it in the chosen location, in January 2022. The materials were ordered beginning of March, when it became clear that delivery times took longer than expected and then usual. Instead of 6 weeks, it was expected to be available beginning of June. In the end the materials came by the end of July. Dura Vermeer could start building half of August and was finished in the first weeks of September.

Figure 9: Milling the pavement

Figure 10: Digging the ground fort he main piping to Ahoy

Figure 11: Milling and cleaning the pavement

Figure 6

Figure 12: Detail of the tubes

Figure 13: Tubes coming together in the so-called collector put

Figure 14: Overview oft he tubes with the loops

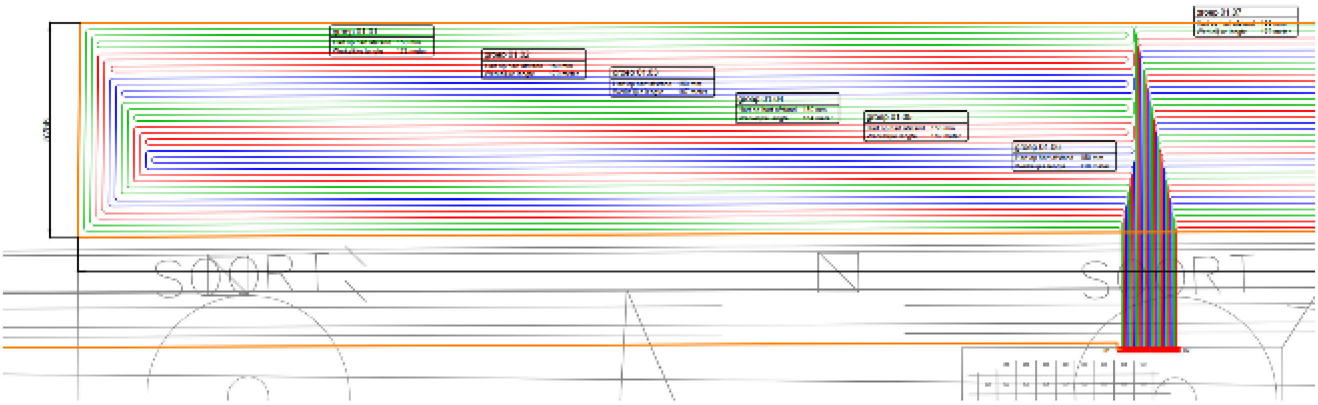

Figure 15: Laying plan of the tubes

4. Business plan

4.1 Financial concept

Financially, the asphalt collector's business case is structured as follows.

The Municipality of Rotterdam is investing in the construction and connection of the asphalt collector to the smart thermal grid.

Eneco invests in the equipment of the technical room (SKID) and carries out the necessary maintenance.

The high up-front investments for the total STG, on top of the RUGGEDISED funding, are equally paid by the consortium partners, Eneco, Ballast Nedam and the Municipality. These costs are paid back, yearly by Eneco, by generated energy from this smart solution (regulated energy prices). When these costs are paid back, the profit is divided by the 3 partners as well. Given the fact that the sales price of the produced energy (heat) competes with the buying price of district heating, we estimate that this installation is not going to be very profitable. For cooling, the compression chillers on the roof of Ahoy are used. They were already in use before the RUGGEDISED project started. For cooling, the pavement collector is competing with these compression chillers. Therefore, this is a true test case to see if harvesting thermal energy from the pavement can compete with compression chillers and district heating. The investment, however, can be recovered and therefor is expected to be cost neutral.
For this reason, it is not recommended to build these kinds of installations within an area where district heating is the competitor and is offered by the same energy provider. While in any other region / cases, this source can be highly profitable, and it has a more sustainable impact.

4.2 Expected impact

The starting point for the design is a yield of 400 GJ for the pavement collector. The expectation is that therefor 400 square meters is necessary, which leads to an average of 1 GJ/m2 and total ammount of 400 GJ/a. The yield per square meter depends on a couple of factors. Of course there's the amount of sunshine and the 'strenght' of the sun. In summer both numbers are high, there this is the best season for this system. Contrary, shadow lowers the efficieny of the system. Therefor a location with a lot of threes of a parking lot is not ideal. Another factor is how deep the collector tubes are placed, closer to the surface provides more energy, because there's less energy lost in the asphalt layers between. The road where the tubes are placed is the main road to Ahoy for visitors and suppliers, therefor the tubes are not placed in the top layer, to avoid damages by heavy traffic.

When connected to the Smart Thermal Grid and thus part of the energy system of the Ahoy centre, this leads to an annual expected decrease in energy consumption of 474 GJ district heating.

We expect a CO_2 impact of 52 ton/year.

4.3 Expected costs

The costs for this smart solution can mainly be divided in two parts. There's is the pavement collector itself and the pumps in the technical room in Ahoy.

To start with the pavement collector, the costs includes the design and engineering, materials (piping, new asphalt) and installation. The piping includes the tubes in the asphalt layer as well as the connection from collector to the technical space. The costs herefor will be approximately € 130.000.

The pumps for this system will be placed in the maintenance room of Ahoy. Here, the pavement collector connects to the smart grid. The costs for the skid – the technical installation with pumps and heat exchanger - will be around € 100.000.

The structural costs per year are estimated at € 10,000 per year. The reduced costs as a result of the avoided purchasing of district heating plus the extra electricity costs lead to a net cost-neutral business case after a runtime of 20 years. The lifespan of the system is more than 20 years. The top layer of the asphalt needs replacement after 10-15 years. Because the collector tubes are not placed in this layer, the top layer can be replaced without damaging of influencing the pavement collector system.

Due to 3 reasons, the total investment was in the end higher then expected.

1. the increasing material prices
2. the delay of the materials. By the time the materials were at hand, Dura Vermeer was urged to get the work done within 3 weeks instead of 2 months. Therefor they needed to use another method to harden the asphalt. This method was more expenive then the original method.
3. More people were needed within the summer holiday period within a shorter time (3 weeks)

The total investment in the end was 235.000 instead of the estimated 130.000.

5. Conclusions and recommendations

The conclusion of the research and designing process is that the extraction of heat from pavement is technically, organisationally, and commercially feasible in the Heart of South area. An adequate location was found and there resulted to be a party interested and capable of implementing the solution. The pavement collectors have a good business case, partly because they demand little to no maintenance. Also, the pavement can be maintained in a normal way, there's no effect on the heat exchanger underneath. Most of the yield of the pavement collector is from the summer months, because in summer the temperatures are higher and there's more sunshine compared to the other seasons. Hence there's not a constant flow of heat. Still there's a positive balance in revenues and costs, which made this solution viable.

There are a few recommendations to be made about this innovative system. First, the location. It is useful to locate the heat exchanger under a road with little to none shadow. Shadow has a negative impact on the amount of yield from the system. A parking lot is also not recommended because of the weight of the vehicles. However, it is recommended to place the heat exchanger close to the technical space of the whole system or grid. Piping is relative expensive. Second, the system. A straightforward system, with pumping in the technical space and just piping underneath the pavement, is the easiest to construct and maintain. Placing the pumps close to the pavement collector is an option but is more expensive (because it is more efficient to have everything together in one place). Third, cooperation between the parties. For an optimum system it is recommended to link different contractors in an early stage. Amongst them they can optimize the system, financially as well as technical.

Another recommendation related to the functioning of the pumping station is to make clear arrangements on:

- Maintenance and ownership. The demarcation of the different part of the installation should be clear.
- Governance of the installation process. Between municipal departments as well as between municipality and external partners like energy supplier and contractors.
- Which stakeholder is responsible for the generation of energy? Can it be the asset owner (ea municipality), should it be the energy provider, or can it be a third private partner?
- Which stakeholder is allowed to sell energy to which parties? Is it an energy source feeding into an open network, or is it an asset belonging to the same asset owner (like an air-conditioning belonging to the building its cooling)?
- Which pricing is used to make the business case? Make clear arrangements at the start of the process and do not be too rigid with the daily price of energy, keep a clear margin.

Appendix List

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