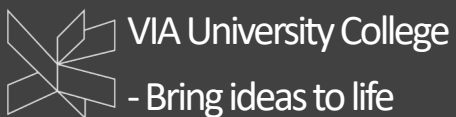
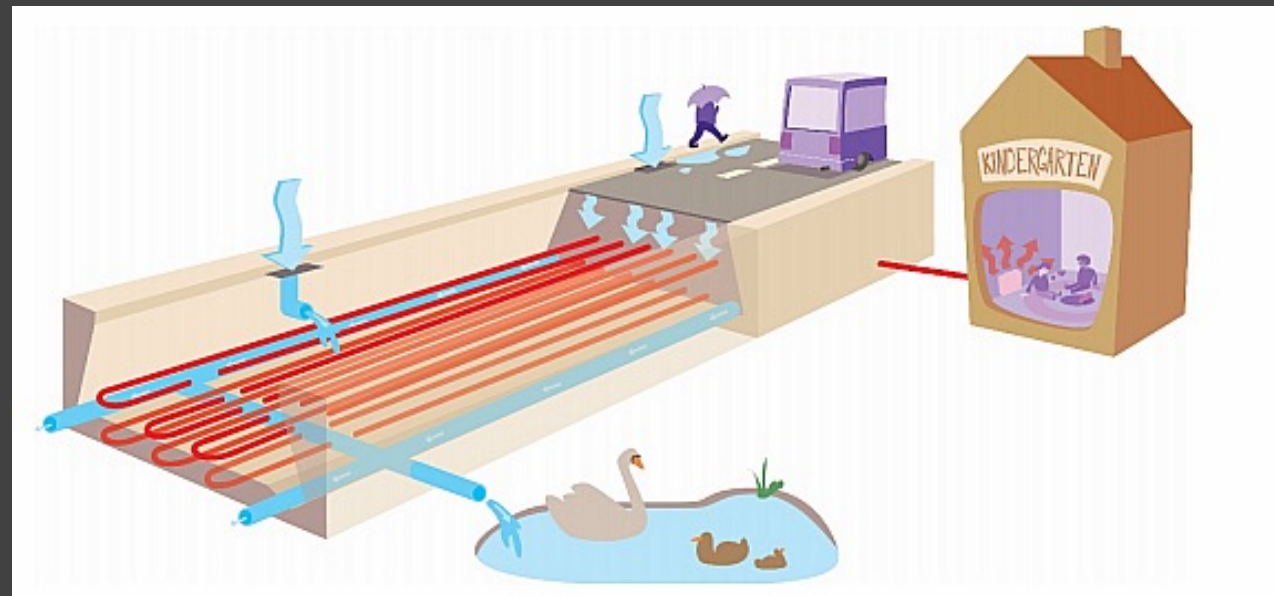


# The Climate Road – A Multifunctional Full-Scale Demonstration Road That Prevents Flooding and Produces Green Energy

By: Theis Raaschou Andersen  
Søren Erbs Poulsen, Karl Voldum og Per Nørmark



# Why climate adaptation and climate mitigation solutions ?

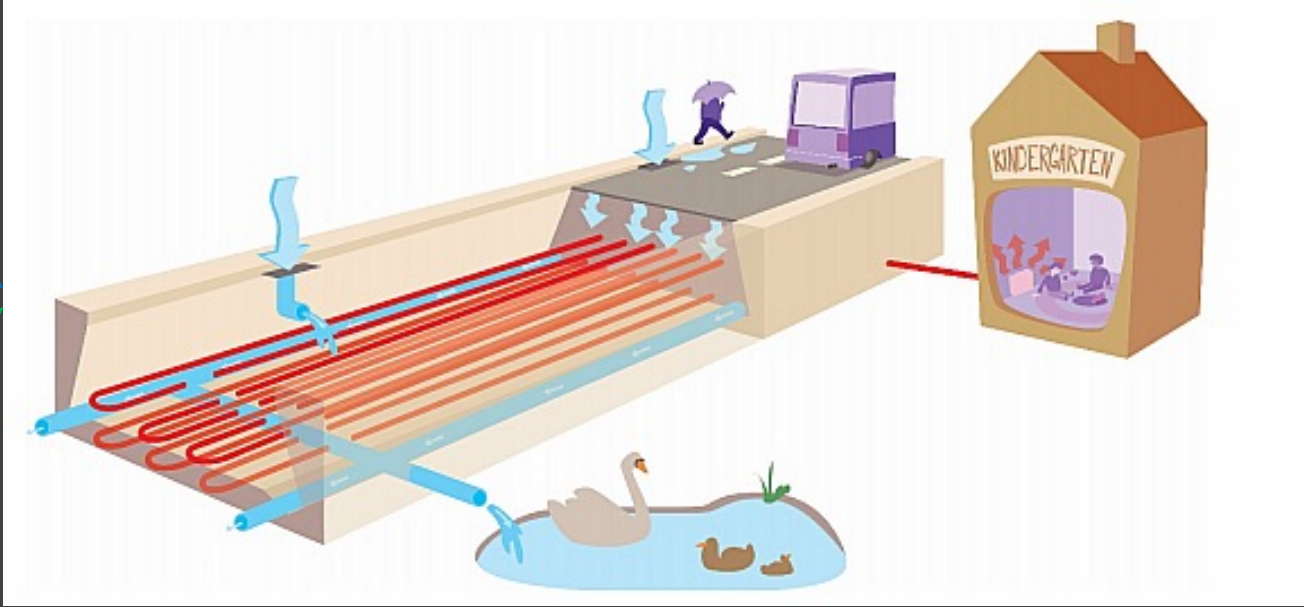
- Denmark has by law committed itself to reduce its CO<sub>2</sub> level in 2020 by 70% compared to the 1990 level as well as having a fossil-free energy sector by 2050. Both in order to reduce CO<sub>2</sub> emissions
- However, we are already seeing the consequences of a changing climate in Denmark. The continuous growth of cities in combination with future climate changes present authorities with significant challenges. In Denmark, climate models estimate that future climate changes will cause an increase in the overall amount of precipitation along with a changing precipitation pattern where more frequent cloudbursts are expected to occur

# Our research hypotheses

- *Can we create a multifunctional climate adaptation and climate mitigation solution in an urban residential area as well as involve the local citizens creating climate awareness among them?*



# The Climate Road



# Construction



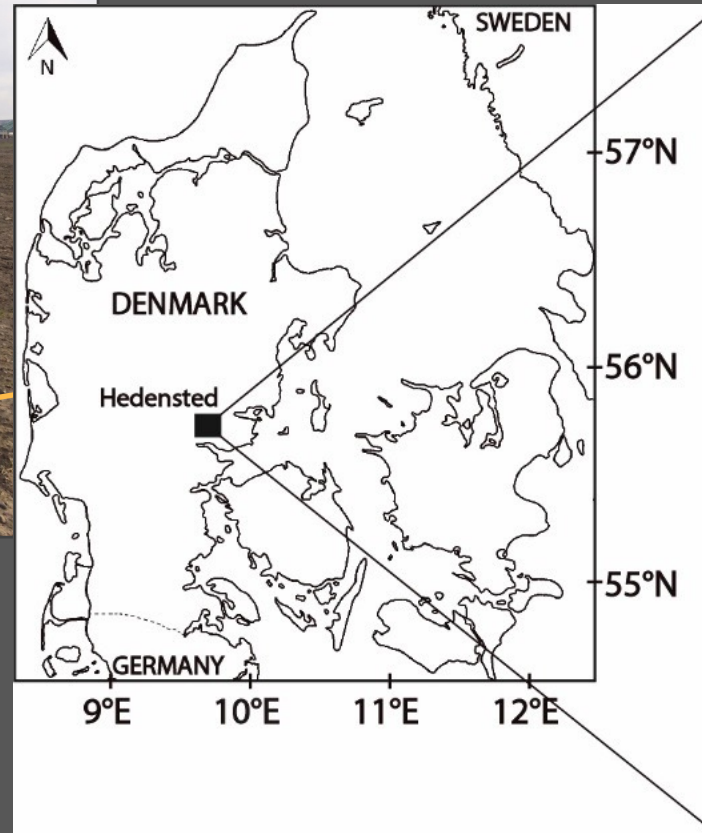
# Construction

## Prototype demonstration

The Climate Road is 50 m long, 1 m deep (road bed) and 8 m wide

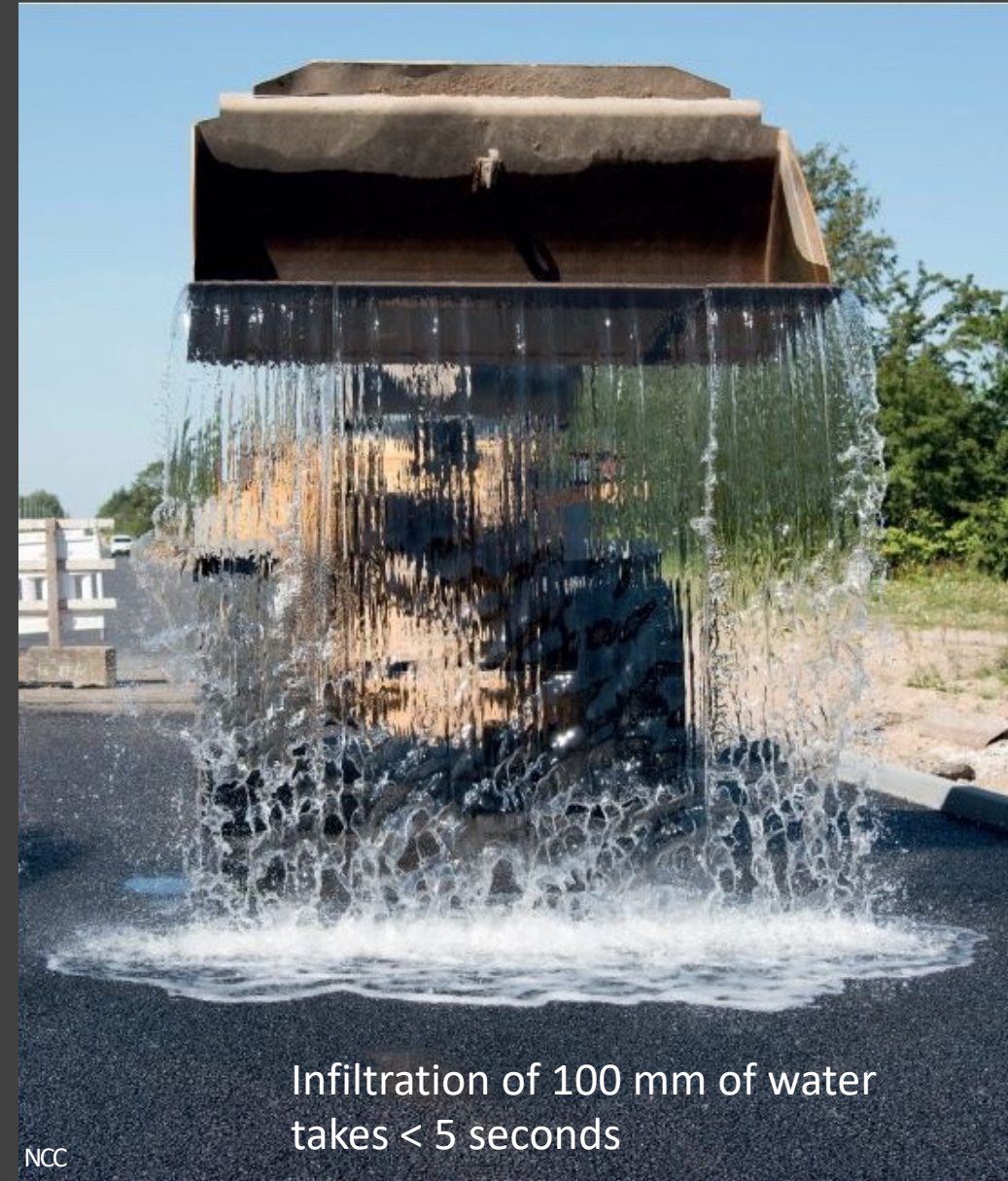


Supplies 913 m<sup>2</sup> kindergarten with room heating and domestic hot water



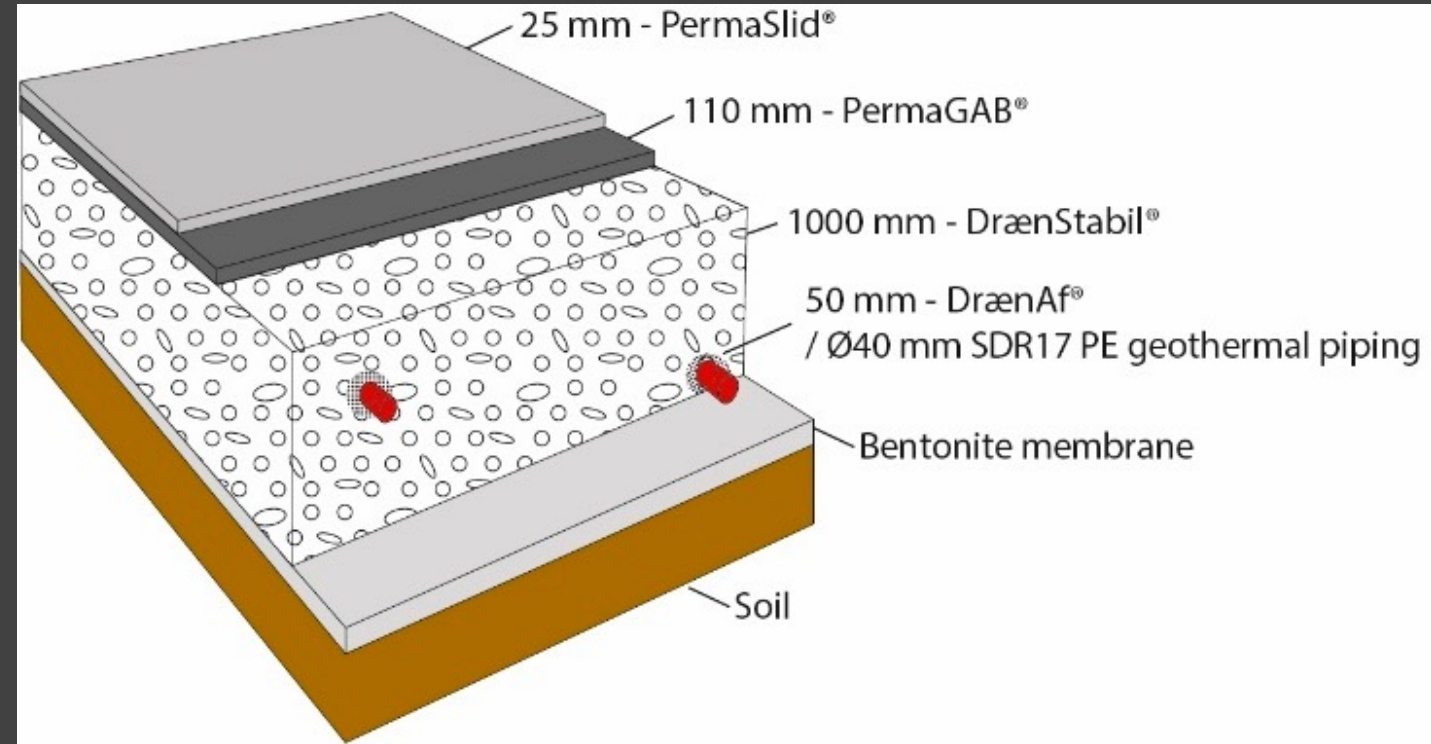
# Construction

- The road is made of permeable asphalt. In the event of rainfall, the water seeps down through the asphalt into the roadbed. The roadbed is constructed using a gravel mix ensuring a porosity of 30 % transforming the roadbed into a large reservoir that can handle a quantity of 120 m<sup>3</sup> surface water equivalent to a 1-in-100-year-rain event



# Construction

- In the roadbed, 800 meters of geothermal heating pipes collect the water's heat energy before redirecting the water to a nearby rainwater reservoir. The geothermal heating system is connected to a local kindergarten and is able to support its annual heating needs - equivalent to approximately 50,000 kWh annually. With this heating, Climate Road is helping to climate-proof the area as well as reducing the kindergartens heating bill through sustainable heat energy





# Functionality



# Functionality

## Advantages with a Climate Road:

- Always dry road
- Avoids drain grids and trenches
- Handles rainwater where it falls
- Connection to the sewer system is not required
- Can be laid as a completely horizontal surface
- Reduce noise

## Disadvantages with a Climate Road:

- Annual (semi-annual) maintenance
- Greater wear on the roadway
- With infiltration comes a risk of contamination



# Functionality

Advantages with the geothermal system:

- Green sustainable energy
- Do not take up space in the urban environment
- The more it rains the more energy is added to the system

Disadvantages with the Climate Road:

- Long term performance is unknown at low temperatures
- Unable to provide cooling to the kindergarten

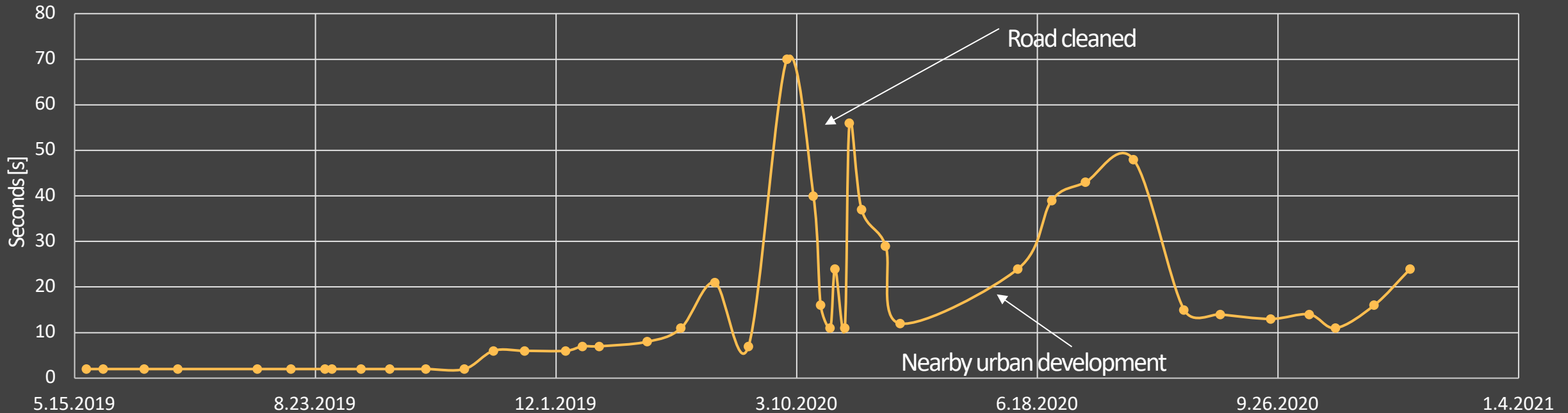


# Functionality

## - infiltration capacity

Tested using Becker's method and the ASTM method

- From May 2019 to February 2020 > 10 s
- During the winter the road was nearly clogged: 60 to 70 s



# Functionality – climate adaptation solution

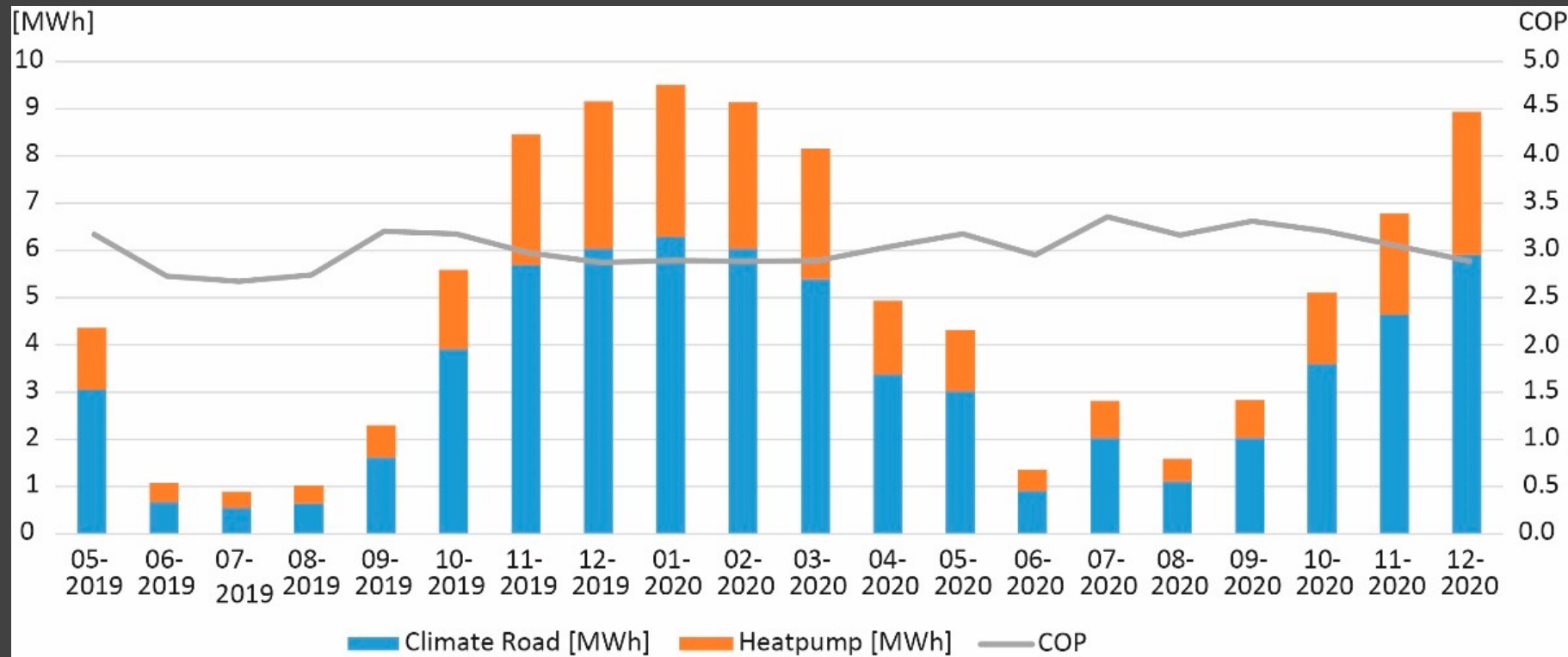
- The event detention time differs from 10 to 130 min, with an average event detention time of 35 min
- Storage capacity of the roadbed. Rain events below 0.7 mm rain depth in general do not produce a significant response.
- Volume reduction capacity of the Climate Road is between 15 and 30%.
- The lowest infiltration capacity measured with the ASTM method was 43 mm/h, which is still able to handle a cloudburst in Denmark (15 mm/30 min).



# Climate Road - energy production

The geothermal system works very good

- During the project period, 100 % of all energy consumption from the kindergarten is delivered by the Climate Road – approximately 50,000 kWh annually



# Conclusions and perspectives



# Conclusions and perspectives

## Conclusions:

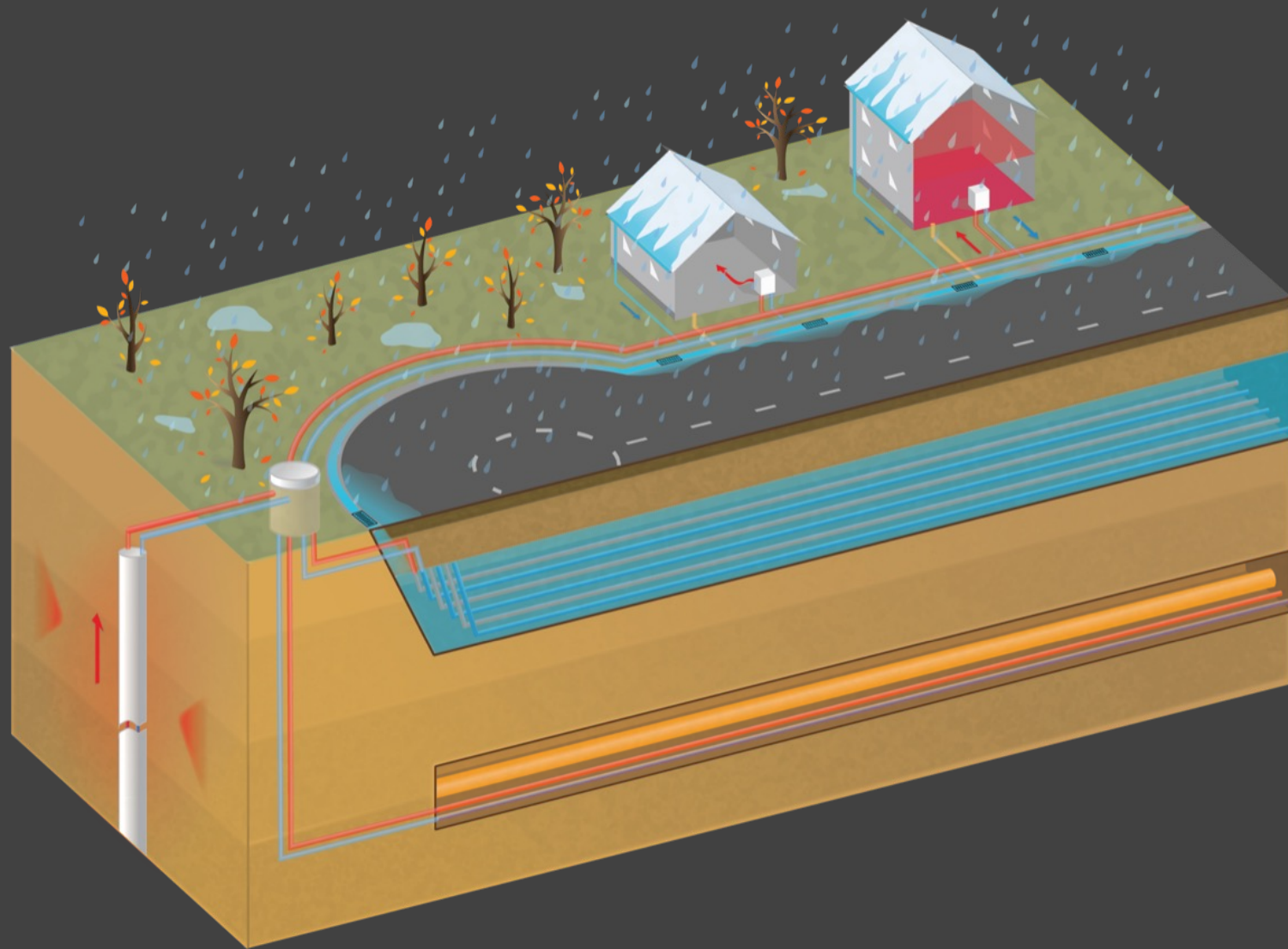
- The Climate Road as a climate adaptation solution performs very well – no flooding has occurred after the road was established
  - The road needs to be cleaned more often than expected – location
- The Climate Road as a climate mitigation solution has outperformed our expectations
  - The road is able to deliver 100% clean sustainable energy to the kindergarten
- The Climate Road has been successful in citizen engagement and to enhance the public awareness of future climate changes

## Perspectives and further research areas:

- Examine the remediation potential of the roadbed (PhD student)
- Investigate the energy potential during the next years
  - Expand the Climate Road solution to larger household areas (create a district network)
    - Room heating and domestic hot water consumption in a new 160 m<sup>2</sup> family house is limited to 14,300 kWh/yr by current Danish building regulations
    - As such, 4 family houses can be supplied with the 50 m prototype Climate Road

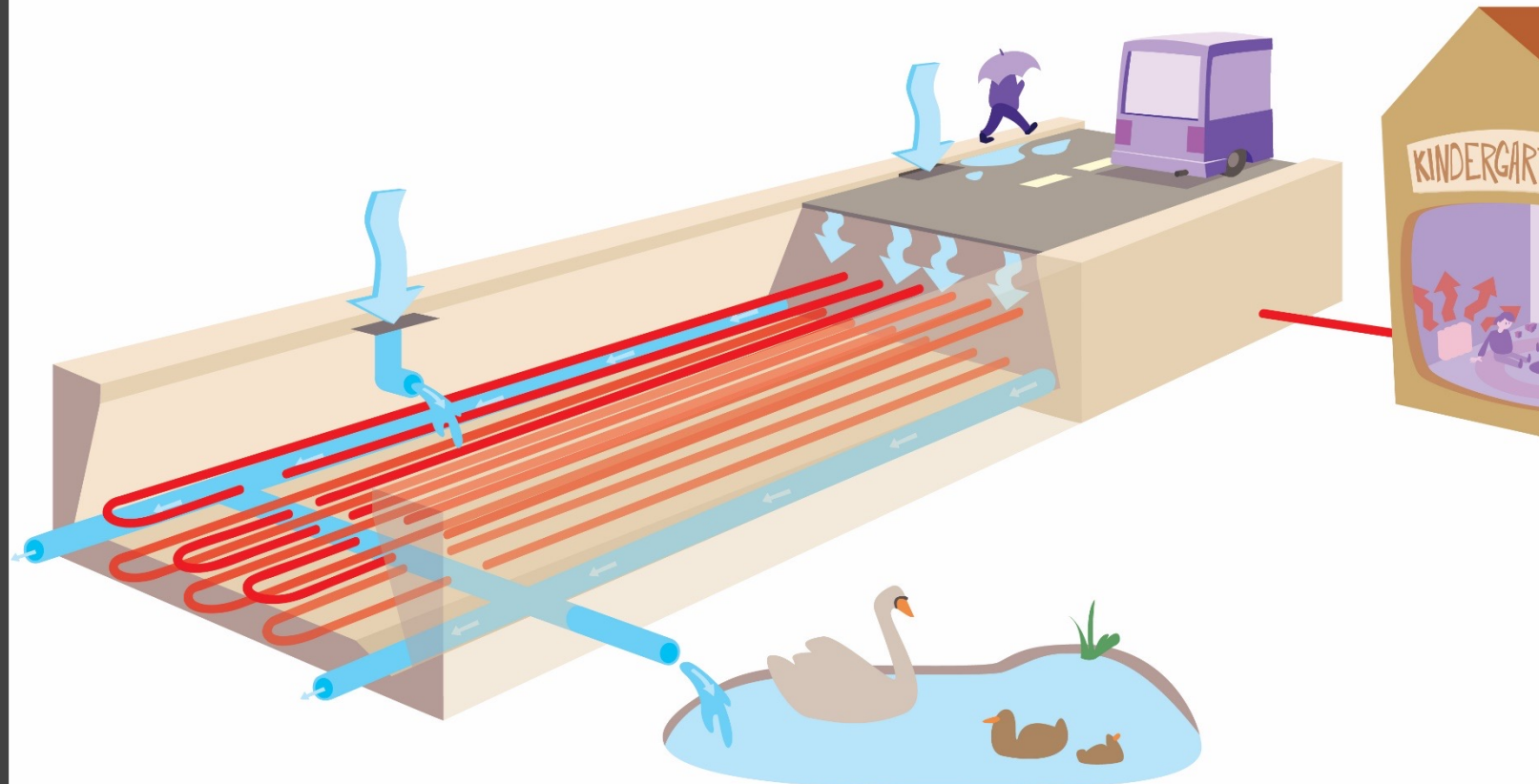


# Conclusions and perspectives



# Thank for the attention

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Article  
**The Climate Road—A Multifunctional Full-Scale Demonstration Road That Prevents Flooding and Produces Green Energy**

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<sup>\*</sup> Correspondence: thra@via.dk; Tel.: +45-8754285

**Abstract:** This paper presents a multifunctional full-scale demonstration road, the Climate Road, which combines climate adaptation and mitigation in a single system. The Climate Road is located at Hedensted, Denmark and is 50 m long and 8 m wide, and the depth of the roadbed is 1 m. Half of the Climate Road, i.e., 25 m, is paved with permeable asphalt and the remaining 25 m with traditional asphalt. All surface water drains into the roadbed, which stores up to 120 m<sup>3</sup> of water, either directly through the permeable asphalt or by drain grates. In addition, 800 m of geothermal pipes are embedded in the roadbed, distributed over four 200 m loops, two buried 1 m below the asphalt and two similar loops at 0.5 m depth. The Climate Road was tested from May 2019 to May 2021. In the project period, a total precipitation value of 1654 mm was recorded, the mean temperature was 9.3 °C and the most intense rainfall was 40.3 mm/30 min. The long-term infiltration performance of the permeable asphalt shows that the overall infiltration capacity slowly reduces. The reduction can be hindered, but not completely prevented, with annual restorative cleaning. After two years of operation, the Climate Road still, by a large margin, fulfills the recommendations of the infiltration capacity of 97.2 mm/h for the vast majority of the road section. The total volume reduction capacity is estimated to be between 15 and 30%. Based on an analysis of 61 single rain events, the event detention time is found to range between 10 and 130 min, with an average of 35 min. During the project period, the Climate Road produced a total of 98 MWh for a nearby kindergarten, with an average coefficient of performance (COP) of 3.1.

**Keywords:** permeable asphalt; climate adaptation solution; geothermal energy; GSHP; SUDS

**Check for updates**

Citation: Andersen, T.R.; Poulsen, S.E.; Tordrup, K.W. The Climate Road—A Multifunctional Full-Scale Demonstration Road That Prevents Flooding and Produces Green Energy. *Water* 2022, 14, 666. <https://doi.org/10.3390/w14060666>

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*Water* 2022, 14, 666. <https://doi.org/10.3390/w14060666>

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Article  
**Full-Scale Demonstration of Combined Ground Source Heating and Sustainable Urban Drainage in Roadbeds**

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**Abstract:** This paper proposes and demonstrates, in full scale, a novel type of energy geostucture (“the Climate Road”) that combines a ground-source heat pump (GSHP) with a sustainable urban drainage system (SUDS) by utilizing the gravel roadbed simultaneously as an energy source and a rainwater retaining basin. The Climate Road measures 50 m × 8 m × 1 m (length, width, depth, respectively) and has 800 m of geothermal piping embedded in the roadbed, serving as the heat collector for a GSHP that supplies a nearby kindergarten with domestic hot water and space heating. Model analysis of operational data from 2018–2021 indicates sustainable annual heat production levels of around 0.6 MWh per meter road, with a COP of 2.9–3.1. The continued infiltration of rainwater into the roadbed increases the amount of extractable heat by an estimated 17% compared to the case of zero infiltration. Using the developed model for scenario analysis, we find that draining rainwater from three single-family houses and storing 30% of the annual heating consumption in the roadbed increases the predicted extractable energy by 50% compared to zero infiltration with no seasonal energy storage. The Climate Road is capable of supplying three new single-family houses with heating, cooling, and rainwater management year-round.

**Keywords:** energy geostucture; ground-source heat pump (GSHP); sustainable urban drainage system (SUDS); sector integration; 5th-generation district heating and cooling; permeable asphalt; rainwater retention; full-scale demonstration; numerical modelling; analytical modelling

**1. Introduction**

The IPCC report from 2022 predicts catastrophic and irreversible climate change unless immediate and sustained reductions in emissions of carbon dioxide and other greenhouse gases are enforced on a global scale [1]. The heating and cooling sector consumes as much as 50% of the total final energy use in Europe and its decarbonization, by implementing renewable energy sources, has become ever more urgent [2]. In 2021, Aalborg University published the report “Heat Plan 2021” that outlines the necessary steps to decarbonize the Danish heating supply towards the year 2030 [3]. The report recommends an increase in the district heating (DH) supply, from approximately 50% of the total heat consumption as of today to 63–70%, through large-scale utilization of industrial waste heat and geothermal energy. Geothermal energy is both clean and renewable and is expected to play a major role in the decarbonization of the global energy sector [4]. On a global scale, the installed capacity of geothermal heat pumps has increased by 70% from 2015 to 2020, indicating a rapidly growing market for geothermal energy [5].

The “Heat Plan 2021” report makes no recommendation regarding the approximately one-third of the total heating consumption in Denmark that cannot be supplied from DH, other than suggesting widespread distribution of individual ground- or air-source heat pumps [3]. Ground-source heat pumps (GSHPs) are efficient relative to air-source heat pumps (ASHPs) and are also able to supply direct/passive cooling due to the constant and low

**Check for updates**

Citation: Poulsen, S.E.; Andersen, T.R.; Tordrup, K.W. Full-Scale Demonstration of Combined Ground Source Heating and Sustainable Urban Drainage in Roadbeds. *Energies* 2022, 14, 605. <https://doi.org/10.3390/en14050605>

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