Intelligent controller for the Rottne DH network in Sweden

Summary

Rottne is small town in Sweden under the administration of Växjö city municipality. The main source of supply for heating needs of its residents is district heating (DH). Several large and small DH networks exist in different regions of the entire area covered by the municipal administration. All these DH networks are operated by a district heating operator called Växjö Energi AB (VEAB), which is owned by the municipality giving it a 100% market share. The main goal of Växjö city is to eliminate fossil fuels completely by 2030, and a significant part of achieving this target is to transform the existing DH plants into 100% renewable energy based. The Rottne DH production plant, which started with a wood fired base load boiler and an oil fired peak load boiler in 1997, already became 100% renewable energy based in 2012. This was achieved by replacing the fuel of the peak load boiler to bio-rapeseed oil making it a fully biomass based operation.

Name	Rottne DH
Location	Rottne, Sweden
Owner	Växjö Energi AB (VEAB)
Year of commissioning	1998
Year(s) of renovation/extension	2004 (Additional wood boiler) 2012 (Replacement of fuel for peak load to bio-oil)
Size	Small, 180 connections in 251 buildings
Customers	70% detached single family homes + 30% larger residential and commercial facilities
Ownership	Owned and operated by ESCO called Växjö Energi AB (VEAB), which is owned by the Växjö city municipality
Production system	Boiler A: 1.0 MW, Wood fired Boiler B: 1.5 MW Wood fired Boiler C: 3 MW Bio-oil fired
Overall system efficiency	73% (2018)
Renewable energy share	98%
Total capacity	5.5 MW
Distribution network	High temperature (75-110 ^{0}C), 10.3 km

Table 1: Key facts of the Rottne DH system

Motivation for the STORM controller

The main challenge for the DH operator VEAB faced was the increasing cost competitiveness of alternative individual heating systems such as heat pumps, boilers etc. Therefore, in order to keep their service attractive for existing and future customers, it was essential that they reduced their energy prices. In order to achieve that, VEAB decided that improving the energy efficiency of the existing system is the most cost effective way forward. A control algorithm, which is largely an AI based optimization algorithms running in the cloud, was an ideal choice for such an endeavor due to its ease of installation and low upfront investment costs. As part of the H2020 project from 2014 until 2019, the STORM controller was envisioned as the first, out-of-the-box digitalization solution on the DH market, which will provide peak shaving and energy efficiency service to DH operators at low costs. It was tested and developed jointly by the Flemish Institute of Technological research (VITO, Belgium) and a local industry partner NODA Intelligent systems (Sweden). As envisioned, it combined latest AI algorithms, IoT and cloud systems to achieve intelligent control of DH networks. It was successfully demonstrated on the Rottne DH system in final tests conducted during the 4 months in 2018 (Mar, Apr, Nov, Dec). Table 2 shows the key facts about the STORM programme.

Name	STORM - Self-Organizing Thermal Operational Resource Management
Duration	03/2015-03/2019
Technology developers(s)	VITO, NODA Intelligent Systems
Partner	Växjö Energi AB (VEAB)

Table 2: Key facts about the STORM programme

Key results

The STORM project resulted in the development of a one of a kind demand side management solution focusing on the DH system. Its abilities to improve energy efficiency and thereby reduce costs and CO_2 emissions was demonstrated successfully. Table 3 lists the key results of STORM implementation in 9 buildings for a testing period of four months in 2018(Mar, Apr, Nov, Dec). The table also shows annual projections in case all or most of the buildings are connected to the STORM controller.

	without STORM	**with STORM**	**Reduction**
Peak oil boiler consumption	155 MWh	135 MWh	20MWh (12.75%)
CO_2 emissions from oil boiler	22.9 Ton CO_2eq	20.0 Ton CO_2-eq	2.9 Ton CO_2-eq
Cost of bio-oil	17000EUR	14800 EUR	2200 EUR

Table 3: Key results with and without STORM controller implementation

1. Rottne – A small town in Sweden

Rottne is a small town located nineteen kilometers to the north of Växjö city and has 2427 inhabitants. The total land area in Rottne is 1,930,000 m^2, of which 201,137 m^2 is built area and the rest is forest area as visualized in figure 1. It is situated between two lakes called Innaren and Sörabysjön. Administratively, Rottne is officially a part of the Växjö city municipality. The vision of the municipality is to set an example by eliminating fossil fuels entirely by 2030, without compromising on the quality of life and profitability for its residents and businesses. The municipality has a track record of working towards environmental and climate issues, and has been implementing innovative measures to renew its energy system. In nearly the entire municipality, several local district heating systems are the main source which provide for the space heating and domestic hot water needs of the residents and the Rottne district heating (DH) system is one of them.

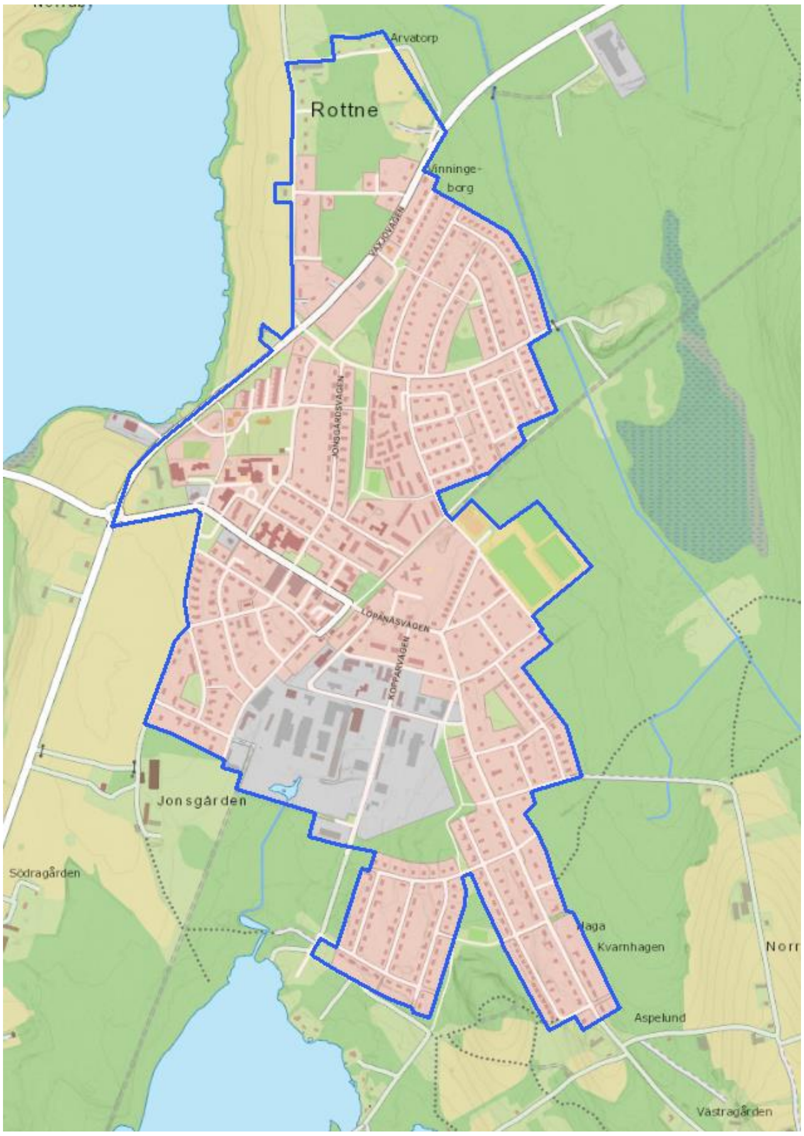

Figure 1: The city of Rottne, the blue line in the right figure visualizing built area. (source: Växjö Municipality)

2. Rottne DH – a history

The district heating system in Rottne is a traditional 3rd generation system with a high temperature distribution network, and a 100% biomass based production system. An aerial view of the plant is shown in figure 2.

Figure 2: An aerial view of the Rottne district heating production plant

History of the plant

1998	The district heating system is commissioned and is equipped with a dry wood fired boiler with a capacity of 1.5 MW for base load, and an oil-fired boiler with a capacity of 3 MW for peak load.
2004	A major rebuild and extension of the plant is undertaken wherein an additional wood boiler of 1.5 MW was installed and the existing wood boiler was rebuilt to be fired with more humid fuel lowering its power to 1.2 MW.
2012 ***(100% renewable)***	The plant becomes completely free of fossil fuels with the replacement of oil with bio-rapeseed oil for the peak load boiler.
2014	Rottne DH becomes partner in the H2020 STORM project. First experimental version of STORM controller is installed for testing and development over the 4 year long project.
2018	Final version of the STORM controller installed and successfully demonstrated resulting in 12.75% reduction in peak consumption.

Sustainability

Besides ensuring a 100% renewable energy based operation, the operator ensures the sustainability of operation as well. The biomass used in the boilers consists of wood chips, branches and other forest residue from the surrounding areas. Furthermore, the flue gases from the biofuel boilers are purified via multicyclones. As a direct result, the NOx and Sox emissions are minimized. Large part of the emissions are also absorbed back by the forest area for growth of the biomass which is later used as fuel. The residual ash left after the combustion of the biofuels, is recycled to be used as a fertilizer, source of minerals in the forest, ensuring an overall sustainable operation of the plant as shown in figure 3.

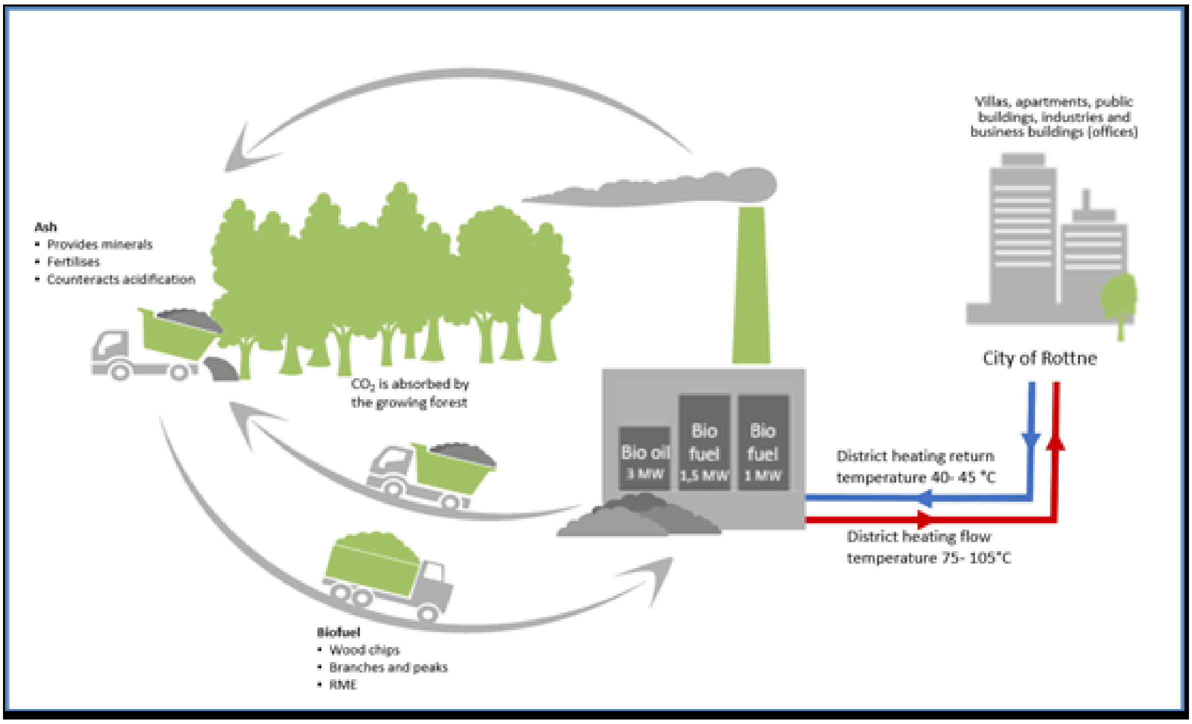

Figure 3: Illustration of the sustainability concept of the Rottne district heating system

3. Distribution network and consumers

Figure 4 shows an overview of the distribution network and the location of the production plant of Rottne DH system. The heat distribution network in Rottne currently connects 251 buildings which represents 180 metered connections each with its own substation. Out of the 180 connections, 70% of them are for detached residential buildings such as villas, small-houses etc. and the rest 30% are for other buildings such as multi-family houses, industries, public buildings, and offices. The distribution network is designed and operated at medium-high supply temperatures ranging from 75-105 degree Celsius and the return temperature is approximately 40-45 degree Celsius. The total length of the pipelines is 10,300 meters with a total volume of 64 m^3.

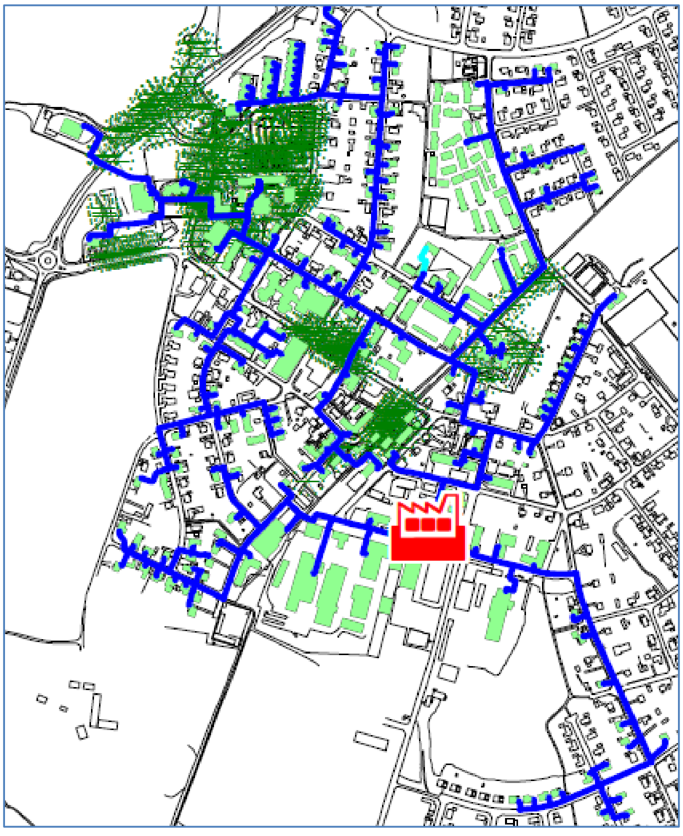

Figure 4: Distribution network and production plant location for Rottne DH system

4. Ownership structure and operational challenges

The district heating system in Rottne is operated by an energy service company called Växjö Energi AB (VEAB), which is fully owned by the Växjö municipality. VEAB is the only company delivering heat to the network in Rottne giving it a 100% market share in that region. Currently, only 34% of the total heat demand of the region is supplied by VEAB through its network. This is represented by 251 buildings. There is huge potential for expansion to an additional 494 buildings which currently use individual heating systems using sources such as firewood, pellets, heat pumps etc.

The main challenge for VEAB is to provide heating services to its existing and future customers at competitive prices. Due to low electricity prices in Sweden, energy efficient technologies such as heat pumps are becoming common and affordable. In order to keep its heat supply service attractive for customers, VEAB decided that reducing expenditure through lowering of cost of energy production can help keep the prices competitive with other technologies. It will also result in additional benefits such as reduced CO_2 emissions and release system capacity such that additional connections may be added with minimal investment costs. A significant part of the operating expenditure is due to rapeseed oil consumption, which is used for the peak boiler operation as shown in figure 5, which illustrates the monthly and annual energy mix of the Rottne network with biomass, electricity, and bio-oil consumption. The fuel cost of rapeseed-oil can be up-to five times more expensive than wood costs, making a large share in the overall operating costs.

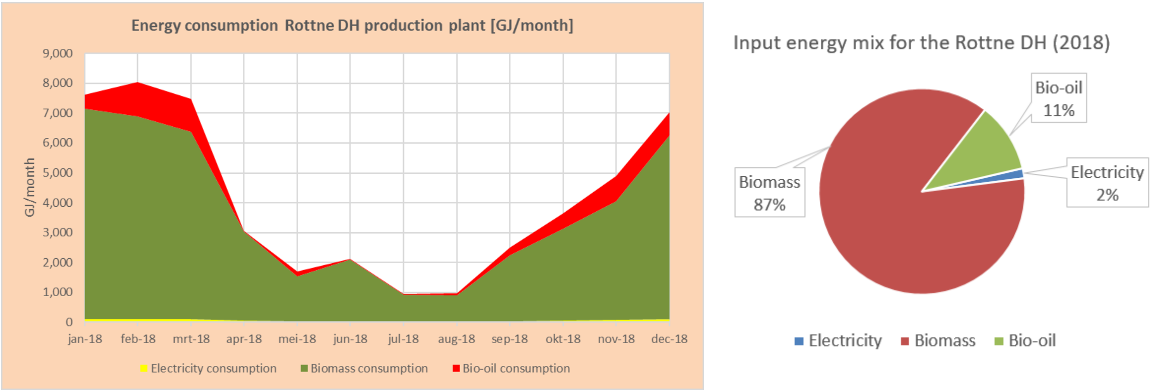

Figure 5: : Monthly (left) and annual (right) energy mix for Rottne DH (2018)

5. STORM – Artificial Intelligence based control for peak demand reduction

Introduction

STORM is an acronym which stands for Smart Thermal Operational Resource Management. STORM is an artificial intelligence-based controller for district heating networks, which achieves operational optimization through active demand side management. It brings together the latest tools, techniques and technology from three different fields name Artificial Intelligence (AI), Internet of Things (IoT), and cloud computing and infrastructure.

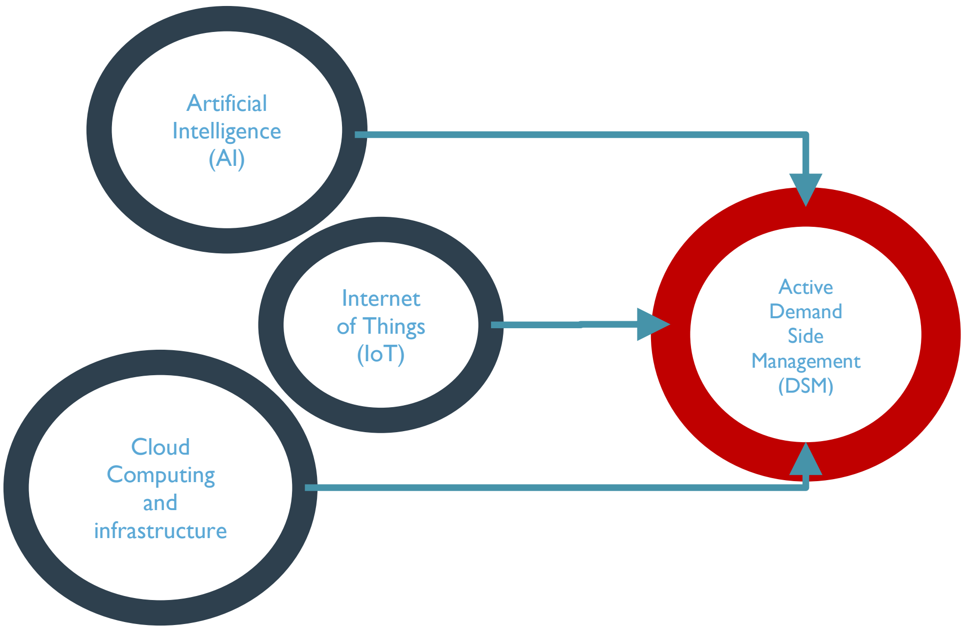

Figure 6: Latest technologies combined by the STORM controller

Working principle

STORM basically utilizes the thermal mass of the buildings connected to a network as distributed storage. When buildings are heated, the walls, air, and other objects inside the building which together constitute the thermal mass of the building are also heated essentially storing thermal energy. In a hypothetical situation where the heating supply of the building is reduced or switched off completely, the thermal mass of the building can release this thermal energy into the building's indoor environment without loss in thermal comfort for a few hours. The duration may vary for each building depending on its construction. The STORM controller controls the heating supply of multiple buildings connected to a district heating network simultaneously, such that the overall energy demand at the grid level can be reduced as illustrated in figure 7, which shows a snippet of the heating consumption for the Rottne district heating plant with STORM controller active and without.

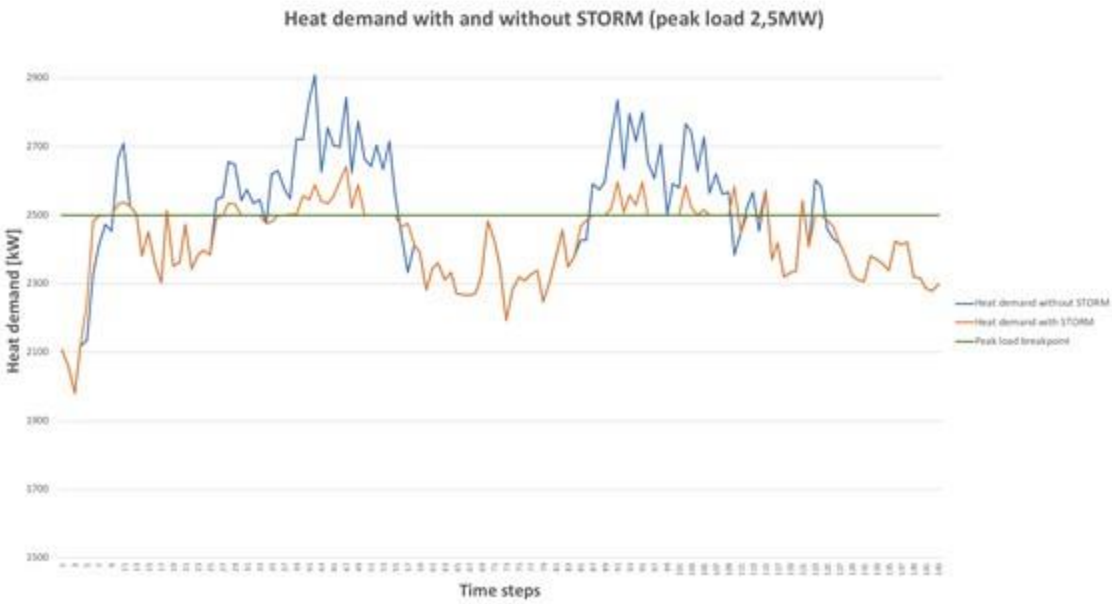

Figure 7: Heat consumption in Rottne demo site with and without STORM controller

Out-of-the-box innovation

Most of the currently existing demand side management technologies are highly focused on the building itself. The STORM controller goes one step beyond, and offers the district heating network operators the opportunity to utilize this potential to reduce their operating expenditure and enable additional connections without heavy investments in additional capacity. Simultaneously, STORM also provides building owners an opportunity to drastically improve their thermal comfort through the use of artificial intelligence (AI) and optimization algorithms. Although AI based algorithms are commonplace nowadays, the real innovation behind STORM controller is its self-learning routines that enable operation without the need for human intervention for tuning and re-configuration. The STORM controller tracks the indoor thermal environment of connected customers in real-time to provide maximum comfort and adjusts the optimization in real time to minimize costs for the network operator at the same time. While the software intelligence of STORM controller runs on the cloud and can be customized, operated and maintained remotely, the hardware IoT device is installed in the buildings' substations. It uses a special temperature override technology making it cheap and compatible with all BMS providers. The STORM controller is a technology, which is designed in such a way that it can be applied to 3rd and 4th generation networks, thanks to the various options for control strategies other than peak shaving. It is a technology that brings digitalization in the true sense of the word to the DH industry and is ready for commercial application.

Implementation in Rottne district heating network and outcome

The STORM programme implemented on the Rottne district heating network, targeted the consumer segment consisting of large building owners. These consisted of non-residential buildings and housing cooperatives. The STORM controller consisting of a software running in the centralized cloud computing infrastructure and a hardware IoT device, was installed in the substations of nine buildings representing 36% of the total heating consumption of the entire network. The STORM controller hardware, which consists of the IoT functionalities can be seen installed in a building substation in figure 8. The locations of the buildings in which the STORM controller was installed is shown in figure 9. The objective of the controller was to perform peak shaving such that the activation of the peak bio-oil boiler is minimized. The controller was tested for a period of 5 months during the heating season of 2018/19.

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Figure 8: Sofie Nielsen, Business engineer at VEAB showcasing the STORM controller hardware installed in a building substation

Figure 9: The locations of the 9 buildings connected to the STORM controller

The STORM controller could achieve a reduction of 20 MWh of peak boiler consumption which represents 12.75% of the overall consumption of the boiler over the 4 month testing period. This was achieved with just nine buildings connected to the STORM system. The overall cost savings for the network operator due to a reduced bio-oil consumption were around 2200 EUR and the CO_2 emissions savings were 2.9 Ton CO_2-eq during the test period. The key results are summarized in Table 1. The reduced operational costs would enable VEAB to reduce its energy prices for its customers and maintain competitiveness in the market.

During the programme, it was of utmost importance that the quality of service delivered to customers connected to the STORM controller is maintained at its highest levels. Therefore, the controller actions were restricted in order to ensure negligible changes in indoor temperatures in these buildings. Since this was a demonstration project, the purpose was to validate the economic and environmental promises of this technology. However, for full commercialization and replication of the STORM technology, it is important to develop innovative business models that help maximizing the thermal flexibility of the buildings by bringing together the network operator and the building owner within a common framework of sharing economic and social value generated by this technology.

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Media summary

Rottne is a small town located 19 kilometers to the north of Växjö city in Sweden with 2427 residents. Rottne falls under the administrative jurisdiction of Växjö city municipality. The municipality is actively engaged in reducing its environmental footprint and has pledged to eliminate fossil fuels by 2030. In nearly the entire municipality, district heating is the main source to provide for the residents' space heating and domestic hot water needs. There are several DH networks in the region including the one in Rottne. The Rottne DH system was commissioned in 1998, and due to the active efforts of the operator VEAB, which is a company owned by the municipality, it became 100% fossil fuels free by the year 2012. Today it is fired by 2 boilers, which use locally sourced biomass from nearby forest and a peak boiler fired by bio rapeseed oil. Achieving a 100% renewable energy mix was not enough to stop the Växjö city's efforts in achieving its climate goals. It was decided to further improve the energy efficiency which would not only result in reducing CO2 emissions, but also lower the total cost of production. The STORM controller which is largely an artificial intelligence algorithm running in the cloud, combined with IoT sensors placed in buildings was a low cost solution fit for the purpose. Thanks to STORM, the peak oil boiler consumption was reduced by 12.75% in just 4 months of testing, resulting in CO2 emissions savings of 2.9 Tons and cost savings of 2200 EUR for 9 buildings.

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