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RUGGEDISED
Designing smart, resilient cities for all

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Digital marketplace for buying and selling heat and cooling

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Executive Summary

RUGGEDISED is a smart city project funded under the European Union's Horizon 2020 program. This report describes a pilot-study done to test the results from two of the nine Smart solution sub projects undertaken in Umeå, called U1 and U3 (Climate smart business models for 100% renewable energy supply).

The pilot project is performed by the Västerbotten County Council (VCC) who manage the hospital buildings (350 000 m^2) and the public utility Umeå Energi AB (UEAB) who produce and distribute district heating and cooling to customers in the Umeå municipality and electricity to more than 50 000 customers all over Sweden. It focuses on cooling demand and the idea that participants in a cooling market can share their produced cooling and produce it where it is the most profitable, economically and environmentally.

The objective is to build a **marketplace** for district cooling, where cooling can be purchased and exchanged between VCC and UEAB. The specific goals for the marketplace were:

1. *The two actors should be able to put criteria to steer when to purchase and when to sell.*
2. *When both actors' criteria align the marketplace should be able to talk to the technical regulations, so that cooling flows in the desired direction.*
3. *The criteria for contract should be both based on price, time and environmental criteria.*

A system solution in the form of a marketplace would open the possibilities for VCC to purchase when favorable, since time of the purchase is less important. Umeå Energi would gain from steering the purchases to times when they are not close to peak production for any production units. At such times the production can also be expected to use less fossil fuels. To test the realization of this possibility the pilot project was performed to both develop a model for a marketplace and to install a technical control system to test the actual transmission at a connection point.

Market place

The solution was to program a marketplace for the two participants with the following functions, also illustrated in Figure i:

- The base for a cooling purchase is a contract and a contract for a purchase can contain criteria put on the purchase, as to what price a participant wants to buy, at what time and what environmental specification is desired (how large fossil content is OK?).

- An interface where orders can be put in manually by the purchasing participant and the desired criteria can be specified. In the pilot project the orders are put in through a web-based interface.

- The interface interacts with a software system, called agent, that works in the marketplace in a somewhat automated way. The agents handle the orders to make the marketplace more automated although the participants are still in control over the orders. The agents get the information from the participants interfaces through several ID:s.

- A matcher with a matching engine (UEMATCHER) keep track of the different orders and identify at what points the orders from buyer and seller match and a purchase should go through. The matcher also contains a flow server (UEFEEDS) that communicates and sends out information about the transactions. They are both based on APIs for retrieving data. It is the flow server that communicates with the control system and makes the execution happen and the cooling trade physically be carried out. The system is built to encrypt the data traffic to and from the matcher (UEFEEDS).

- In the hospital buildings owned by VCC, the installed Siemens PLCs can communicate with external devices using the BACnet protocol. But here, the output from the matching engine comes as a FIX-

protocol. Since the PLC responsible for cooling exchange logic communicates with BACnet it cannot understand the output from the FIX-based matching engine. To remedy this problem the protocols from the matching engine had to be translated to something the responsible PLC could understand. The existing protocol adapter that could handle BACnet was expanded to translate the FIX messages to MQTT messages and the MQTT to be converted to values written to BACnet objects.

- When VCC wants to purchase cooling, a valve is opened at Umeå Energi and the cooling is transferred through a heat exchanger. The cooling transfer is run until the desired energy delivery is achieved or the agreed three-hour period has elapsed. The energy delivered every 15th second is registered and by accumulation, the total delivered amount of kWh is known. When the ordered amount is approaching the valve closes to throttle the flow. The pump slows down, and less power is transferred, so that only a small amount of cooling is delivered until the limit is reached and the right amount has been transferred across the heat exchanger which is the connection point.

○ As an overarching mechanism there should be a business agreement between the participants. They all need to agree to being part of the market, and the agreement should contain guidelines for what can be sold and purchased and what the different criteria means. If cooling of different environmental characteristics should be traded, all participants must have the same view of how the environmental classes available are defined.

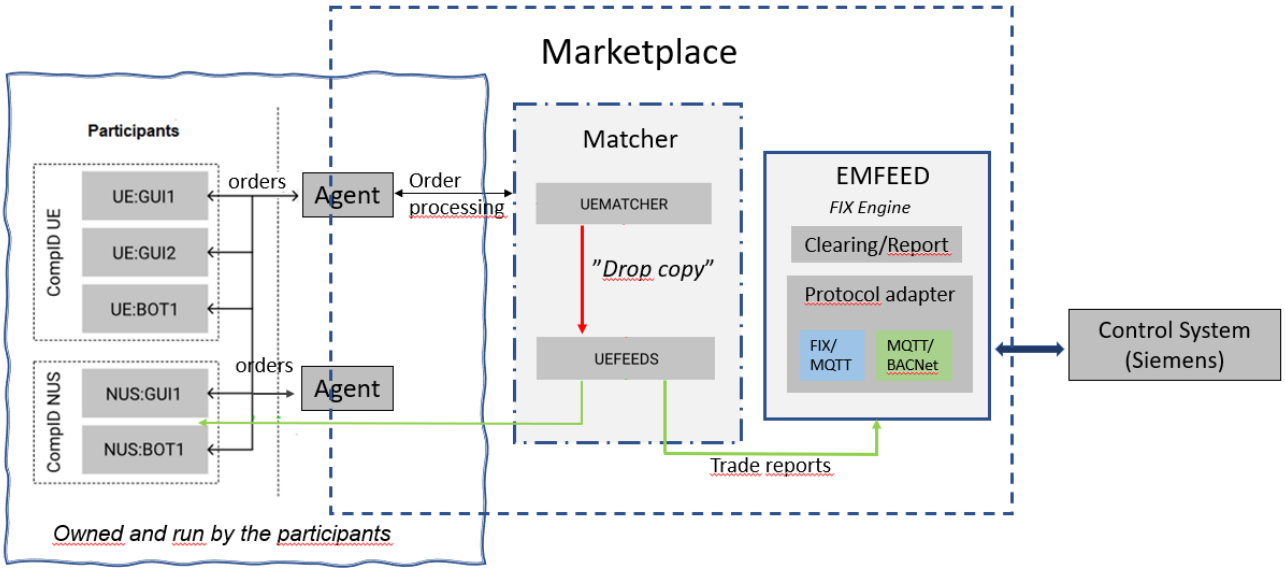

Figure i. A schematic picture of the entire market place, getting orders from the participants, and their agents and communicating with the control system to execute the trade.

Results

This pilot project covers the programming of a cooling trade market, and the result is the delivery of an ordered amount of cooling. The trade has been tested, with orders put, matches found, contracts in place with cooling delivered and a trading report saved in database. Hence, the entire event chain went through and worked as planned. Different contracts are tested, being generated as combinations, and the system correctly delivered in the contracts resulting from any combination trading.

Glossary

Participants: All the actors/organizations that take part in the market, both to sell and to purchase energy. The participants can put orders and trade in the marketplace.

Agents: A software system that works in the marketplace in a somewhat automated way. The agents handle the orders for the participants to make the marketplace more automated.

Marketplace: The entire system that makes the cooling trade possible and that the participants interact with. The marketplace consists of all the components needed (between the user interface and the control system) to purchase and sell cooling.

The matcher and the matching engine: In this context the matcher is the component made up by the matching engine (UEMATCHER) and the flow server (UEFEDS), even though market data flows and reporting usually not is considered a part of the matcher.

Contract: The agreed upon delivery of cooling, that makes a purchase go through and a trade to happen.

Base contracts: Contract for delivery of cooling without specific criteria, in order to secure the cooling of the hospital.

Manual orders: The manual instructions for what is desired to purchase or sell within a given time-period and with certain environmental classification

Combination contracts: Virtual contracts that are made up of purchase/sell combinations of other contracts. Examples are” bundles”, that put several contract together during a longer time period and ”spreads”, that purchase and sell in combinations, in order to move the delivery in time.

Content

1 INTRODUCTION

1.1 Background

RUGGEDISED is a smart city project funded under the European Union's Horizon 2020 research and innovation program. It brings together three lighthouse cities: Rotterdam, Glasgow and Umeå and three follower cities: Brno, Gdansk and Parma to test, implement and accelerate smart city solutions across Europe.

The three overall aims of RUGGEDISED are:

1. **Improving the quality of life of the citizens,** by offering the citizens a clean, safe, attractive, inclusive and affordable living environment.
2. **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, not only to reduce emissions, but also to enable smart grid balancing.
3. **Creating a stimulating environment for sustainable economic development,** by generating more sustainable jobs, stimulating community involvement in smart solutions and to boost start-up and existing companies to exploit the opportunities of the green digital economy and Internet of Things.

To achieve these aims, all three lighthouse cities of RUGGEDISED performed projects to demonstrate combinations of integrated smart solutions for energy and e-mobility and appropriate business models with the right incentives for stakeholders to invest and participate in a smart society. The goal was to implement and test the results. This report describes a pilot-study done to test the results from two of the nine Smart solution sub projects undertaken in the Umeå, called U1 and U3 (Climate smart business models for 100% renewable energy supply). The two sub projects were interconnected, and all the work was performed in a common working group and the report of the development phase was also merged into one.

Umeå is a city in Northern Sweden, located 600 km north of Stockholm (Figure 1). With 123 000 inhabitants it is the 11th largest city in Sweden. The climate of Umeå is subarctic, with short and fairly warm summers. Winters are lengthy and freezing but considering the latitude very mild due to the influence of the Gulf Stream.

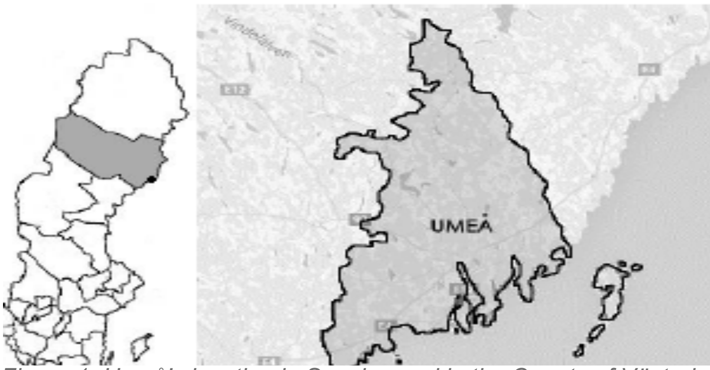

Figure 1. Umeå's location in Sweden and in the County of Västerbotten.

Umeå is a center of education and technical and medical research. The public sector (municipality, county council/hospital and Umeå University) is the main employer. The private sector in Umeå is quite diversified with IT, research based on biotechnology and forestry and the engineering industry well-represented. Six of Umeå's export companies have turnovers higher than 100 M€/year.

Within RUGGEDISED, Umeå focused on the University City area situated immediately to the east of Umeå city center. The university was established in 1965, and this area is now the main campus for two universities with research facilities and the regional hospital, serving all northern Sweden´s 876 00 inhabitants. There are also apartment buildings with more than 1000 on-campus residents, and a sports center which is the largest training facility in Scandinavia. All in all, with recreational and commercial buildings there are approx. 40 000 daily visitors in the University City area. The area is being developed and there are plans for 2000 new apartments and more commercial activities. The area is shown in **Fout! Verwijzingsbron niet gevonden.**.

Figure 2. The University City area with mainly university and hospital buildings.

The two largest property owners in the area is Västerbotten County Council (VCC) who manage the hospital buildings (350 000 m^2) and Akademiska Hus AB (AHAB) who manage the university buildings. These two together with the public utility Umeå Energi AB (UEAB) were responsible for the two RUGGEDISED smart solutions U1 and U3 in Umeå. VCC and AHAB require about 65 GWh heating and 17 GWh cooling annually of which about 46 GWh of heating and 3,6 GWh of cooling are purchased from UEAB. This equates to about 10 % of UEAB's total heat production annually.

UEAB produce and distribute district heating and cooling to customers in the Umeå municipality and electricity to more than 50 000 customers all over Sweden. The heat production is mainly based on waste incineration (47 %) and biomass (47 %) but also includes electricity (5 %) and oil (1 %). The baseload electricity is produced from waste and biomass in two combined heat and power plants and from wind power, hydro power and, in smaller amounts, solar power. Reducing the need of heat production during peak hours would cause a great effect on reducing both operational costs and emissions of CO_2e.

But also, VCC and AHAB produce heat and cooling with heat pumps, and VCC has a large geothermal storage at the hospital in Umeå that was taken in full operation during 2017 (see Figure 3). Since the two property owners both operate in this area and both use and produce heat and cooling it is reasonable to think that the energy in general would be used more efficiently if they could share it and use it where it is needed the most. One building may have an excess of heat/cold when another one needs it and the need for heating and cooling vary as different buildings in the area operate at different times during the day and also during the year. It has been identified that this area has a potential for a large increase in renewable energy supply and given the Swedish climate goals of net zero CO_2 emissions in 2045, this is desirable.

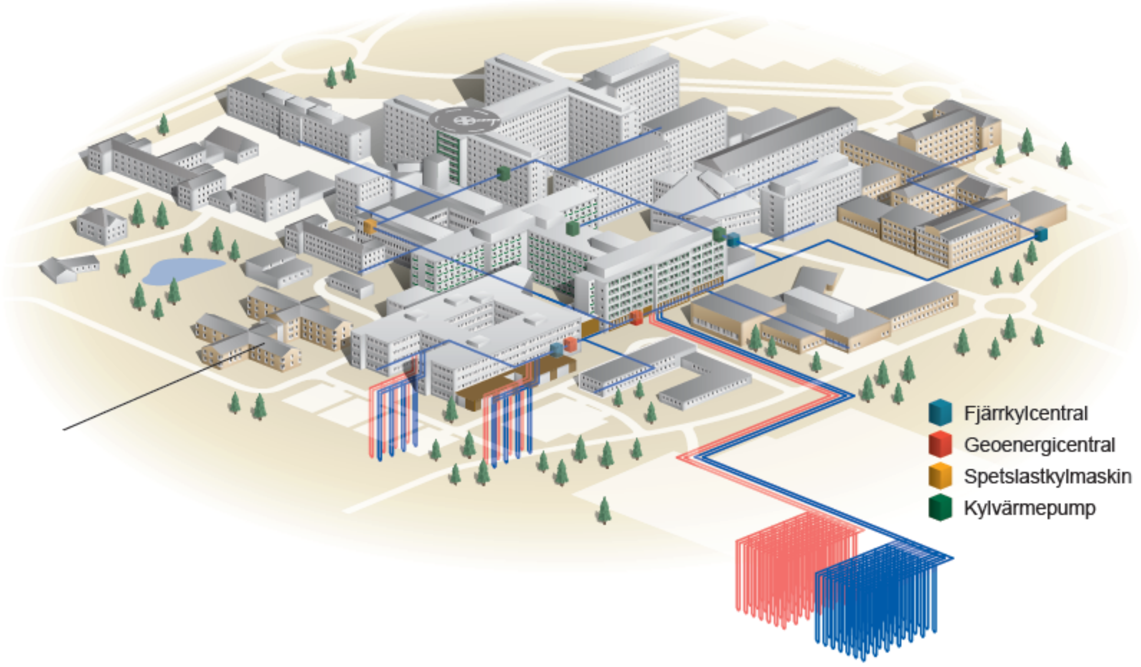

Figure 3. The geothermal storage supplying VCC with cooling and heating capacity.

1.2 Summary of RUGGEDISED Solutions Phase 1 project

The sharing of energy between the actors in the University City could lower the total energy demand since less energy would be wasted and existing energy used instead. It could also reduce power spikes in the grid and reduce peak load production at UEABs facilities if the production in the area was used as a buffer. Hence, this strategy could support several of the measures that need to be taken to reduce the CO_2 emission from energy use in the University City. The measures have been identified as:

1. Reduce the need of new production
2. Minimize power spikes by redistributing the energy use over time
3. Maximize the use of production capacity with low climate impact
4. Introduce more renewable heat and electricity production to the system

In the RUGGEDISED solutions U1 and U3 the objective of the solutions was therefore to analyze the possibilities to supply the University City area with 100% renewable energy. What technical solutions will be required? What role can the sharing of the existing geothermal heating/cooling storage play if a common grid is loaded with heat or cooling from all operations/buildings and used by all when needed. But also, for the technical potential to be realized, there must be a business model that supports the implementation and steers the actors to act according to the strategies. AHAB and VCC need to share their surplus of heat and cold to the UEAB. In return the energy company should provide the tenants and the property owners with the energy they have stored. The existing legal business model between land owner and energy company is not suited for this kind of cooperation. A new way of thinking must be developed.

Technological potential

To understand what technical solutions and measures that are required to reduce emission, both buildings and energy supply system need to be analyzed together. This was done using an energy systems approach. A model was built for the energy demand and production units for the entire area, including district heating production units and internal production units owned by AHAB and VCC (see Figure 4). The model was then used for scenario analyses of different cases of technical measures. The model case based on data from 2017 became the baseline. The operational cost and the emission of CO_2 equivalents ($CO_{2\,e}$) were compared for all renewable energy investment cases, in order to analyze the potential for CO_2 mitigation.

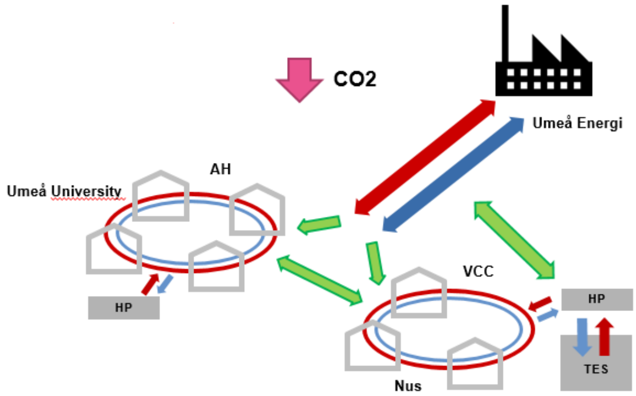

Figure 4. A schematic visualization of the energy model

The technological cases (scenarios) were:

1. Pellet boiler for heat production, that may supply surplus heat to the district heating grid.
2. Energy efficiency measures at VCC of 2% yearly
3. Energy efficiency measures at AHAB of 2% yearly
4. Hot water storage tank that can be loaded with heat from pellet boiler or district heating, but not from peak production
5. Increased deposition of heat pump heating and cooling in existing geothermal storage (GS) due to more actors on the grid
6. New geothermal storage
    a. Similar temperature level as the existing one
    b. High-temperature geothermal storage

These most promising cases were also combined, and Table 1 below shows the reduction in yearly CO_2 emissions per SEK (tonnes CO_2 /SEK, year) of the individual cases and the analyzed combinations. It was clear that there is a potential for emission reductions in the area,

Table 1. Results for reduction of CO_{2e} due to investment in individual and combined cases

	Case	Individual cases' max CO_{2e} reduction	Combined Cases	Combined cases' max CO_{2e} reduction
0	Baseline	0; 1,394 tCO_{2e}		
1	Pellet boiler	-37 %	1+5	-81%
2	VCC Energy efficiency	-4 %		
3	AHAB Energy efficiency	-2 %	3+4+5	-59 %
4	Hot water storage tank	-21 %	3+4+6a	-24 %
5	Increased deposition in GS	-20 %		
6a	New geothermal storage	-11 %	6a+5	-61 %
6b	New high temperature	-26 %		

Business model innovation

When all the technological cases were analyzed, three business models with different business logics were chosen. The aim was to evaluate which type of business logic, could support mitigation investments the best. All the cases in Table 1 were evaluated for all three business logics, except case 6b that was too unproven to be a realistic option today.

Drawing on the idea that a business model is essentially a set of key decisions which determine how a business earns its revenue, incurs its costs, and manages its risks, innovations to the model can be viewed as changes to those decisions: *what* your offerings will be, *when* decisions are made, *who* makes them, and *why.* Successful changes along these dimensions improve the company's combination of revenue, costs, and risks.

To develop a business model for energy trade which steers towards less climate impact one must identify driving forces for all concerned actors. In this work future policy implementation is not considered among the driving forces, but an attempt is made to systematically evaluate the economic driving forces under different business logics. The business logic defines or constrains how the actors operate, and steers towards the agreements.
Three different business logics were evaluated:

BAU- Business as Usual
A customer- supplier relation with an individual perspective to maximize revenues. The actors have individual ownership and complete control of their own assets.

JV- Joint Venture
A partnership relation with the shareholders shared perspective. The partners agree on a method for financial redistributions, liability distribution and risk-reward. Business value is valued through the Joint ventures' shareholders mutually shared perspective on return on investment.

COOP – Cooperative
A cooperative business logic is determined between actors in control of energy production, storage and end-use based on individual drivers for a common framework and cooperation This transactional structure is based on many small independent energy transactions between equal actors, who trade values, e.g. through automated processes. A defined set of rules provides the basis for cooperation, but the actors have individual ownership and complete control of their own assets.

Main Findings

A cash flow calculation was made to evaluate how the different business logics supported different cases. The results for the six most interesting cases are shown in Figure 5.

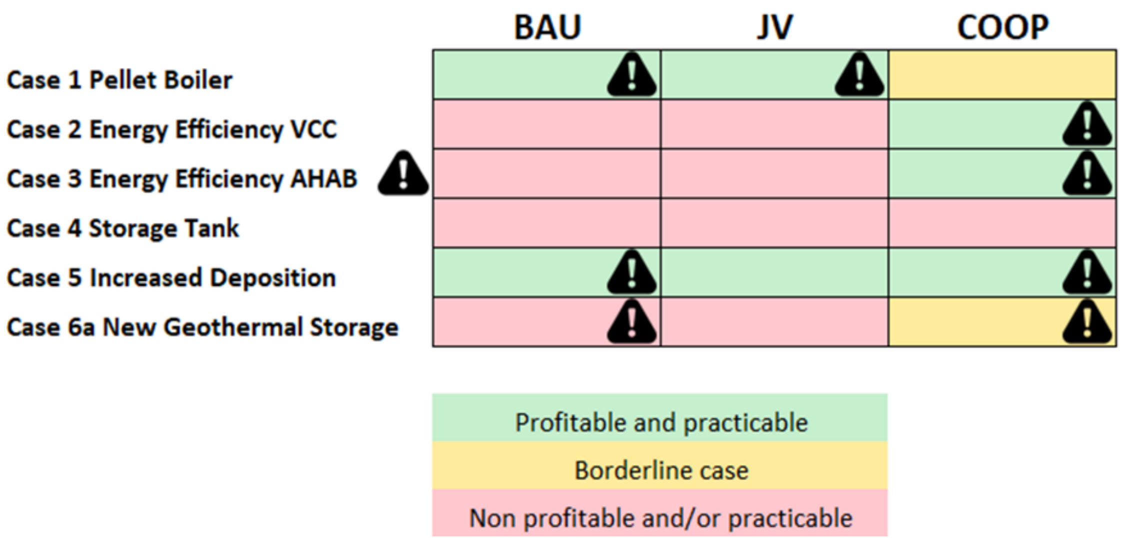

Figure 5. The results of the cashflow analysis of the six different cases under three business logics. The black triangles indicate that the case is profitable for two out of three actors.

The green color indicates that the combination of investment in the technological measures and the applied business logic can be profitable. The black triangles indicate that the case is profitable for two out of three actors. The cooperative business logic seems to have the largest potential to make the mitigation measures profitable (see Figure 5)

As a conclusion, the results indicated that:

- There are measures to implement in the university city area that would reduce CO_2 emission.
- Investment in these measures seems to have a larger potential to be profitable for more actors if a business model of the cooperative kind is used.

1.3 Introduction to Phase 2 Pilot Project

Västerbotten County Council (VCC) and the public utility Umeå Energi AB (UEAB) have taken RUGGEDISED to a Phase 2 of implementation and testing. The participation in the RUGGEDISED Project for these two actors is based on the aim for a future society where energy is used in a smarter way. A smart city has an energy efficient infrastructure where different actors can sell, store and exchange their electricity, heat and cooling. The interaction and cooperation should be maximized, with open data to connect buildings, energy system, transport systems and communication systems and to enhance smart steering.

From the RUGGEDISED part 1 solutions U1 and U3 it was shown that a cooperative business logic has the largest potential to make climate mitigation measures profitable for the actors in the University City area. A conclusion was that future work could test that kind of local energy cooperation in a limited and well-defined pilot project, examining the implications of a type of energy service being traded with a cooperative business logic. At the same time the actors could discuss common values to include in the business logic.

The part 2 Pilot project is based on the demand for cooling and the idea that participants in a cooling market more effectively can share their produced cooling and produce it where it is the most profitable, economically and environmentally. The pilot project has identified a desire for (VCC) and (UEAB) to find a system where they can sell and purchase cooling, together with a technical solution to perform a purchase order. So far there has been a one-way trade where UEAB sells to VCC when the VCCs own production does not cover the demand.

A system solution in the form of a marketplace would open the possibilities for VCC to also deliver surplus to the city´s cooling net. Such a solution could also contribute to an optimized use of all production units within the area and hence a reduction of greenhouse gas emissions. To test the realization of this possibility the pilot project was performed in order to both develop a model for a marketplace and to install a technical control system to test the actual transmission at a connection point.

The main idea is then summarized as that Västerbotten County Council (VCC) has the need of purchasing cooling, but the time of the purchase is less important. Umeå Energi would gain from steering the purchases to times when they are not close to peak production for any production units. At such times the production can also be expected to use less fossil fuels.
A marketplace could accommodate both these needs with the positive effects of:

- Times of reduced energy use and thereby reduced climate impact
- Production units using less fossil fuels
- Economically beneficial for both participants

1.4 Objectives of Pilot project

This report describes the pilot project that was the result of the two RUGGEDISED Smart city solutions U1 and U3. The objective is to build a **marketplace** for district cooling, where cooling can be purchased and exchanged between Västerbotten County Council (VCC) and the public utility Umeå Energi AB (UEAB). This will lead to increased knowledge about the usefulness of open marketplaces for energy trade and the climate effects that such a tool can achieve.

The specific goals for the marketplace were:

4. *The two actors should be able to put criteria to steer when to purchase and when to sell.*
5. *When both actors' criteria align the marketplace should be able to talk to the technical regulations, so that cooling flows in the desired direction.*
6. *The criteria for contract should be both based on price, time and environmental performance.*
7. *A receipt should be produced after each purchase, to show how much cooling was exchanged and to what price.*

An important goal was to implement a real working solution and test the transactions. The design of the interface and other details was of less importance than to show that trade according to specific criteria was possible.

2 DISTRICT COOLING SYSTEM

Umeå Energi (UEAB) is the energy provider for the entire city of Umeå and there is a well-developed district heating and cooling network. The production of district cooling mainly takes place absorption chillers and compressor chillers.

Today VCC has their own cooling network under the university hospital in Umeå. The capacity of the network is basically able to produce and distribute cooling to the entire hospital area. The cooling is mainly produced by cooling machines (compressor cooling) connected to geothermal energy. VCC sometimes need to purchase cooling during times when their own production is not sufficient. However, those occasions often occur at the same time as when UEAB also has problems producing enough cooling for Umeå city. Today this is regulated with an annually renewed agreement. There is three exchange points where VCC can add cooling loads from UEABs network. The VCC control system ensures that this happens when there is a demand.

However, the VCC cannot sell district cooling to UEAB, since the nets have different temperatures and if the cooling produced by VCC came into the UEAB net the temperature would increase and not suit the system configurations of UEABs clients anymore.

3 MARKETPLACE SET-UP

To set up an operational trading market several different functions are required, and they need to be able to communicate with each other. Figure 6 illustrates the functions that make up the type of marketplace implemented in the pilot project.

- The base for a cooling purchase is a contract. There must be instructions for how much cooling should be delivered and at what time. A contract for a purchase can look different and be made up of many different criteria put on the purchase, as to what price a participant wants to buy.
- When several different contract criteria can be put specified in different orders, a matcher with a matching engine is needed to keep track of the different orders and identify at what points the orders from buyer and seller match and a purchase should go through.
- A user interface lets the participants put the orders and specify the criteria.
- The matcher must communicate with the control system, so that the cooling trade physically can be carried out.

- As an overarching mechanism there should be a business agreement between the participants. They all need to agree to being part of the market, and the agreement should contain guidelines for what can be sold and purchased and what the different criteria means. If cooling of different environmental characteristics should be traded, all participants must have the same view of how the environmental classes available are defined.

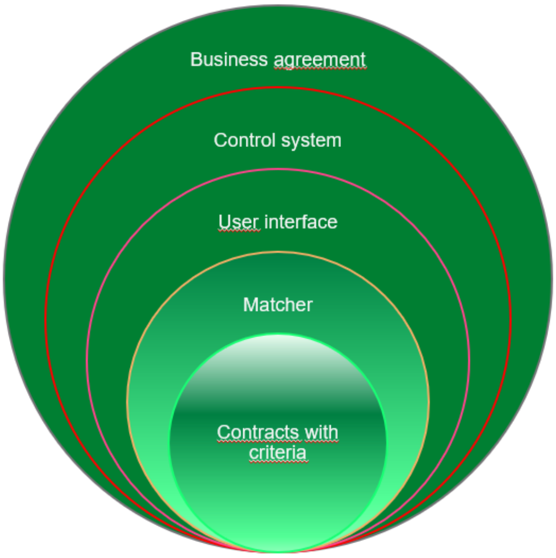

Figure 6. The components that make up the marketplace in the pilot project

4 MARKETPLACE COMPONENTS

4.1 Criteria for the contracts

The whole point with a marketplace is that the participants should be able to purchase and sell energy according to pre-defined criteria. The set of criteria needs to be predetermined and known to all participants and can at any time be expanded or decreased. In this pilot study the criteria tested were price, environmental classification, and time.

4.1.1 Base contract

Since cooling is essential in operating hospitals, VCC needs to ensure that there is always enough cooling, even if no orders with extra criteria match. In this pilot project, for the purpose of trying out the concept of cooling trade only one of the three cooling exchange points between VCC and UEAB is affected. The other two function as usual and they have the capacity to supply the hospital with the cooling needed. The purchased cooling in the pilot project is only supplementary. The way to solve this in a larger market in the future could be to develop base contracts for a certain amount of cooling. The basic operation is always prioritized, and then the manual orders come in and overrides the base contract when they match. That way the immediate need for cooling gets fulfilled even if the desired criteria does not match.

4.1.2 Environmental Criteria

Since cooling can be produced in different ways with different environmental effect, it can be important for a participant to steer what cooling is purchased. In the Greenhouce Gas Protocol Corporate Standard for accounting and reporting of CO_2 emissions, the purchased energy in Scope 2 can be accounted as marked-based or location based. Location based accounting is based on the mean emission factors in the region, for example the Nordic electricity mix in the Swedish grid. But it is also accepted to account for the marked-based emissions, based on the specific electricity contract with the utility. When using a marketplace like this the emissions of market-based cooling within the GHG protocol would be the emissions of the cooling purchased on the marketplace.

To keep track of the environmental performance of the purchased cooling, three environmental classes K1, K2 and K3 were defined in the pilot project, and the marketplace was set up for contracts with different environmental classification. The definition of the environmental classes is something that the participants on a market needs to agree on. However, today the utility Umeå Energi has no way to separate the physical delivery of a specific environmental classification and the classification of the pilot project was therefore just hypothetical. The suggestion from the pilot project was to focus on CO_2 emissions, and to define the environmental classes of cooling as:

K1 – Balanced energy (based on excess heat and free cooling)
K2 – Active cooling based on renewable energy
K3 – Active cooling with a higher proportion of fossil fuels

When an order is put the participant not only specifies the price condition under which the purchase can be made but also the environmental criteria. The idea is that the order will only go through if there is cooling from the desired environmental classification to be purchased. Defining quite broad environmental classes is to make it easier to understand and to find a match. If the environmental criteria are too complicated and the number of classes too large there might be very few, if any matches between what the purchasing participant indicates that he wants to buy and what there is to sell. But an order to sell cooling of class K1 can also be matched with purchase orders for K2 and K3 since it exceeds the environmental requirements for those classes. If the environmental classes are sold at the same price, K1 is chosen over K2 and K3.

4.1.3 Price Criteria

The selling participant can also set a price for the cooling, and the purchasing participant can accordingly set a maximum price for which it is willing to buy cooling. The prices can be defined for each environmental classification if, for instance, the purchasing participant is willing to pay a higher price for cooling from class K1 with lower climate impact than for K3. Table 2 shows an example of orders put in from a purchasing participant. A base contract specifies the maximum amount of cooling that can be purchased during a contract period of three hours (max/base contract). The purchasing participant then decides how much extra cooling could ideally be stored in the geothermal storage (max/total) and to what price they are willing to purchase from each environmental class.

Table 2. Example of orders with different amount of cooling wanted and different price and environmental critera

Max/total	Max/ base contract	Price K1	Price K2	Price K3
10 000	100	99,02 SEK	99,00 SEK	98,00 SEK
15 000	100	98,50 SEK	98,40 SEK	0 SEK
20 000	100	98,00 SEK	0 SEK	0 SEK

As can be seen from Table 2 the participant is willing to purchase the first 10 000 units for 99,02 SEK if K1 is delivered, for 99,00 SEK if it is K2, and 98 SEK for K3. The subsequent 5000 units are not purchased if only K3 is available since the geothermal storage does not need this cooling and environmental concern can hence be guiding.

4.1.4 Time Criteria

The desired (or accepted) price can also be specified for certain times. In the pilot project the time slots for orders are three hours. A shorter time would make everything have to start and stop very often which is not optimal since the cooling nets are quite slow. The timestamps containing information about the date and time are given in UTC," universal coordinated time", to avoid problems with contracts of different lengths when switching to and from daylight savings time.

4.2 Interface and agents

Since this marketplace is not fully automatic, it needs an interface where orders can be put in manually and the desired criteria can be specified. In the pilot project the orders are put in through an interface and Figure 7 shows what the interface looks like to the user. VCC can specify the maximum price for different environmental classes, how much cooling that can be purchased during a contract period and the total desired volume. The criteria entered in the screenshot in Figure 7 shows a desired purchase for a week where all contacts delivered during the week should not exceed 10 000 units and where no three-hour time slot can buy more than 100 units. This is to spread out the delivery during the week to make sure there is capacity to handle it and store it.

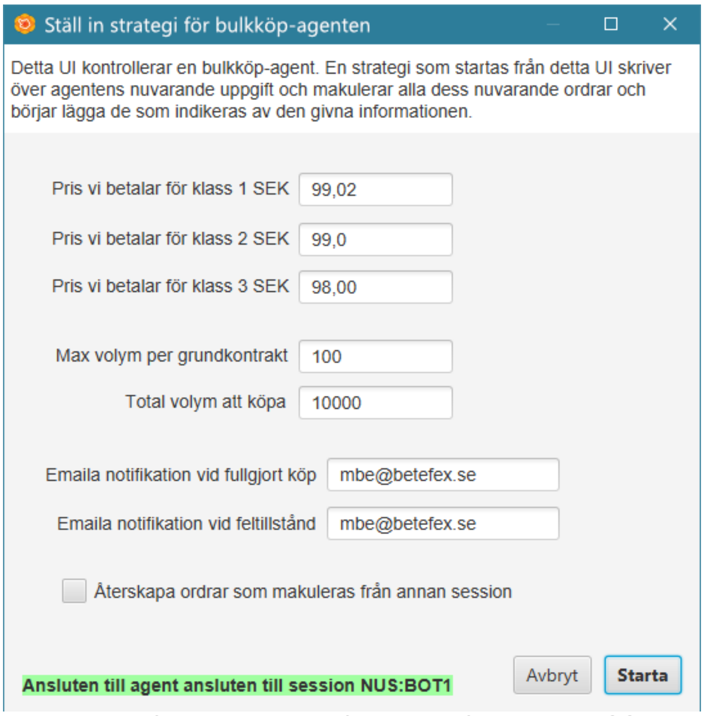

Figure 7. A screenshot of a proposed look for the interface where VCC put their orders.

However, the interface interacts with a software system, here called agent, that works in the marketplace in a somewhat automated way. The agents handle the orders to make the marketplace more automated although the participants are still in control over the orders. The agents get the information from the participants interfaces through several ID:s.

In the pilot project there are two participants and for the trade get have and ID each: Umeå Energi with ID UE, and Västerbotten County Council med ID NUS. Since each participant often wants several clients and/or agents they get Sub-IDs. This can be seen in Figure 8 with three Sub-IDs for UE: GUI1, GUI2 and BOT1 and two for VCC: GUI1 and BOT1. Sub-IDs belonging to the same participant can see and handle each other's orders but a client for UE cannot see an order for NUS.

Figure 8 also illustrates that the agent is on the border of the marketplace and not entirely integrated as it would have been if the market had been fully automated. The agent is not a part of the matcher, but a client to the matcher and cannot handle the orders without the participants involvement. The participant who needs cooling have the responsibility of conducting trade and to give input through an agent. The participant VLL owns the agent and is responsible for its operation and maintenance. However, intuitively the agents and interfaces can be thought of as a part of the marketplace since they are crucial for its successful operation.

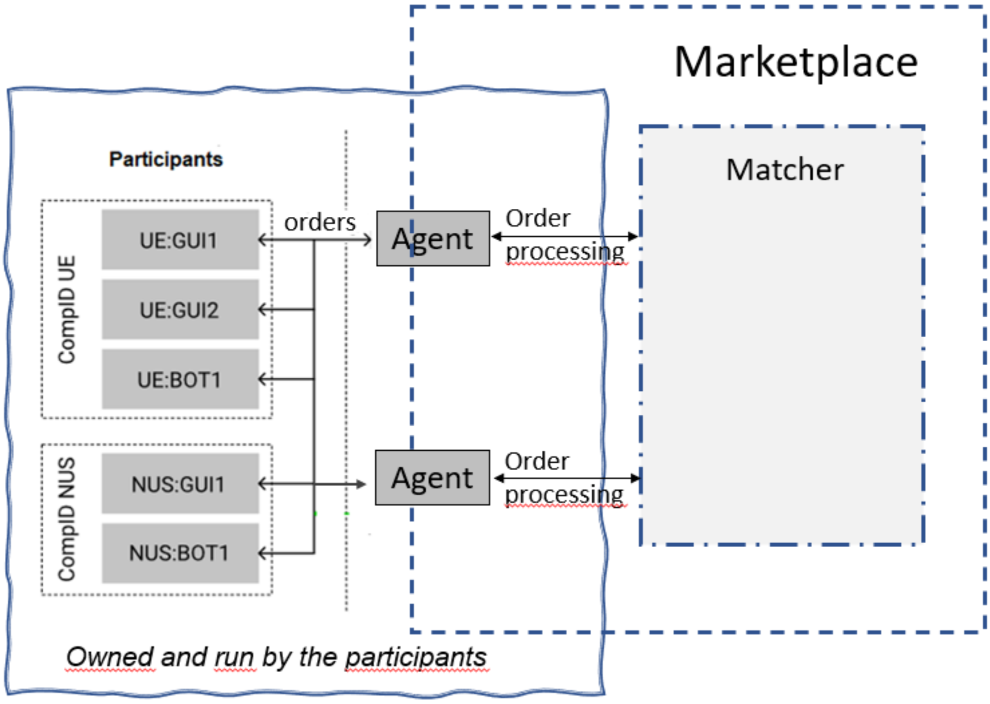

Figure 8. A schematic illustration of the function where the participants interface connects to the agent and the agent places orders with the matcher and keeps track of the trade.

When a person at VCC through the interface starts the process, the following chain of events take place:

1. The interface connects to the agent and specifies the new strategy
2. The agent cancels previous orders that it might be working on
3. The agent retrieves information on how much is already purchased through the previous contracts and of all combinations of base contracts and new contracts that can be ordered
4. For a specific contract the agent places an order to purchase X unites where X is small enough to not exceed max/base contract and where all specified orders together during the week will not exceed max/total (see Table 2).
5. When an order leads to a purchase the agent keeps track of the total volume transferred and can stop the client if max/total is reached.

In this pilot project only so-called limit-orders are used. When the agent places an order with a quantity and a maximum price the order goes through only if at least a part of that quantity can be supplied to the desired price or lower. The seller has then also received its minimum asking price.

4.3 Matching Engine standards

To be able to find time slots where all criteria match each other so that a purchase can go through, a matching engine is needed. The matching engine must handle information from all the participants and be able to identify orders with matching criteria and pass on the information that a purchase is possible. Such a function can be set up in different ways, and the project recognized the following functionality goals:

1 *The trading activity should be understandable by the participants with minimal specialized tooling, training, or support. This is key, as a system without visibility may hide any amount of risk and will struggle to achieve any significant buy-in by participants.*

2 *The pricing of cooling in the system should be transparently presented, making it clear what costs would be involved in any given trade. Allowing this information to over time drive suitable investments (for example sizing investment in storage by considering predictable price fluctuations).*

3 *The trading should be presented in such a way that it builds trust in the system and in the fellow participants, by making visible benefits to all parties.*

4 *The trading should differentiate between environmental classes of cooling, and through the visibility already discussed make the ecological impact of both individual participants and the overall market possible to analyze. This is important as taking the single-participant perspective in isolation risks simply moving the ecological impact around the system, creating a discounted situation for a single "black sheep" participant who takes on all the ecological impact, offsetting any apparent gains made.*

5 *Create a clear trustworthy entry-point for additional participants and infrastructure investments.*

Since the idea of sharing things in a marketplace is not entirely new, the project evaluated several alternatives for the design and presentation of the matching functionality previously implemented elsewhere.

4.3.1 Alternative 1: The null hypothesis of not doing a general market

As background the alternative of not including active trading at all was continuously considered. Specifically in the form of adding the physical connection and doing ad-hoc long-term contracts for their use. This would fulfill goals 1 and 3, in that it is extremely easy to understand, but would not in itself address goal 2 or 4 and would fully abandon goal 5.

4.3.2 Alternative 2: FED

The Fossil-free Energy District (FED) project of the City of Gothenburg was a research project in a similar vein to the pilot project described here, with an objective of more effective control and environmental benefits. It was however larger and involved the exchange of several types of energy across a large number of buildings at Chalmers university and explored intelligent steering and an automated marketplace.

The outcome of the project was a technical report documenting the decisions made and analyzing some problematic areas. Of specific interest here is the matching technology that acted very independently. It consisted of intelligent agents, operating autonomously as part of a common fabric of data sources and control systems, placing bids in a mostly invisible auction market to trade the energy the assets (buildings) represented. To enter the market the participants gave up the full control over their own systems.

Some key problems the report recognized was that:

- The matching functionality was fairly complex and not very transparent, causing significant issues. From the conclusions of the report:

  > *The complexity in market design can have negative effects on transparency and intuitive understanding of the market and the resulting prices, which can lead to a lower trust for the market clearing function and hence constitute a barrier to implementation.*

- Both the costs and the barriers of entry to the system became high. The complexity of the standardized intelligent agents required specific sensors, data sources and control systems. All of which require technical sophistication and substantial investment. For example:

  Measurement equipment and data collection have been a major issue and was identified as the main technical challenge in the project.

- The report draws the general conclusion that social acceptance is extremely important and requires simplicity and transparency.

As such the FED project was in many ways a model for this pilot project, goals 1-3 and 5 being phrased effectively in response to the problems that the FED project identified. This pilot project being smaller in scale avoided some of the complexity issues, but the goal of keeping the matching simple, and placing it as a central interface for all automatic systems as well as human operators was a direct result of the FED experiences.

4.3.3 Alternative 3: Full decentralization and blockchains

The blockchain technology is widely used for transactions and smart contracts and could seem like a good option for this pilot project. The role of a blockchain in a marketplace network can be described as a shared, immutable ledger that facilitates the process of recording transactions and tracking assets.

Blockchain provides immediate, shared and completely transparent information that can be accessed only by permissioned network members. A blockchain network can track orders, payments, accounts, production and much more. And because members share a single view of the truth, they can see all details of a transaction end to end, giving confidence to the process. However, the transactions are automatic, and blockchain is often used when the process needs to be fast. A set of rules, sometimes called smart contracts is stored on the blockchain and executed automatically. Blockchain-based decentralization has mostly been considered in the case of various types of “microgrids”, tiny energy networks loosely and/or opportunistically connected to a larger area grid. The advantage blockchain solutions offer is completely trustless communication and verification on the computer network level, with no participant needing trust any other as far as computational results and accounting are concerned.

For this pilot project however, this has no real benefit. Trust is a general goal of the project, necessary both to attract participation and investment, and ultimately needed to make headway on broad environmental goals. Even more immediately, however, the trustless nature cannot extend down to actual sensors and actuators, which necessarily exist outside a blockchain context (while they may be connected to a secure network some participant will own the devices themselves, and pipes must connect to other participants, requiring trust on the purely physical level). As such the decentralized approach was rejected, adding technical complexity without any added benefit.

4.3.4 Alternative 4: Financial exchanges

At the stock exchange an extensive trade is going on and there are solutions with a matching engine. The financial market also works with limit-orders, even though there are two fundamental execution options possible:

1. Place the order "at the market": **Market orders** are transactions meant to execute as quickly as possible at the current market price.
2. Place the order "at the limit": **Limit orders** set the maximum or minimum price at which you are willing to buy or sell.

For this pilot project a limit-order market was suitable for the purpose of the trade.

Another advantage of the financial market system over the FED is that the market is an independent component, and all the action is going on at the participant level. All participants still have control over their own operations and are responsible for how they act on the market. A similar marketplace could be constructed for energy where the marketplace exists as a place to share the infrastructure and resources and trade energy at different times and of different environmental classes in very specific orders. A matching engine could be used just to connect everyone and execute the collaboration.

4.4 Pilot project matcher

According to the findings described in section 4.3 the pilot project wanted to create a market structure with small, standardized contracts with simple controls on a central market. The project wanted to make the marketplace easy to understand and follow but also somewhat automated. The choice was therefore made to design the matching functionality as a primary abstraction layer; making it manually accessible with minimum training and intending automatic systems and agents to interact with this system in the same way a person would. This preserves this view of the market as the primary window through which a person can understand what is happening in the system and what can be achieved within the system both in the moment and in the future. The project created a matching engine that can handle limit-orders with specific criteria and match the time, price and environmental criteria. When a match is found a transaction is made and a purchase is executed for a three-hour time span

Besides the participants shown in Figure 8 there are two more IDs to the system: one for the matching engine itself (ID UEMATCHER) and one for the feed server (ID UEFEEDS). The matcher is hence made up of two components, as shown in Figure 9. The matching engine UEMATCHER makes the matching itself amongst all the orders, and the feed server UEFEEDS can communicate and send out information about the transactions. They are both based on APIs for retrieving data.

But when the matching is done and a trade opportunity is found, the matching engine is not concerned with the execution. It is the feed server that communicates with the control system and makes the execution happen. The control system connects to the feed server as a client and asks for data. The system is built to encrypt the data traffic to and from the matcher (UEFEEDS).

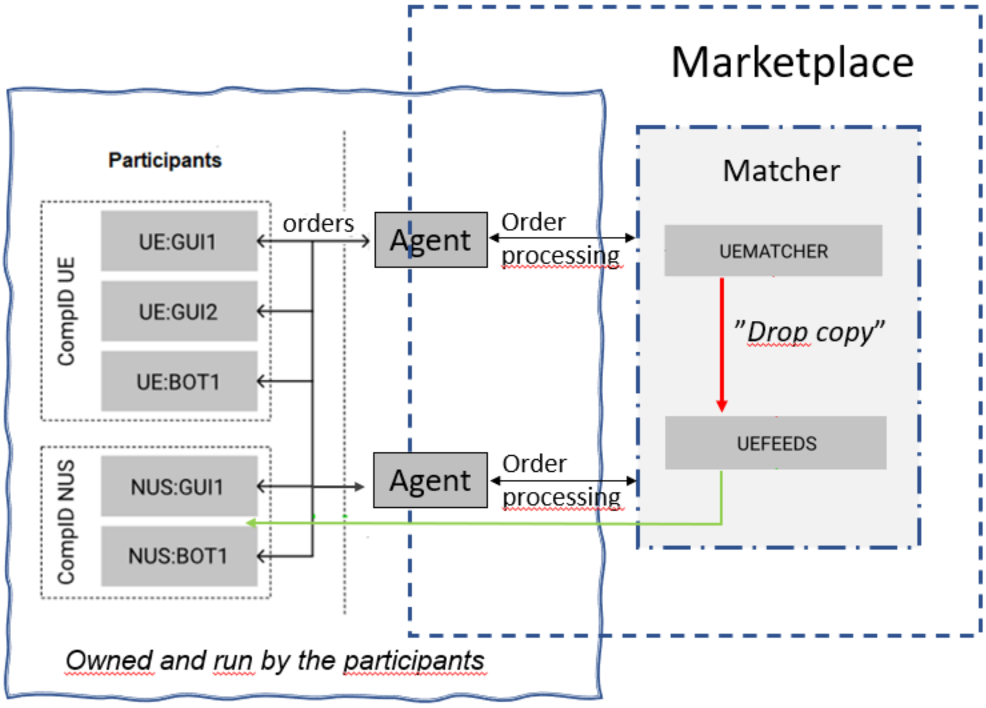

Figure 9. The matcher is made up of the matching engine UEMATCHER and the feed server UEFEEDS.

4.4.1 Sessions

A session is a group of activities that occurs during a certain period. One single session can include several activities, or as in the pilot project – transactions. In the pilot project, the Participant´s sessions towards UEMATCHER start at 00:05:00 Monday morning (UTC time) and ends 23:55:00 Sunday night. When the session ends, the matching engine erases all information about what happened in that session. Figure 10 illustrates two sessions with only two transactions in each.

UEFEEDS creates the market data flow based on the information from UEMATCHER, illustrated by the "drop copy"-flow in Figure 9. This session runs forever, and hence allows UEFEEDS to always recreate everything that has historically happened in the matcher, beyond the weekly limit.

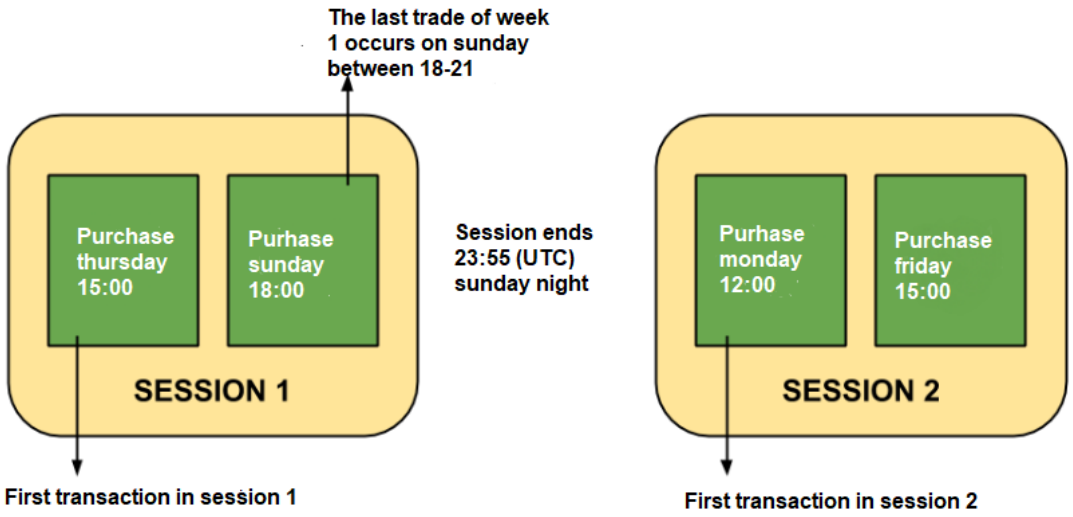

Figure 10. A session in the pilot project lasts a week and includes all the trade activities that occur during that week. Then a new session starts, erasing the information about last week's transactions in the old session.

4.5 Control system

Even though the matching engine can identify when an energy purchase can occur, it cannot execute it. A cooling system is a physical system of pipes and pumps and valves, and these need to be informed how they should steer the cooling flow.

4.5.1 Steering the cooling system

Figure 11 shows a flowchart of how the district cooling is transferred from Umeå Energi to the VCC cooling net, called NUS KB100. This process is controlled by a Siemens regulation control device (PLC), which execution logic depends on input signals. When VCC wants to purchase cooling, a valve is opened at Umeå Energi and the cooling is transferred through a heat exchanger. Umeå Energi has a pump on its side that is set to maintain a certain pressure. It is a power regulated system where the Siemens steering device wants to know what instantaneous effect should be transferred, how many kWh of cooling energy should be delivered and what time the transfer should start and stop. The cooling transfer is run until the desired energy delivery is achieved or the agreed three-hour period has elapsed. The energy delivered every 15th second is registered and by accumulation, the total delivered amount of kWh is known. When the ordered amount is approaching the valve closes to throttle the flow. The pump slows down, and less power is transferred, so that only a small amount of cooling is delivered until the limit is reached and the right amount has been transferred across the heat exchanger which is the connection point.

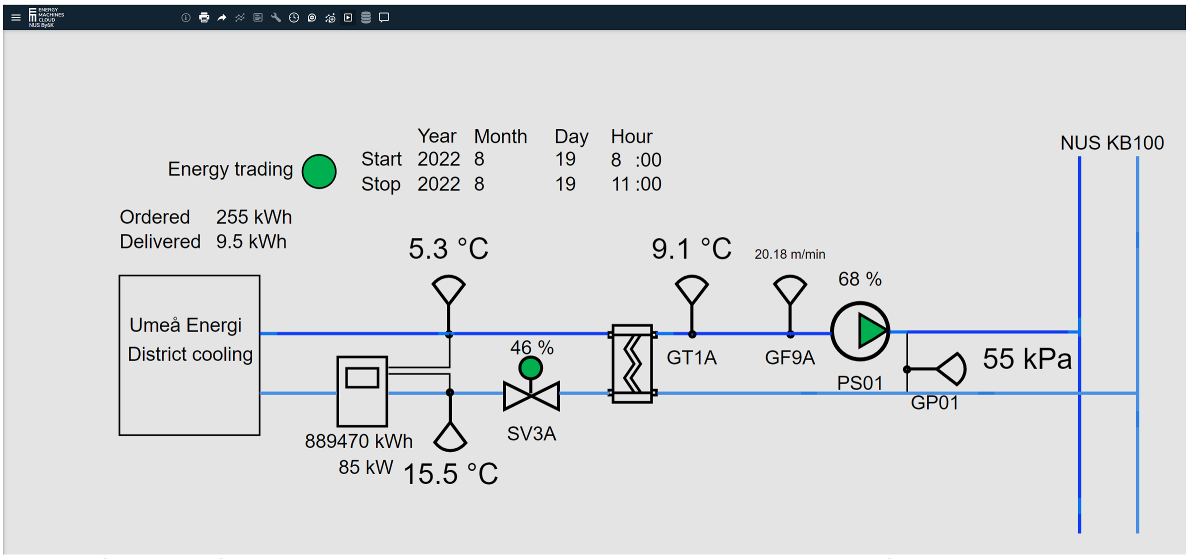

Figure 11. A. flowchart of the physical district cooling network where the cooling is transferred through a heat exchanger.

4.5.2 Siemens PLC

The cooling network owned by VCC is controlled by programmable logic controllers (PLCs) in the Siemens steering devices. A PLC function as a special purpose computer used where high reliability without advanced programming is needed. It continuously monitors an input, and then makes decisions based upon a custom program to control the state of the output devices. Each PLC in the VCCs buildings is programmed to run the HVAC system according to system specifications relevant to the energy system in the building.

For the energy market to work, the PLCs of the cooling system needed to be reprogrammed and adapted to understand what to do to execute an order. This was done by an engineer contracted by VCC who programmed the PLC logic to receive an order with variables and deliver information on what physically happened. When the PLC can react to external communication it can be a part of the energy purchase because it makes the pump and valve regulate to let the right amount of energy be transferred. Increased pump speed and an open valve lets more cooling be delivered.

4.5.3 Protocol adapter

In the hospital buildings owned by VCC, the installed Siemens PLCs can communicate with external devices using the BACnet protocol. BACnet™ (Building Automation and Control Network) is an open data communications protocol that is designed to handle many types of building controls, including HVAC, lighting, security, fire, access control, maintenance, waste management, etc. BACnet has an object-oriented nomenclature and defines a standard set of "*Objects*", each of which has a standard set of "*Properties*"; that describes the object and its status to other devices on the BACnet internetwork. But here, the output from the matching engine comes as a FIX-protocol. Since the PLC responsible for cooling exchange logic communicates with BACnet it cannot understand the output from the FIX-based matching engine.

To remedy this problem Energy Machines were involved. Energy Machines is a company that works with the design, implementation, and operation of integrated energy systems for buildings. By combining proven best-of-breed technologies with purpose-built digital platforms, Energy Machines enables buildings to operate as fully integrated systems that outperform traditional alternatives on operating cost, energy usage, and carbon emissions. At the VCC Hospital of Umeå, Energy Machines have today delivered six energy systems acting as producers of heating, cooling, domestic hot water, and air conditioning. The Energy Machines Cloud platform is deployed, monitoring these systems and other producers, allowing engineers to analyze gathered energy data efficiently remotely using encrypted data traffic.

Therefore, Energy Machines were involved in this pilot project sprint 3 phase to translate the protocols from the matching engine to something the responsible PLC could understand. The Energy Machines Cloud could already handle the BACnet protocol, but not the FIX protocol. The solution was to build a separate part of the protocol adapter that could translate the FIX messages to MQTT messages to be converted to values written to BACnet objects.

MQTT is a commonly used messaging protocol for the Internet of Things (IoT). MQTT stands for Message Queuing Telemetry Transport. The protocol is a set of rules that defines how IoT devices can publish and subscribe to data over the Internet. MQTT is used for messaging and data exchange between IoT and industrial IoT (IIoT) devices, such as embedded devices, sensors, industrial PLCs, etc.
Figure 12 illustrates the situation where EM cloud already could serve as a protocol adapter translating MQTT to BACnet and where the protocol adapter was expanded within this pilot project to translate FIX to MQTT.

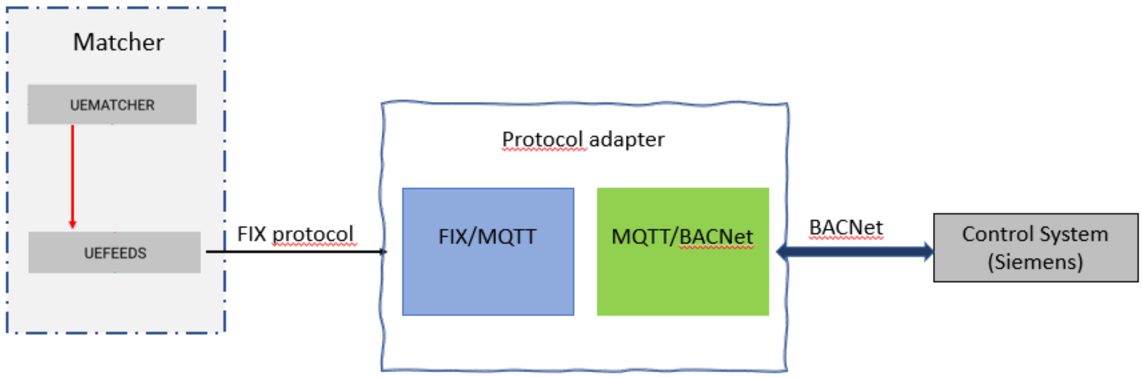

Figure 12. The protocol adapter within EM Cloud was expanded to translate FIX to MQTT in addition to the existing MQTT/BACnet translating.

The protocol adapter is a part of the FIX engine called EMFEED. Figure 13 shows the marketplace, now with all components included. The protocol adapter constantly checks with UEFEEDS on one side to see if there is a FIX message to react to. The protocol adapter then combines all orders within the same three-hour period to be forwarded to the Siemens PLC and written to the agreed BACnet object value.

The marketplace can then finally be summarized by the 4 different sections shown in Figure 13; the interface is not technically a part of the marketplace, see section 4.2:

1. The matching engine UEMATCHER handles public trade and decides when orders match
2. UEFEEDS is the part of the matcher with the information flows. The other components connect here to get information about the trade.
3. EMFEED interacts with UEFEEDS to pass on information to the control system through the protocol adapter and makes a simple clearing report over what really happened.
4. Integration with Siemens control PLCs to make things happen

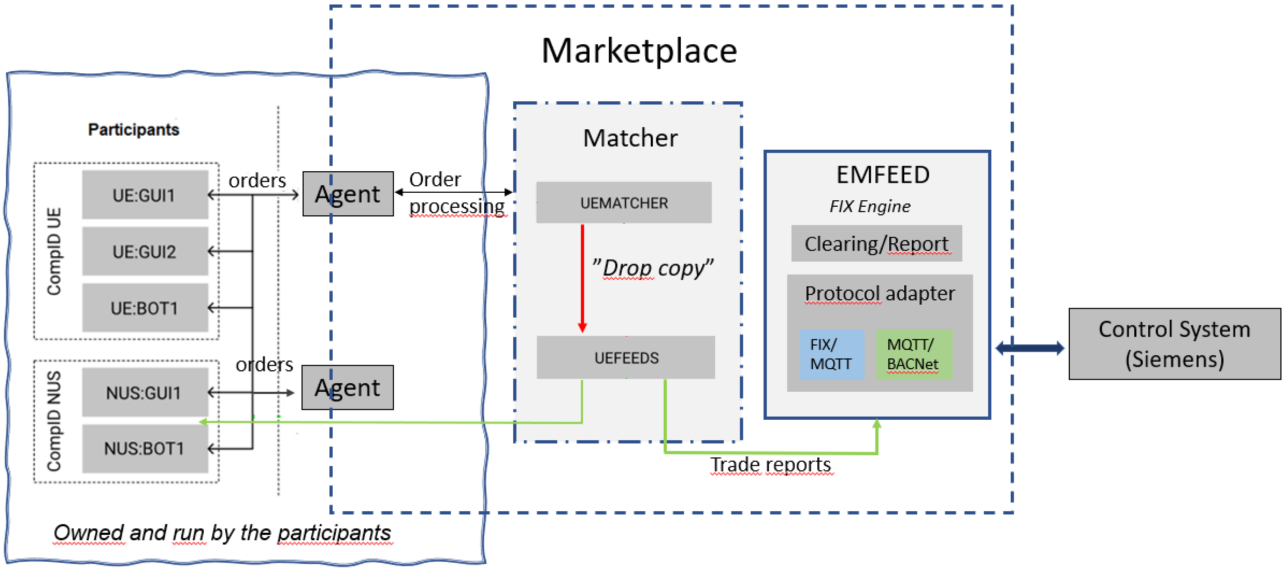

Figure 13. A schematic picture of the entire market place, getting orders from the participants, and their agents and communicating with the control system to execute the trade.

4.6 Receipts

When trade in the market has been performed and cooling has been delivered it must be registered and invoiced. It is the EMFEED that communicates with the control system and makes the execution happen. It is also the EMFEED server that can send out information about the transactions. In the pilot project the functionality that has been tested is that the cooling that has been delivered (amount and at what time) is logged and information saved to a database. EMFEED compiles the information, and this could in the future be sent out as confirmation orders by e-mail. It would also be possible to ask UEFEEDS for reports and larger compilations.

5 Combination contracts

The design of the energy market opted for very simple basic contracts, with standardized units of energy, time, and a limited number of environmental classes. This makes the market easy to understand and inspect, but more sophisticated trading can also be built on this base. This is achieved by combination contracts, which are virtual contracts that combine simultaneous trading in various other contracts. Note that this means that when it comes to delivery only the result matters and one contract at a time is executed. Still, during trading more complex strategies can be created using combination contracts. Combination contracts are generated in three ways in the pilot market.

5.1 Bundles: representing longer time spans

For some participants the three-hour trading time slots may be too short to be useful. For this purpose, the system contains both day-long contracts and week-long contracts. These represent getting cooling delivered evenly across a full day (eight separate three-hour contracts) or week (56 separate three-hour contracts). These can be freely traded in but are just virtual combinations. In the reporting and delivery on the market they are broken down into their three-hour constituent contracts. See Figure 14 for the contracts displayed in the trading client.

5.2 K0: extra-compensated energy

The participants can put climate criteria on the cooling in the manual orders (Section 4.1.2) and K1 is the most fossil free environmental class. K1 can be explicitly specified in a manual order or delivered within an order with lower demands. However, the market also offers virtual K0 contracts, which represent buying a single cooling unit, but with a further environmental offset achieved. This is done by combining buying *two* of the corresponding

K1 contracts and selling *one* corresponding K2 contract. Then only one unit of K1 energy is delivered. Still, in addition to that delivery, the trade causes some participants looking to buy K2 energy to get delivered K1 energy instead, with the combination purchaser paying the price difference. This can then be seen as a climate offset, making K0 as much better than K1 as K1 is better than K2. A participant may want K0 to maintain a policy of fully compensated energy, to offset other energy use (e.g., pumps running) or having bought K2 at another time.

Figure 14: The view of ecological derivatives in the trading client, the 12:00 contract selected represents buying extra K1 and reselling as K2 to get additional ecological offset on the delivered cooling.

5.3 Spreads: pricing storage

The market also contains spreads, combinations that buy a unit of energy in one timeslot and sells one unit in another timeslot. These can serve several purposes:

- Moving the time of delivered energy. For example, if VCC has bought 500 kWh of energy for delivery 09:00-12:00 on Monday, but circumstances have changed, and it now needs to be delivered 06:00-09:00. Then rather than first selling and then rebuying the energy (which risks losing out on it) VCC may purchase a spread which *simultaneously* sells in the 09:00 contract and buys in the 06:00 contract.

- Getting paid for storage capacity, and hence driving investment in the storage. A participant with storage facilities may not want to get a net surplus of energy, so rather than buying and selling energy directly they can buy the spread representing getting energy delivered a certain time and then themselves delivering it at another time. The price of spreads then directly represents the *value* of storage and can be used to invest in suitable infrastructure. Such a spread contract view is illustrated in Figure 15.

Figure 15: The spread contracts view in the trading client. The selected contract in the last row corresponds to buying cooling Saturday (when it likely is cheap since it is the weekend) and selling cooling on Monday. The price of the contract will reflect the value of providing two days of energy storage.

6 IMPLEMENTATION

The work with the pilot project has been ongoing during two years with varying intensity during three sprints, as shown in Figure 16. The pilot project was also discussed already within the frame of RUGGEDISED Part 1, which means that the participants were aware of the idea and possible solutions. The participants had also signed a letter of intent to take the RUGGEDISED results further, for example in a pilot project like this.

Sprint 1 - 2020

During the second part of 2020 the work started with an analysis of future market needs through business intelligence. It was important to discuss and choose the technical platform for realizing the idea so that the posterity sprints had the basic conditions established. The project also tried to learn from previous experiences with other actors and organisations and thereby obtaining an inventory of different trade market solutions and their benefits and drawbacks. Hence, the main activities in sprint 1 were:

- External analysis
- Analyze future market needs
- Choose technical platform
- Inventory of trade market and matcher solutions

Sprint 2 - 2021

Sprint 2 focused on the detailed requirements for the marketplace. It was important to decide how the marketplace should interact with the control system and what was possible due to limitations in the HVAC and control system. It was discussed how the interface should work and what contract scenarios and criteria that the marketplace and the matching engine were supposed to handle. All the desired functions were documented and were the basis for the matching engine requirements. Throughout the development, it must also be ensured that the pilot project is aligned with other projects and initiatives in the participant organizations.
Hence, the main activities in sprint 2 were:

- Requirement specification of all parts of the matcher and interface
- Iterative development
- Inventory of dependencies to other energy projects
- Communication about the project
- Plan of implementation and testing

Sprint 3 - 2022

The final sprint within the project included the programming, testing and documentation. The different parts of the matcher and matching engine were programmed, the control system was adapted, and it was tested that the different steps could be executed correctly and that the different parts of the market could communicate.

Hence, the main activities in sprint 3 were:

- Programming
- Implementation into existing infrastructure
- Commissioning of the matching engine
- Testing and verification of all functions
- Documentation in the form of a project report

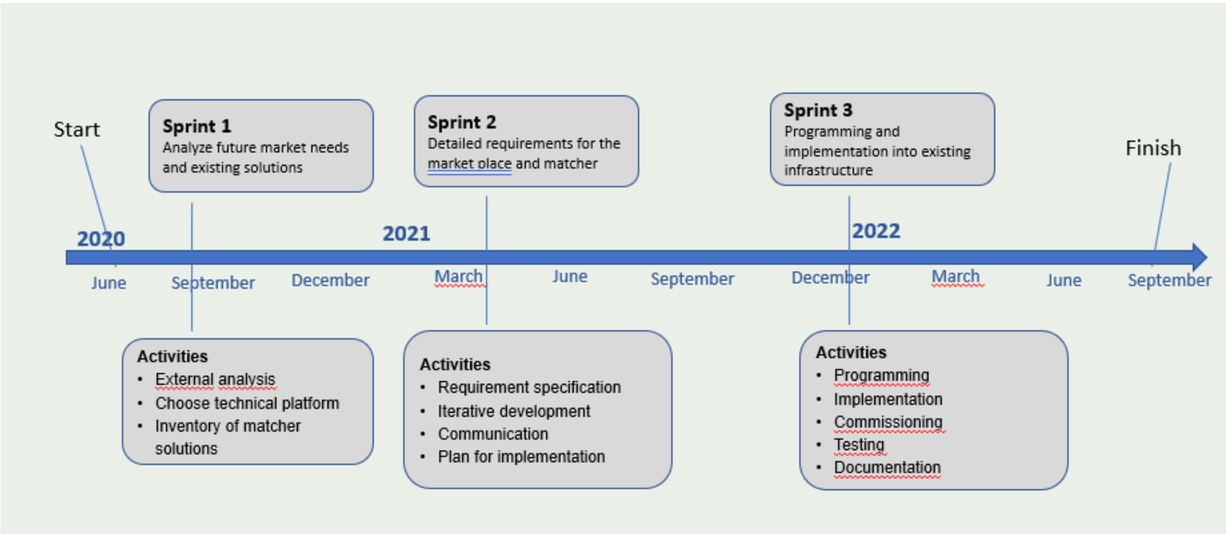

Figure 16: The time plan for the pilot project and the main activities for the three sprints

7 RESULTS

This pilot project covers the programming of a cooling trade market, and the result is the delivery of an ordered amount of cooling. The trade has been tested, with orders put, matches found, contracts in place with cooling delivered and a trading report saved in database. Hence, the entire event chain went through and worked as planned. Different contracts are tested, being generated as combinations, and the system correctly delivered in the contracts resulting from any combination trading.

Figure 17 shows an overview of what orders the participant has put and Figure 18 show an overview of what has been delivered.

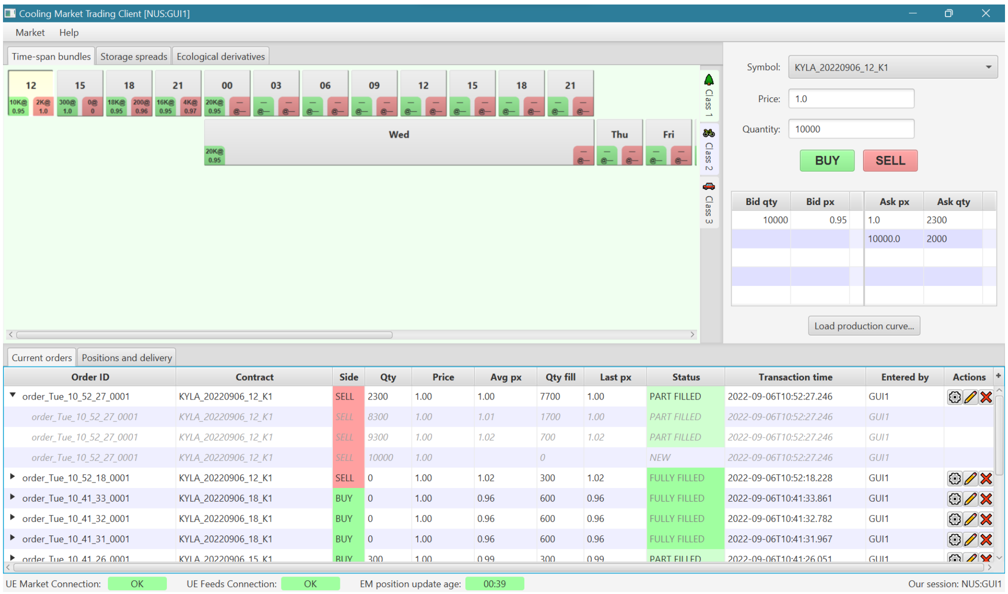

Figure 17: View of the status for orders put by the purchasing participant

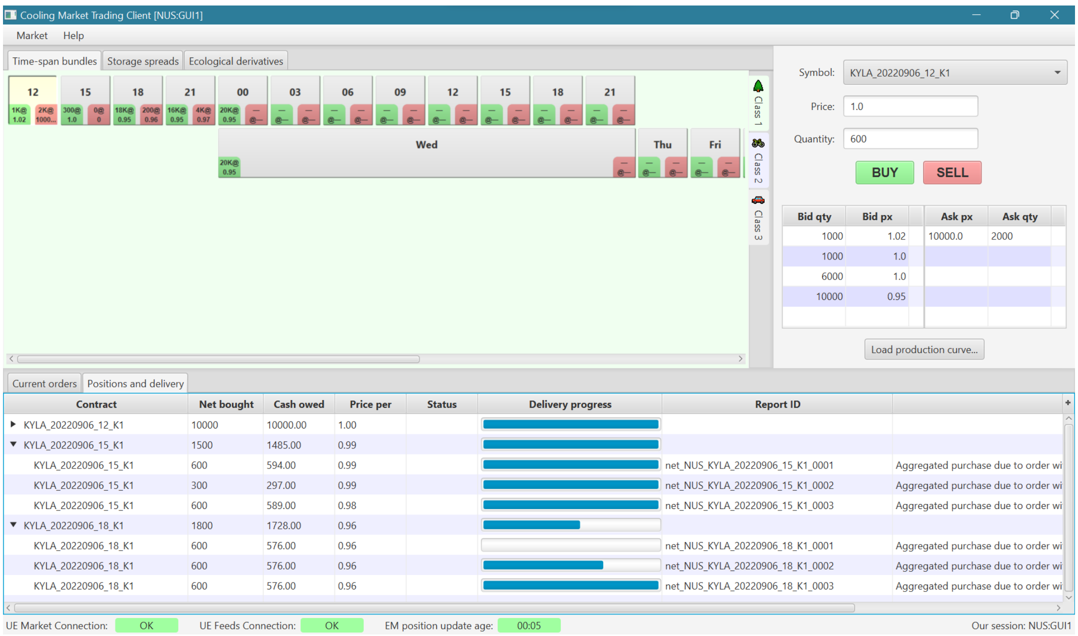

Figure 18: View of the status of delivered contracts

To show the physical mechanisms involved in the delivery on the market, pictures are taken of key components of the system, which are seen in Figure 19 to 22.

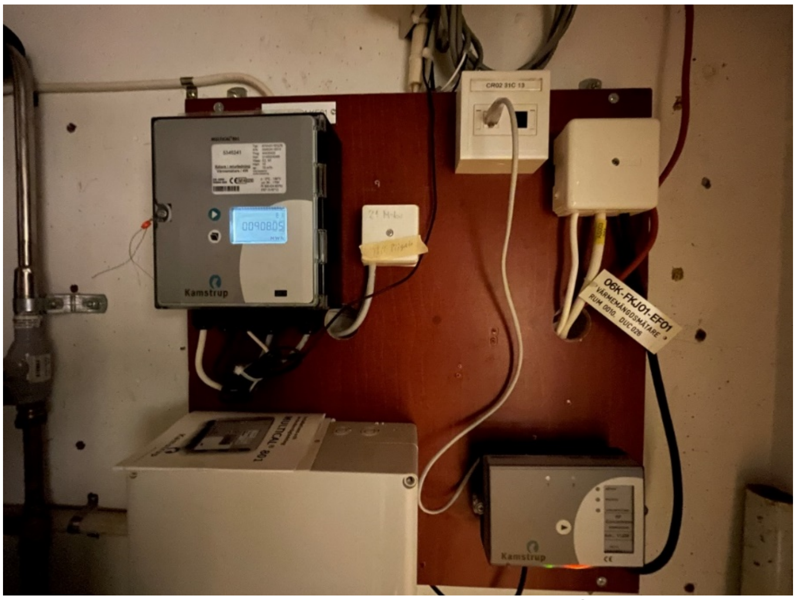

Figure 19: The energy meter that registers the amount of cooling being traded.

Figure 20: The connection point between the VCC cooling grid and the UEAB cooling grid.

Figure 21: The control system that steers the energy transfer point between the grids and the collection of energy and power data from the energy meter.

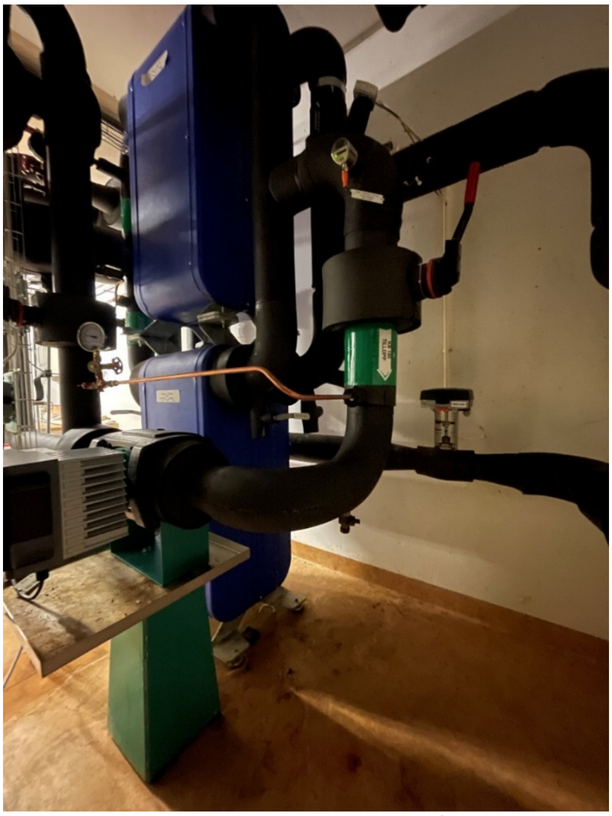

Figure 22: The valve that regulates the cooling transfer can be seen to the right.

The receipt of transferred cooling is saved to a database. The information in the database from a purchase is shown in Figure 23. This information can be extracted in different ways to create confirmation e-mails or larger reports showing trade for a week, month, or year etc.


```
<Contract>
	<ID>KYLA_20220819_06_K1</ID>
	<Actions>
		<action>
			<amountToRealize>50</amountToRealize>
			<amountRealized>50</amountRealized>
			<pricePerUnit>1,0</pricePerUnit>
			<priceForUnitsRealized>50,0</priceForUnitsRealized>
			<transferStatus>Amount Realized</transferStatus>
			<FIXMessage>Acting as liquidity provider for order</FIXMessage>
		</action>
		<action>
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Figure 23: The logged information about the delivered cooling from one trade contract

8 FURTHER WORK

Even though the marketplace fulfills the requirements set out in the goals for the project (section 1.3) it does so in a basic way, and there are several improvements that could be implemented for the marketplace to work more smoothly or in a larger scale.

Two-way market
To extend the trade to a real market where all participants can both buy and sell cooling the physical properties in the infrastructure need to change. Today the VCC has a temperature range in their cooling grid of 9-19 °C. The UEAB net is cooler with temperatures between 6-16 °C. The more cooling UEAB purchases from VCC the warmer their cooling would be, and problems would arise with their customers who has designed their facilities according to incoming cooling of 6 °C. Figure 23 shows both the current conditions and an alternative set-up with a cooling machine on the VCC side to cool from 9 to 6 degrees and hence achieve the right temperature to be able to sell cooling to UEAB.

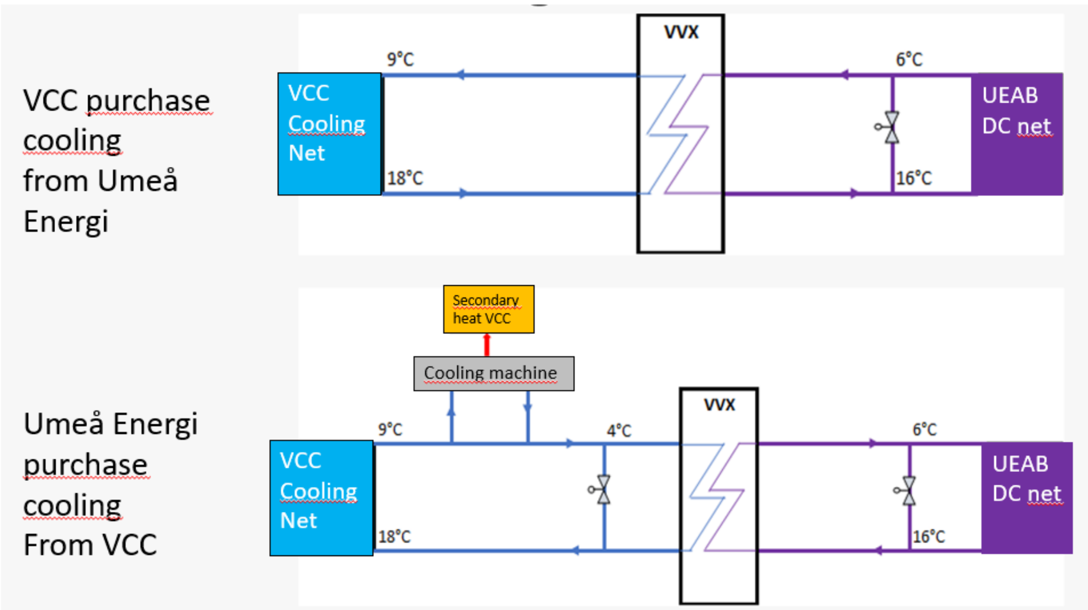

Figure 23: The top picture shows the current infrastructure, where VCC can purchase cooling from UEAB. The bottom picture shows a set up with a cooling machine on the VCC side to achieve the right temperature to be able to sell cooling to UEAB.

Several participants
The development of trade systems like this is of course that more participants can be connected to purchase and sell. One option for a larger market could be that each participant signs up to be able to trade with some of the others, but maybe not all, and that everyone in the market can see who can trade with each other. For this to work, the marketplace needs to work with more languages and protocols and be able to handle the web of participants and the business case for them.
If the Siemens control system had been able to communicate through FIX protocol, the two-step translation between FIX/MQTT/BACnet would not have been necessary. A larger and more advanced system should be built from the start so that fewer translation steps are needed, and hence less risk that something goes wrong in one of the steps.

Besides more participants, the market can also be expanded to other types of energy and not just cooling. District heating would be desirable to work with and could probably make a good business case since the heating demand is large with several participants in the area, for example Akademiska hus AB, who manages the university buildings.

Automated forecast-driven market
In the pilot project, all orders are put manually, where a physical person puts an order for a specific time slot and chooses the criteria that will apply for the order. It would be interesting if the participants in the future could trade for longer periods and more automated. If a participant knows from experience that the cooling need is large in June they could purchase in advance and store the cooling. A more automated trade could also monitor price and environmental criteria and purchase when it is favorable and store the cooling.

To take the automation even further, an agent connected to a weather forecast could steer the orders depending on the weather and hence the projected cooling need. This has great potential since energy use is correlated with temperature. In hot weather the demand for cooling increase and during cold periods more heat is needed. With more correct prognoses of the cooling demand, the momentaneous power output could be reduced to the benefit of all participants. This would give a more refined strategy for putting orders, than the rough estimates of the need that exists today. The VCC has ongoing development work together with Energy machines, to get better prognoses for the capacity of the geothermal storage. In the future the development work could also include testing weather forecast software.

Invoice and reporting
A part of the pilot project that was not prioritized was the solutions for invoicing and trade reports. The trade is recorded, and a delivery report is saved in a database, but this could be developed to something much more advanced. The database could be developed with records of contracts and deliveries and the difference between them, for example by combination contracts. Besides the technical aspects, the business case can be developed so that all participants are part of a framework agreement for the trade which is monitored by a responsible party that manages and maintains the trading system.

9 IMPACT AND COST ASSESSMENT

Simulations from the RUGGEDISED solutions U1 and U3 show a potential for climate mitigation from implementing some technical measures (cases) based on the strategy of sharing energy between actors in the University City.

The marketplace described in this report can provide the platform to realize this potential. The 2016 emission baseline that was calculated for the RUGGEDISED phase 1 (U1 and U3) report showed greenhouse gas emissions of 1634 ton CO_2 per year. Depending on the level of ambition and the amount of financial resources invested, that baseline emission can be reduced to different levels.

- **Optimized use.** By optimized use of the heating and cooling grids, to steer the usage hour by hour towards the most low-fossil production units, the CO_2 emission could decrease by 15% compared to the baseline. The marketplace enables the optimization. But physical expansions are needed to reduce bottle necks etc.

- **Cost**: Roughly calculated, the development of the marketplace, implementation and physical installations can be estimated to 3 – 15 MSEK.
    a) 3-5 MSEK for developing the marketplace, connecting to the energy exchange points in the buildings, market agents connected to the weather forecast, an expansion to include more types of energy than cooling and to be compatible with more control systems.

    b) 10-12 MSEK – Physical expansion and installations to the i nets to enable the optimization of energy use.

-

- **Fossil free boiler**. Jointly build a boiler run of renewable fuels that can deliver to all participants when needed. This gives a 37% CO_2 emission reduction compared to the baseline. The boiler could be run by the marketplace

- **Cost**: 25 MSEK.

- **Hot water storage tank** – A jointly built hot water storage tank connected to all participants by the marketplace. This gives a 10% CO_2 emission reduction compared to the baseline.
  Cost: 100 MSEK.

There are even more cases with a potential for large CO_2 mitigations, and the marketplace is the common denominator for implementation.