Delivery 8.3
Demonstrations in Horsens

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Abstract

On Bornholm, flexibility in electricity consumption has been demonstrated on hundreds of heat panels and heat pumps installed in residential houses.
During the last two heating seasons a part of this demonstration has been replicated on heat pump installations in buildings owned by Horsens Municipality (plus one in Vejle, and one in Skanderborg). The purpose of the replication is to demonstrate flexible electricity consumption in a different setting, and secondary it is an exercise in the transfer of the tools developed for demonstration of flexibility in residential houses on Bornholm to another infrastructure and hardware environment in Horsens.

Differences between Bornholm and Horsens setups

The key differences in the demonstration setup:

- There are very few installations (15 in total) and the heat pumps have a higher capacity with an electric power between 6 and 15 kW. Each location has from 1 to 4 heat pumps.
- The buildings are much bigger and have different usage patterns during a day from a regular household.
- The customer is a municipality that runs several institutions like schools, elder care homes and kindergartens. The end users of the heat constitute other categories than the private house owners on Bornholm.
- Measurement values of power consumption are only for heating purposes vs on Bornholm, where the measurements are for the entire household.

Physical setup

Installations

Test Sites in Horsens Demonstrations

The test sites in the Horsens Demonstrations are equipped with 1 to 4 large “Air to Water- source” heat pumps of different brands and sizes. Stiebel Eltron, Wamak and Vølund heat pumps in a cascade setup from 5,5 kW to 58 kW installed electrical power. The total theoretical installed electrical power across all installations is 389kW.

The Horsens sites, in majority, runs as hybrid setups, where either an oil or gas furnace is activated if the reference buffer tank temperature gets below the desired setpoint. One installation only has a single heat pump as heating source. All the heat pumps are owned and operated by Best Green, a daughter company of Insero.

Best Green has a general installation setup where a specific heat pump is selected as “master heat pump”. Only the master HP produces hot water and must run at all times. The other heat pumps produce only room heating and can be completely turned off in periods with a reduced need for room heating, as they each cover an equal share of the peak heating demand

At most of the sites, special power limiter solutions are installed to prevent the heat pump installations power-draw to exceed the site´s available power limit.

On the control side Best Green uses different gateways from LIAB (Linux in a box) allowing 2-way communication and surveillance of the installation. This secures the ability to see the overall performance of the installation by means of energy consumption and production, temperature, pressure, operation status etc. In relation to EcoGrid, the aggregator communicates directly to the LIABs using the XMPP-protocol.

As an extra comfort security measure, room temperatures are being monitored in selected rooms using IC-meters.

Challenges with master HPs and hot water

The group of test site buildings includes Eldercare facilities, Sport facilities, Schools, Kinder gardens and office/administration buildings. In common they all have Best Green heat pump installations. The different building categories have different types of challenges when offering flexibility to the market.

For an example it is not acceptable for an Eldercare facility to be without hot water supply during almost any time of day or night. At sport facilities there is a need for hot water supply from early mornings to late evenings both on weekdays and in the weekends. A school on the other hand, has a large internal heat production from many pupils and teachers.

This combined with the building thermal inertia makes it possible to cut off heat production for longer periods without affecting the indoor climate.
The hot water is stored in a tank after being heated to allow a buffer to the consumption. Unfortunately, it is not possible to measure the temperature in these tanks. If possible, this could allow for using the master heat pumps to a larger extend.
If the master heat pump is a part of a flexibility pool of installations, this will potentially generate problems that are not acceptable for the building owners. Thus, master heat pumps were only included in testing when there was no risk of compromising demand for hot water. In addition to that the building janitors and the building administration can call and opt out of the tests if there is a special reason or alternative activity in their buildings.
The municipality of Horsens represented by Charlotte Høitbjerg Davidsen, has agreed to let EcoGrid use their buildings as test facilities, if it doesn't affect the indoor climate. Resilience House in Vejle represented by Dorte Bramsen and Hylke Skole in the municipality of Skanderborg represented by Jette Hedelund, are both participating on the same terms.

Aggregator

Functional description of the aggregator

The overall idea behind the aggregation principle is a pool approach, focusing on the overall operation of a portfolio of heat pumps, which is optimized as a whole, rather than focusing on optimizing the operation of the individual heat pump. The aggregator can be described as a pool controller, where it is the entire pool of heat pumps that contribute to the portfolio´s delivery.
Based on the historical electrical power measurements of the connected heat pumps, the portfolio´s total power reference (aka baseline) and flexibility is estimated. Simple constraints are considered in the building, such as room temperature, permitted temperature fluctuations and prioritization of hot water heating. The aggregator operates on the total summed pool of heat pumps and learns the power characteristics of the pool with this specific composition of heat pumps. It does not consider details about what is going on in the individual buildings.
It is the amount of flexibility from the pool that is bid into the electricity market.
During the operating day (intra-day), the portfolio controller determines which heat pumps are to be started and stopped and activates them to achieve the desired response. Here the aggregator benefits from having measurement data for the electrical consumption from the heat pumps alone, not the entire building. This means that the aggregator can control the heat pumps in a closed loop and actively start/stop heat pumps at runtime to ensure the desired flexibility is delivered. As long as there are available heat pumps, not constrained by run/rest times or comfort levels.
The aggregator is not considering whether it is economically optimal for the individual installation to run at a specific time, but that the pool as a whole delivers the agreed behavior. When the pool controller is running, it monitors the power consumption of all the individual installations. If there are deviations from the agreed flexibility, the controller determines whether to start or stop additional heat pumps and which heat pumps, based on knowledge about which heat pump is most suited to start or stop, in respect to run/rest times. Heat pumps are best suited for longer activations/deactivations to perform at their best. Because of this, the heat pumps are run for a minimum of 30 minutes before stopping. Similarly, they are stopped for at least 30 minutes before re-starting. Too many starts will wear down the equipment too quickly and result in a low overall performance.

Aggregator setup

The demonstration setup in Horsens acts as a third aggregator that trades on the market. The two others being the IBM and Insero aggregators that trades on behalf of the Bornholm flexibility providers.

The aggregator setup used for the demonstrations in Horsens is a combination of tools developed as part of the demonstrations on Bornholm, tools developed as part of the daily operations of the heat pumps and tools developed specifically for this application. See figure 1

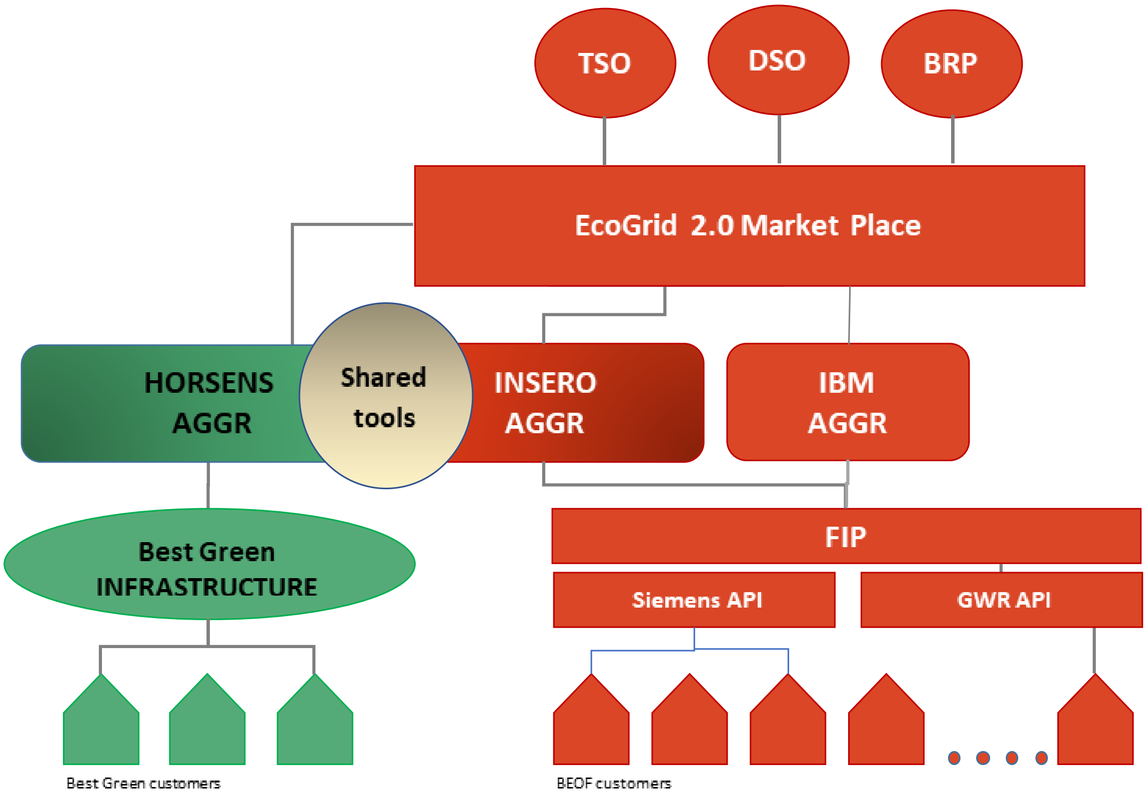

Figure 1 Full EcoGrid 2.0 aggregator setup

The part of the aggregator tools that interfaces with the EcoGrid 2.0 market trades TSO based services, is mostly re-used from the Bornholm setup.
The infrastructure is the existing Best Green infrastructure, used for remote management and monitoring during daily operations.

Infrastructure

The infrastructure in the Horsens aggregator setup is built upon the existing Best Green infrastructure. The aggregator communicates with the gateway at each installation site through the XMPP protocol. In some cases, there is a firewall that prevents direct communication to the gateway. In these cases, the communication goes through a proxy server. The gateway read measurement data from electricity and heat meters on site through Mod-bus and relays this information to the aggregator. The gateway is also able to block the heat pumps by switching a relay, when requested from the aggregator. See figure 2.

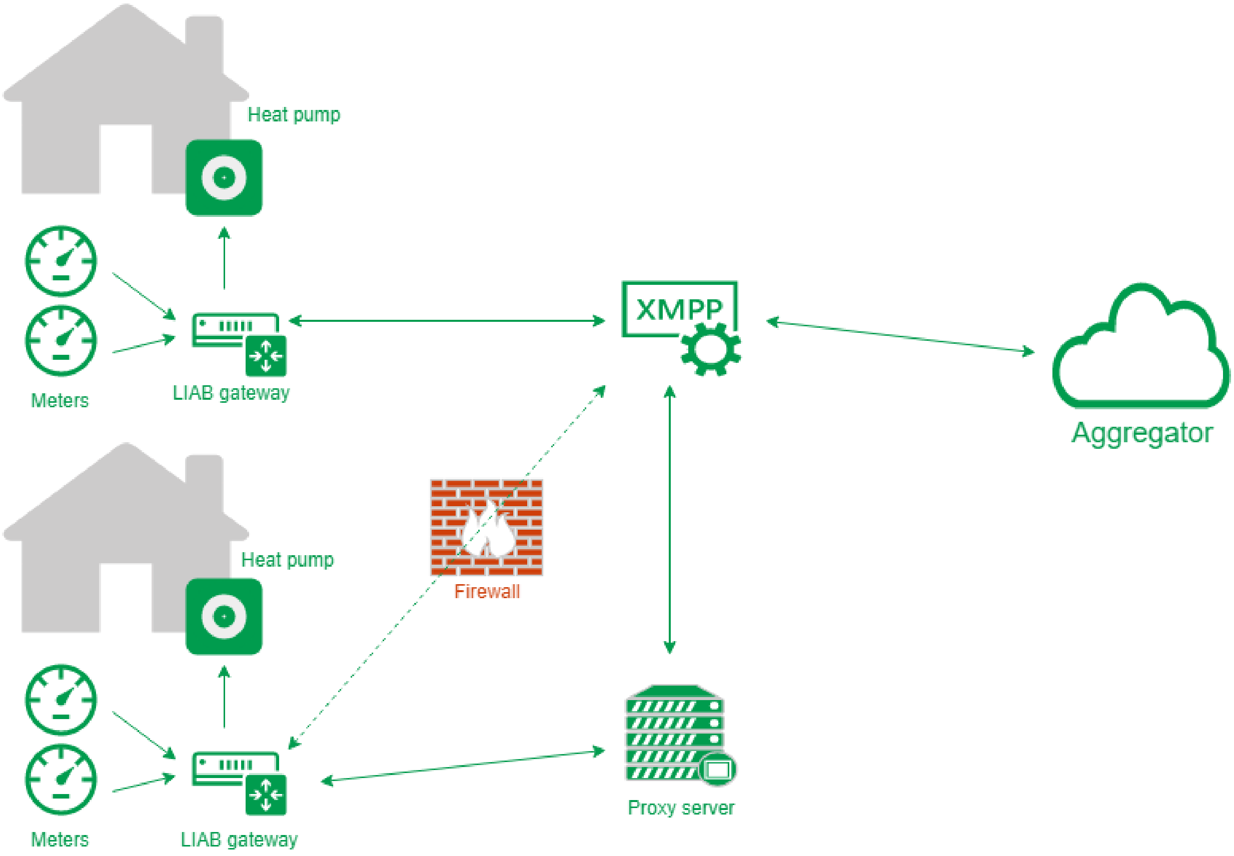

Figure 2 Horsens aggregator infrastructure

Horsens Aggregator

The Horsens aggregator is developed from a pragmatic point view, using existing components where possible and implementing simple solutions where needed. The components that are custom made for this application are baseline and flexibility calculation and control logic.

Forecasts and baseline

The following describes the principles for calculating the baseline delivered from the aggregator in the project. In order to be able to provide various regulatory services, there is a need to have a starting point for the delivery.

Baseline calculation principle

Baseline is a reference plane for heat pumps in a pool for the next 24 hours. It describes the expected heat consumption of the heat pumps and is calculated before the aggregator can enter the spot market. When baseline is estimated, it is based on a model for the pool, which is automatically estimated and maintained over time. The model parameters are estimated based on the following input:

- Historical indoor temperatures from the individual heat pump installations
- Data from historical weather forecasts
- The electrical power consumption of the heat pumps and supplied heat

The baseline is estimated from:

- Model parameters
- Weather forecast
- Comfort settings for each location
- Master data from the heat pumps (power consumption, run/rest time limitations)

If services are offered in the market, this is done with the registered baseline as reference.

Accuracy for baseline and forecasts

The horizon for how far in the future a baseline can reach depends primarily on how far out the future weather forecasts will reach. However, with the limitation that the farther out into the future there is estimated, the greater uncertainty the weather forecast will have, and at the same time uncertainty from user behaviour accumulates over time, which will influence the baseline uncertainty. Another aspect of the accuracy of the baseline is the number of heat pumps pooled. The more heat pumps in a pool, the easier it is to estimate a baseline and at the same time the usage behaviour is uncorrelated so that will to some extent, cancel itself out over time. The small number of heat pumps has been a challenge in the Horsens demonstrations. The total electricity usage for all running installations at normal day-time hour is typically approximately 200kW. One single large heat pump contributes with 15kW, or roughly 7,5% of the total consumption. This means the total consumption fluctuates quite a bit as heat pumps start and stop as part of normal operation. These fluctuations make it more difficult to calculate baselines and affects forecasts of flexibility.

Calculation of flexibility

The dynamic range of a pool can be defined as the range from 0 to the sum of all heat pump's nominal power output. It is generally not possible to utilize the entire dynamic range. First, it is never possible to stop every heat pump, as there are always some that have just started and

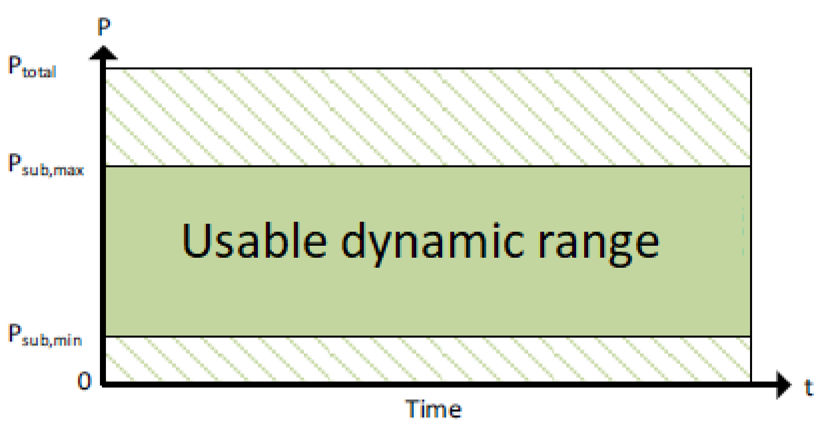

Figure 3 Usable dynamic range for portfolio of heat pumps

therefore locked and partly because some heat pumps must run for the sake of keeping the temperature within comfort limit or an urgent need for hot water.

Similarly, all heat pumps cannot always be started, for example because they just might have stopped and therefore have a need to rest and partly because the indoor temperature is already at the upper comfort limit. In the figure below, the usable dynamic range is defined by a lower and an upper limit. $P_{sub,min}$ and $P_{sub,max}$. The reason why the unused area is greatest at the top is that the heat pumps are typically remotely controlled using the relay input. It ensures that one can force a heat pump to stop but not force it to run, only allow it to run. The exact amount of flexibility that is offered is tuned based on empiric data from early experiments and continuous evaluations. Th aggregator will try to offer as much flexibility to the market, but it needs a reserve in case some of the blocked heat pumps needs to start during an activation. The size of the reserve and thus the amount of flexibility to offer is determined based on historical data, and fine-tuned continuously.

Control logic

The control logic essentially blocks heat pumps until the desired amount of flexibility is achieved. Heat pumps are selected based on how long they have been running since last stop and they are spread across installations if possible, to have a minimal effect on the indoor comfort in the individual buildings. During the activation, the electrical consumption is monitored to counter if one heat pump must be started due to the indoor temperature reaching comfort levels. If one heat pump needs to start, another heat pump is blocked to keep the desired response during the activation. This mode of operating with a closed loop regulation is significantly different from the Bornholm demonstrations, and made available by the fact that we have electricity consumption from the heat pumps alone, not the entire household. When we still see a discrepancy between the theoretical response and the actual, it is caused by the system not having any more available heat pumps to stop. Which is caused by the uncertainty of the baseline and flexibility estimation.

Shared components

The Horsens aggregator was designed to share as much infrastructure with the Bornholm setup as possible, as is indicated in figure 1.
The shared infrastructure includes:

- The market trading platform for the TSO, so bids can be made into not only the same markets, but so they can also happen in the same time frame as the Bornholm aggregators.
- The offering strategy tool for the TSO, that calculates the pricing information for offers sent to the market trading platform. This means the prices calculated between the different aggregators are comparable and meaningful for the market trading platform to work with.
- Parts of the aggregator software itself, which includes all the software components that are used to interact with the market trading platform and the underlying databases.
- The experiments register in EcoEx, which is used to track all activations in EcoGrid 2.0.

Sharing as many components with the Bornholm setup was highly desirable, not only because it means more code/software-reuse, but also because it proves that the EcoGrid 2.0 setup can be used in other contexts than just Bornholm. In fact, the Horsens aggregator used many of the re-usable EcoGrid 2.0 components in a setup that actually differs significantly from the setup on Bornholm. Proving it can be used for example in the context of big commercial customers in future projects.

Missing FIP integration

Notably, one of the significant components that weren't shared was the FIP. This component requires a special mention because it was built on the idea that it would be used as an "adapter" for unsupported equipment and could be re-usable so that the protocol an aggregator uses always is the same so it does not have to worry about what type of equipment it is communicating with.
A couple of reasons can be mentioned why this was not re-used for the Horsens aggregator:

- The communication setup with the equipment is significantly different from that on Bornholm as it requires real-time communication to both control and query data on the equipment. The heat pumps in Horsens are controlled in a closed loop due to the high uncertainty of the baseline with so few heat pumps.
    - The "data-driven" approach applied on Bornholm simply does not work when so few (but large) heat pumps are involved, which means that not only the protocol messages would be different but also how and when communication happens would be different.
- Various parts of the communication setup required specialized handling for a variety for reasons, for example:
    - The customers having different types of heat pumps where not all should be controllable all the time because of various requirements by individual customers.
    - Firewalls blocking all outgoing non-HTTP communication making communication with some customers tricky.
- It would put the entire burden of implementing the equipment support for the Horsens setup on Uptime.
- And finally, given the significant focus on ensuring there would be no comfort issues in the test period we decided it would be safer if we were in direct control of the heat pumps with no middleman in between that could cause additional errors.

Missing DSO Market Integration

While the interaction with the TSO market was tested to be working for the Horsens aggregator, the DSO market was not. The reasoning behind this can be summarized as:

- There is no logical purpose to this type of test in the Horsens setup as all the individual buildings are placed far apart and most are connected to different DSOs.
- The pool of heat pumps available to the Horsens Aggregator would be too small in a DSO context because the available heat pumps would have to be split up between different "virtual DSOs" (like on Bornholm) so a baseline could be calculated for each of these in order to offer the flexibility. Such baselines (based on essentially 7-8 big customers with heat pumps) would be too unstable to be usable for anything. Arguably, we have found that even the baseline for the TSO market setup is also unstable and that includes all customers.

- If all the installations were instead considered to be simply a part of the same virtual DSO, then such DSO market tests would represent essentially the same thing as the TSO market tests, except that the underlying market protocol would be a slightly bit different, to accommodate for conditional activations
- It was also a matter of prioritization of what would be possible to do with the available resources in the available timeframe.

Demonstrations and results

Initial tests in heating season 2

A contract was signed with Horsens Municipality during HS2, setting the conditions and responsibilities regarding the tests. For the municipality, as well as for other types of customers, it is crucial that the temperature comfort of the users of the buildings is not compromised in the future, when flexible electricity consumption is executed automatically, and market based to meet the needs of the energy system. One purpose of the tests was therefore to check basic functionality in the system for remote control and collection of measurements. The function of the gas boilers was also checked.

In the replication tests commands were trigged manually and sent from a central computer to the control system of the HPs one-by-one. The heat pumps were blocked and released again after a few hours in a Load Reduction test. The response was verified by measurements.

The conducted tests were made as part of the preparations for a full operation with portfolio control of the HP's, including market mechanisms to be conducted in next heating season (HS3). By portfolio control the HP's are blocked and restarted automatically to meet the demands of the electricity supply system in a cost-effective way.

Demonstrations in HS3

The goal for the third and final heating season was to add the Horsens aggregator to the TSO market as part of the full EcoGrid running scenario. This meant spending time between heating season 2 and 3 fixing the issues encountered during heating season 2 and implementing the missing features to allow market integration. The first part of heating season 3 was mainly spent testing and performing load reduction tests to fine tune the baseline and flexibility estimations on the combined portfolio, now with 15 sites. After new year the aggregator was added to the EcoGrid 2.0 market and was running automatically for the remainder of the heating season during weekdays. Additionally, occasional manual load reduction tests were performed.

In the evaluations we focused solely on the demonstrations performed after new year, because the test before were only used to tune the system.

During this period the aggregator has performed 25 manual load reduction tests and 54 market requested activations.

Manual load reduction tests

25 load reduction tests were performed during January to March 2019, all of them with a 30-minute duration. Manual load reduction tests were performed at times where there were no market activations, to either test implemented changes to the system or to fine tune parameters.
The results from the manual load reduction are

- Flexibility achieved 30-100kW
- Average expected flexibility ~80kW
- Average actual flexibility ~70kW
- Average rebound 1'st hour ~15kW

The graph below shows the electrical consumption for the portfolio of heat pumps during a manual load reduction test.

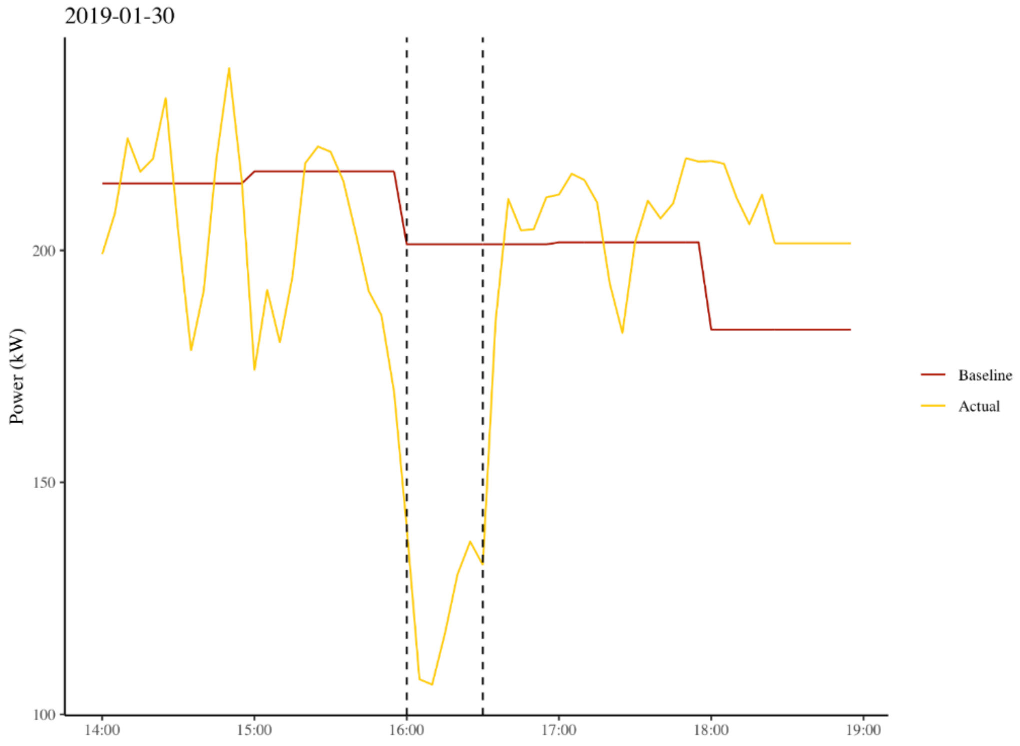

Figure 4 Electric consumption during 30-minute manual load reduction test

Because of the high degree of uncertainty, which is clearly visible in figure 4, the average response and rebound values are based on statistics. The boxplots in figure 5 below show the actual and expected responses and rebound values from the manual load reduction tests. The boxes illustrate the interquartile range from the 25th percentile to the 75th percentile.

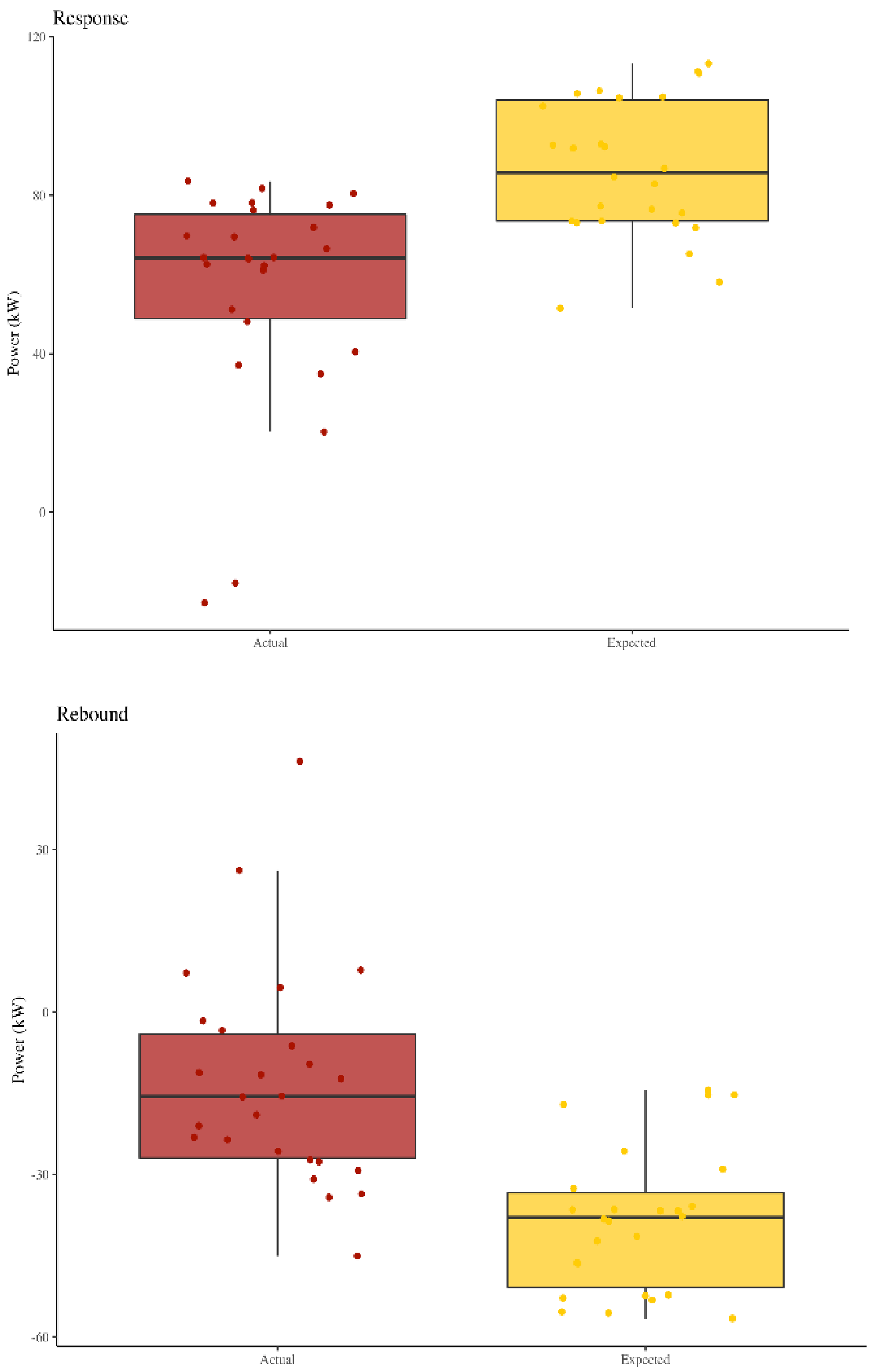

Figure 5 Box plots showing responses and rebound from manual load reduction tests

The box plots in figure 5 further illustrates the uncertainty and fluctuations in consumption, as the spread for actual values are much higher than for the expected. Especially for rebound values that are lower than responses and thus closer to the uncertainty of measurements. The actual rebound values are also considerably lower than expected.

Market driven activations

The Horsens aggregator has been bidding into the TSO market during the last part of heating season 3. The market driven activations are bids that are accepted by the market and later executed by the aggregator. During heating season 3, the Horsens aggregator has performed a total of 54 such market driven activations. 53 of those activations where 30-minute duration activations and 1 was 60 minutes.

The results from the 60-minute duration activation are

- Expected flexibility ~80kW
- Actual flexibility ~70kW
- Average rebound 1'st hour ~10kW

See the figure below

Figure 6 Electric consumption during 60-minute market driven activation

The remaining activations were 30 minutes duration. The results from these activations are.

- Flexibility achieved 30-100 kW
- Average expected flexibility ~55kW
- Average actual flexibility ~40kW
- Average rebound 1'st hour ~25kW

Figure 7 shows a 30-minute market driven activation

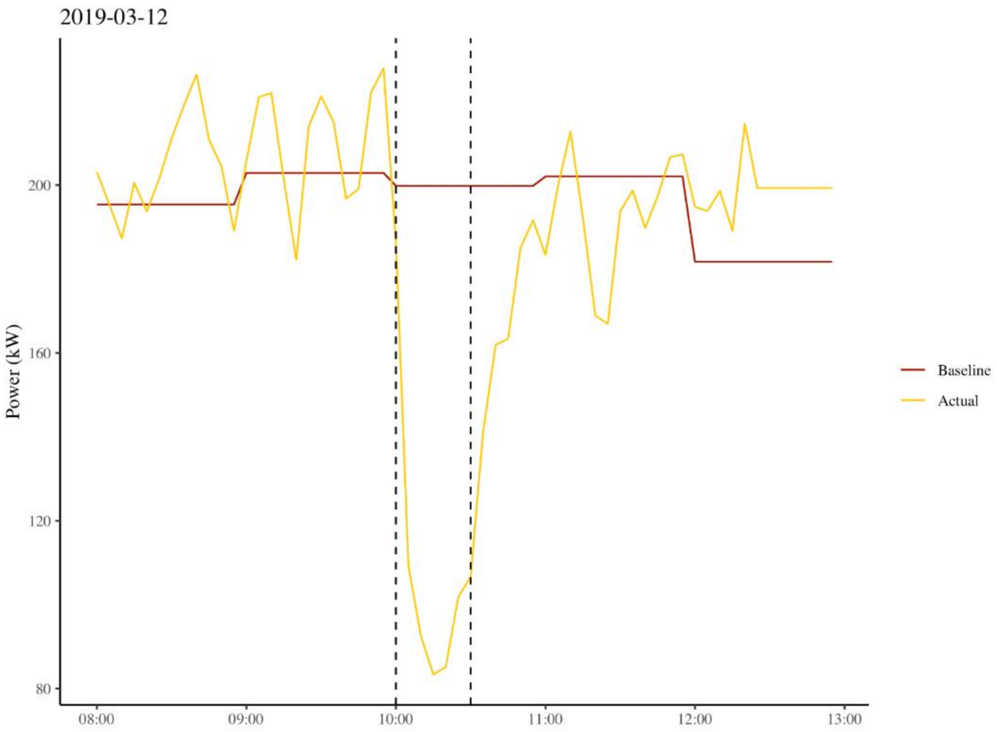

Figure 7 Electric consumption during 30-minute market driven activation

The actual responses and rebounds for the 30-minute activations are shown as boxplots in figure 8

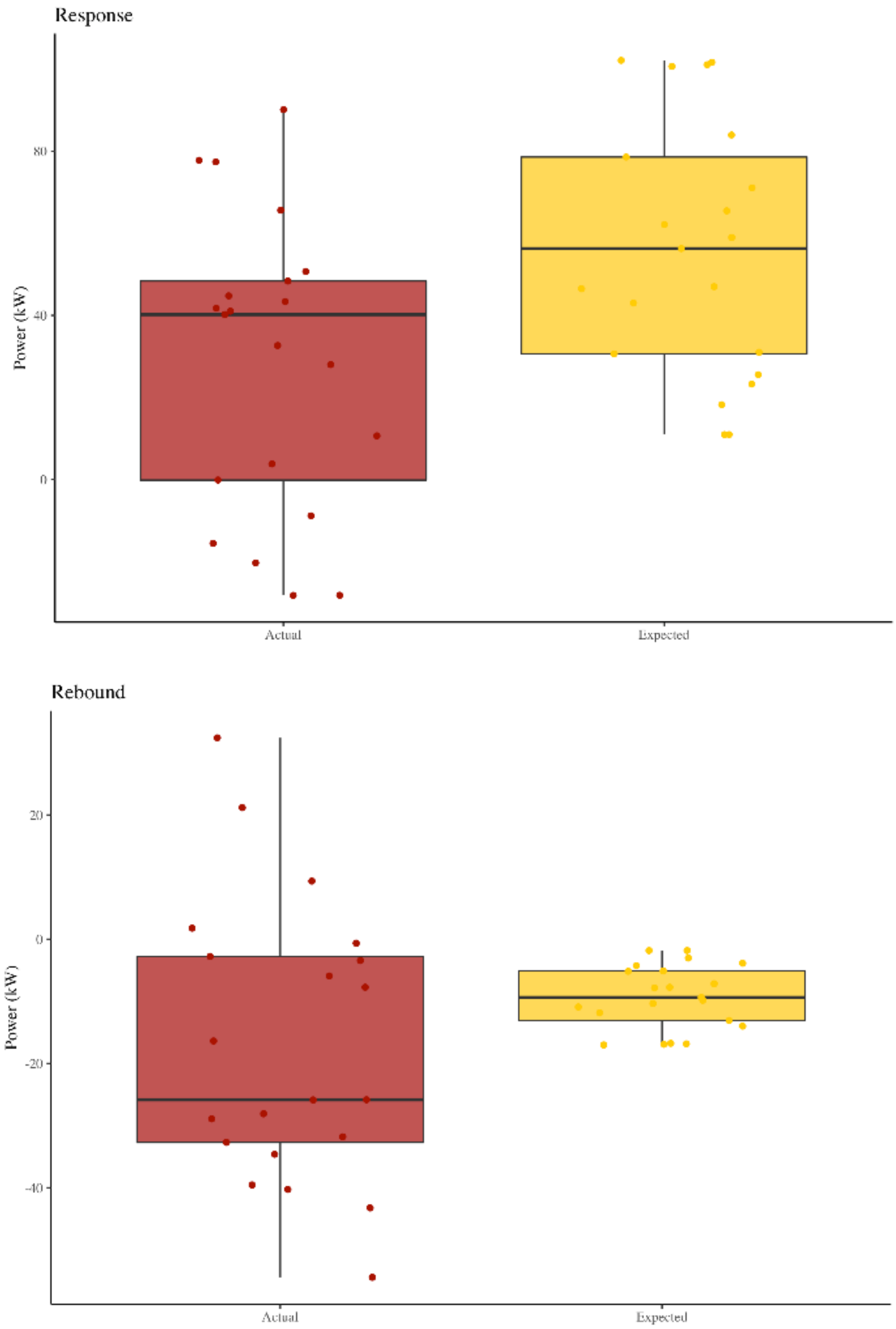

Figure 8 Box plots showing responses and rebound from 30-minute market activations

The box plots in figure 8 shows a large spread in the actual delivered response, with some values even negative. As with the manual load reduction tests, this is a product of the large uncertainty caused by so few installations.

Economic results from market activations

It is difficult to get a good overview over the economic results from activations. There is no standard method for calculating the actual price of an activation or to verify the delivery. Also, there is no overview over the actual cost of delivering flexibility. Instead we have looked at the prices that the aggregator has bid into the market with. This will give a rough idea of the expected turnover from selling flexibility to a TSO. The prices are calculated in the exact same way, using the same tools as the Insero aggregator on Bornholm. These prices are based on the expected cost of delivering the same amount of energy through traditional methods, such ramping up electric production on the TSO or BRP level.

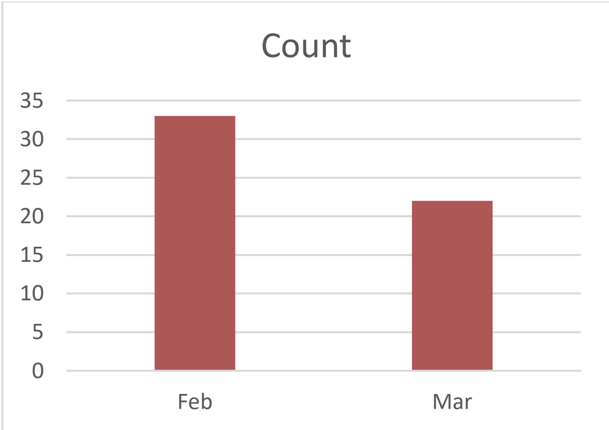

Figure 9 Number of market driven activation pr. Month

There have been 33 accepted market bids in February and 22 accepted bids in March. Based on the offered sales price for each of the activations, we have the calculated the total turnover during the heating season.

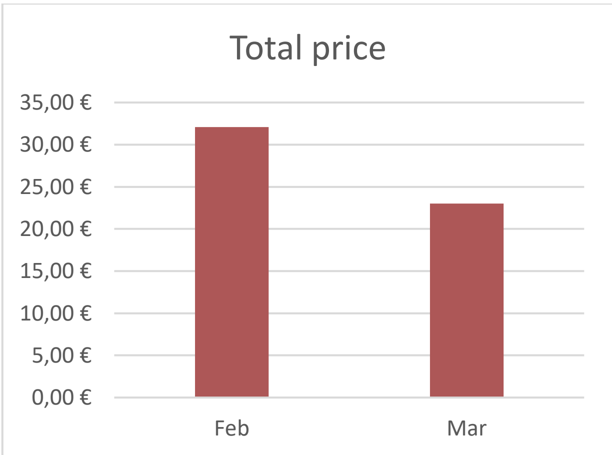

Figure 10 Total turnover from offering flexibility during the heating season

As figure 10 shows, through the market activations during February, the aggregator has traded for a total of 32€. During March the total turnover is 23€, and 55€ for the entire period or roughly 1€ pr. activation.

Rebound/gas furnace

As illustrated in figure 5 and figure 8, the rebound is generally lower than expected for most of the activations. The heating installations of the buildings being tested are gas-hybrid installations. This might lead to the assumption, that the lower rebound on the electricity consumption is explained by the gas furnaces starting and covering for the missing heat from the blocked heat pumps. However, this is not the case. Analysis of the gas usage shows no correlation between activations and any increase in gas usage. The graph below shows the gas usage in 15-minute values over a whole day. During this day, the aggregator activated the heat pumps 60 minutes from 11 AM. This activation is also presented in figure 6.

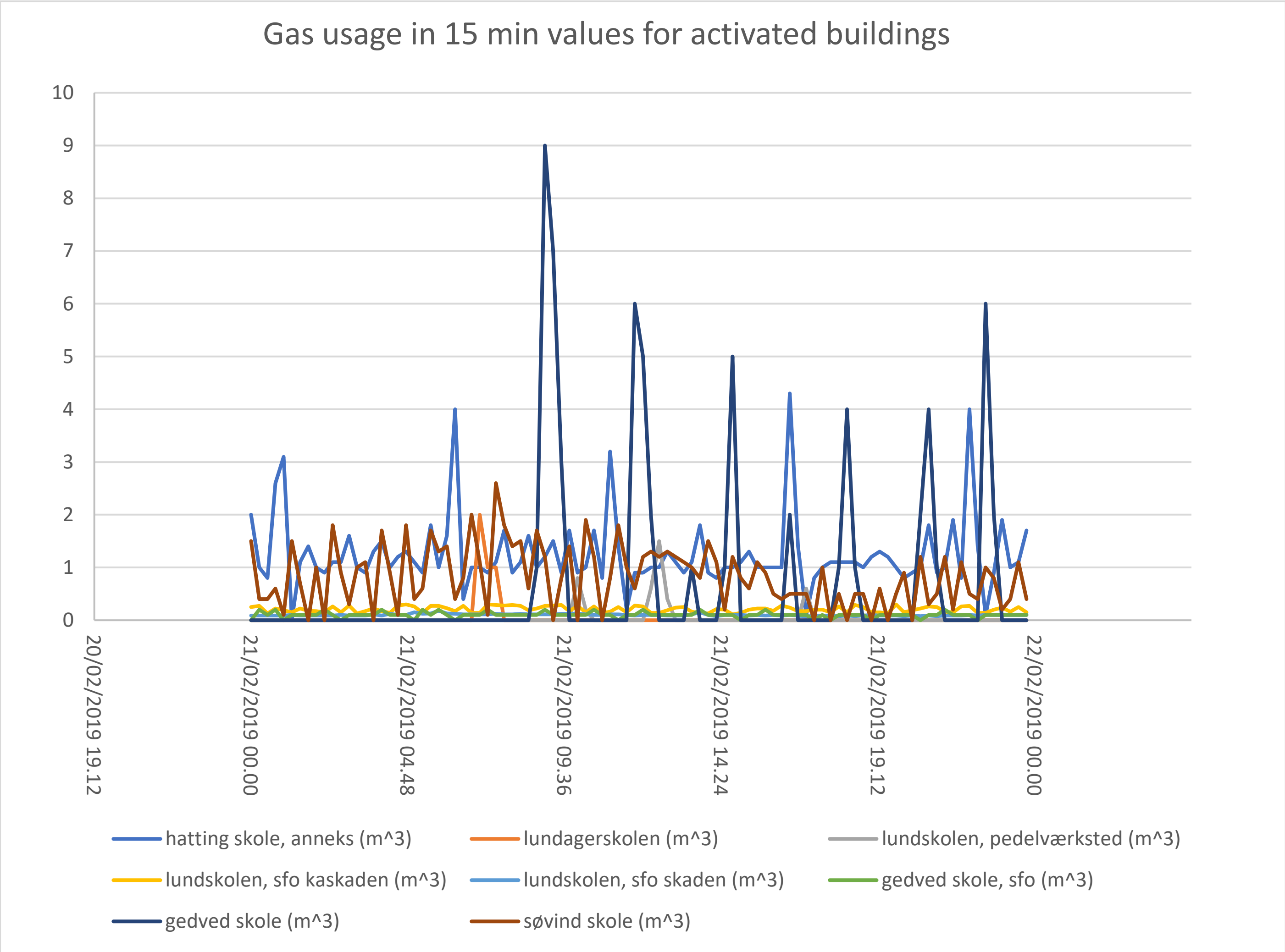

Figure 11 Gas usage during a day with an activation 11AM - 12 PM

The graph shows no significant increase in gas usage during or immediately after the activation at 11 AM.

The reason for the lower rebound effects must be found in the combination of large buildings with high thermal inertia and the fact that a lot of people in the buildings contribute to the heating of the buildings. The only site where there might be a little sign of increase in gas usage, is the grey line.

The Janitors workshop on "Lundskolen" (the school in Lund). This is a smaller building with only very few people. This further supports the thesis that the low rebound is caused by thermal inertia in the buildings and heat from the users. No attempts to shape the rebound has been performed in Horsens, this has not been deemed necessary, due to the already low rebound effect.

Indoor temperature

Reliable measurements of indoor temperature have been a challenge during the whole of EcoGrid, also in Horsens. The indoor temperature is measured by IC-meters placed in various rooms in the buildings. During the heating season there has been several problems with securing reliable data. Many of the meters are placed where they can be reached by the users of the buildings, so from time to time the meters have been disconnected or otherwise interfered with. The general unreliability of the temperature data has been problematic, because when executing activations, buildings without temperature data would normally not be used in order to avoid compromising comfort. During the first weeks of testing it was decided to go ahead and perform activations regardless of whether data was available because too many buildings were unable to contribute to the flexibility due to missing data. Interviews with the customers have later confirmed that it was possible to offer flexibility without causing discomfort, even without complete temperature data.

The figure below shows the indoor temperature of two building during an activation. During this day, the aggregator activated the heat pumps 60 minutes from 11 AM. This activation is also presented in figure 6.

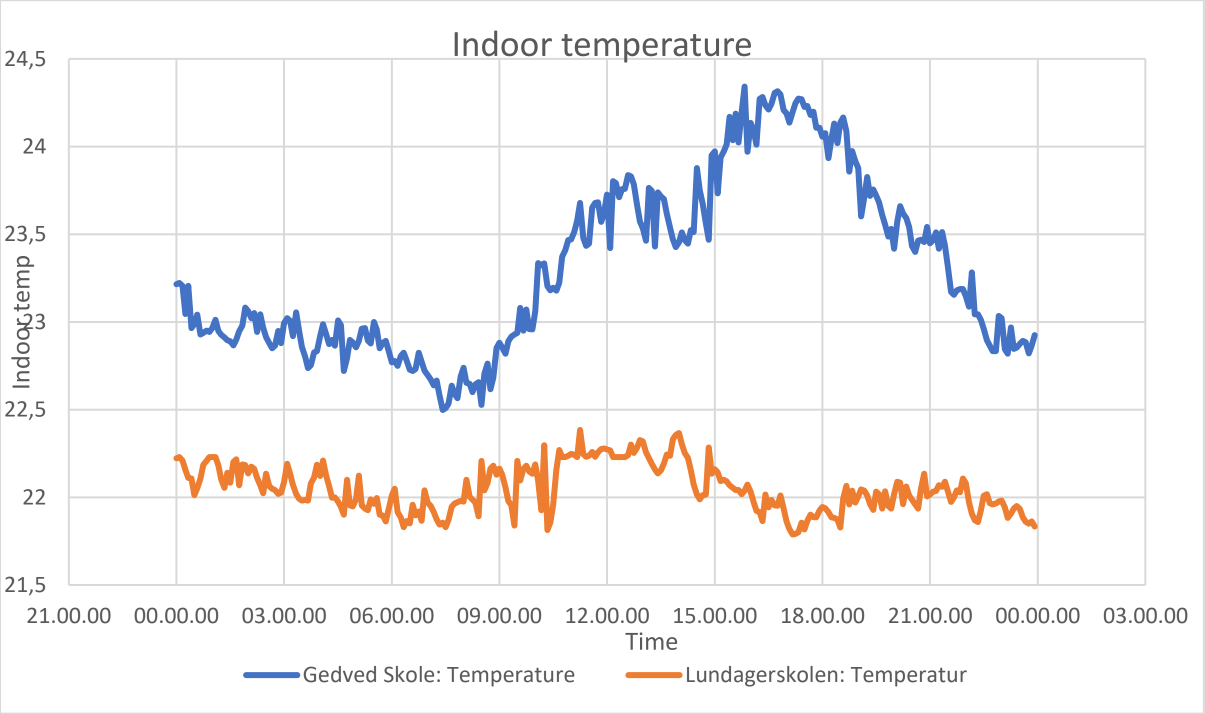

Figure 12 Indoor temperature during a day with 60 minutes of activation

The graph shows no sign of a significant drop in temperature during or after the activation at 11AM.

Conclusion

Achieved results

The Horsens aggregator and the demonstrations performed in Horsens aimed to prove two assumptions:

1. That it is possible to apply the same general principles of delivering flexibility from a completely different type of buildings from the setup on Bornholm.
2. That the functionality can be reused and/or re-implemented on a different infrastructure.

By having the Horsens aggregator successfully act as the third aggregator on the EcoGrid 2.0 market on equal terms with the two original aggregators, the technical feasibility of the general principle used for delivering flexibility in EcoGrid 2.0 has been proven for municipal building. The delivered flexibility is in the same order of magnitude as the demonstrations on Bornholm, only with much fewer sources. This proves the success in terms of applying the aggregator principles in a very different setup.
The complete Horsens aggregator is developed with a much more pragmatic and lot less theoretical background, re-using existing components and generally keeping everything as simple as possible. The experience from operating the Horsens aggregator and results achieved, along with the reuse of components from the Bornholm aggregator, not only proves that is it possible to reuse the functionality, but also that it is sufficiently well designed to be applied in a different setup with relative ease.

Findings from interviews

During the late part of the final heating season, interviews were conducted with the representative for Horsens municipality Charlotte Høitbjerg Davidsen and with the janitors from two of the schools. The municipality is generally very positive towards the project and happy to let the local EcoGrid participant perform tests on their buildings. This is not necessarily due to a specific interest in EcoGrid, but rather because the municipality has a broader strategy to become a frontrunner and preferred test zone for new technology. The EcoGrid purpose also goes well along with Horsens being a “Klima Kommune” and actively working towards a higher level of sustainability.
When the school caretakers/janitors were asked about their experiences with the tests performed in EcoGrid, they replied that they did not even notice any tests being performed. Additionally, they were happy not to have used any significant amount of extra gas despite of the tests performed.

This firmly supports the claim that the Horsens aggregator has delivered flexibility without compromising comfort for the users of the buildings.

Suggested improvements

The most pressing issue to address in the future is the economic feasibility. Two months of market operations resulted in 55€ worth of flexibility being traded. It is hard to base a business case of this size of turnover. Obviously, there are some external factors that needs addressing, such as pricing and delivery verification. These factors are out of the influence of the individual aggregator, and thus not within the scope of this evaluation.
What can be done by the individual aggregator, is to optimize the operations. This means maximize available flexibility from the buildings and minimize installation and operating costs. In the Horsens aggregator we already re-use most of the existing infrastructure as well as many of the software components. The running cost of operation has also not increased much from the original setup with heat pumps operation. This leaves the optimization of flexibility from the buildings as the area with the most potential for improvement.

To increase the available flexibility from the buildings, the biggest improvement would come from being able to utilize the master heat pumps. The concern with using master heat pumps is the requirement for hot water. The hot water is supplied through a buffer tank to allow for peaks in demand due to e.g. showering. By measuring the temperature in the buffer tank and subsequently releasing the master heat pump if the temperature drops, it would be possible to block the master heat pumps without the risk of running out of hot water. The typical baseline consumption during activations is around 200kW. We have achieved up to 100kW of flexibility without master heat pumps. This leaves roughly another 100kW of theoretical flexibility, if it is possible to block master heat pumps without risk of problems with hot water. On top of this optimization, the simple solution to increase profit, is to add more buildings. As long as the existing infrastructure is usable, the deployment cost is relatively low, making the solution quite scalable.

Read more at www.ecogrid.dk