Use Case 7—Integrated markets for energy and flexibility
Digital workshop 4—Nov 4th, 2022

Workshop summary

Buildings and heating flexibility

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Workshop goal

Highlight opportunities and challenges related to flexibility from buildings, and discuss the status and outlook on flexibility from buildings and neighbourhoods

Topics

- What are the latest research findings related to flexibility from buildings and heating?
- What is the status and outlook for technology, user acceptance, and business related to flexibility from buildings?

Session 1

Testing heating flexibility for intraday bidding in a market pilot
Benjamín Manrique Delgado, SINTEF

Activating building energy flexibility with predictive real-time control and thermal storage
Laurent Georges, NTNU

Practical challenges toward the data-driven application of real-life buildings
John Clauss, SINTEF

Dynamic thermal comfort in buildings
Matteo Favero, NTNU

Session 2

Panel discussion
Sjur Usken, Clevair
Ella-Lovise H. Rørvik, Aneo
Jon Iver Bakken, Celsio
Tor W Stålsett, Elvia

Breakout rooms, followed by a wrap-up
Technology
User acceptance
Business models

Workshop Summary

Water and interior space heating represent the largest share of energy consumption in buildings. Therefore, building and heating flexibility are closely related and widely researched. However, it is still unclear how much flexibility can be provided by buildings, especially those that do not have heating storage. This potential depends on many particular characteristics, such as the building type (residential, office, etc.), the current heating technology, and what range of temperatures the occupants consider comfortable.

The monetary motivation to provide energy flexibility is often unpaired with who bears the cost. That is to say that the building owner gets energy cost savings or revenues in return for the investment, but it is usually the tenant that pays the electricity bill. It is also essential to weigh the cost of providing flexibility to its benefit. Today, buildings can adapt to hourly price signals from electricity prices and/or power grid tariffs to optimise energy consumption. In the near future, it is expected that buildings can coordinate and provide bids to a relevant flexibility market. The cost of trading and which platform to use are uncertainties at this time.

Energy flexibility from building heating requires planning because delaying energy usage will require preparation (pre-heating) or recovery afterwards (post-heating). There exist methodological frameworks, including model predictive control, that can do this planning for some hours ahead, given well-defined user preferences and good predictions of relevant parameters. To provide such information for modelling, data collection of the relevant parameters is crucial; however, real-life data tend to have unsatisfactory quality.

User acceptance is essential to enable building flexibility on a large scale. The concept of "thermal comfort" is key to consider. Research generally finds that people prefer slow-changing temperatures and tolerate more heating than cooling variation. Nevertheless, thermal comfort is subjective, and there seems to be no "one-size-fits-all" regarding acceptable temperature changes in buildings. Automated controls should include users in the loop as the best way to produce good results and enhance acceptance levels.

Workshop overview

Organised by: FME NTRANS + FME ZEN

Number of participants: 40

Participants included researchers and partners of FME NTRANS and FME ZEN. Researchers and partners from related research centres were invited and represented, including FME HydroCen, PowerDig, and FME CINELDI.

In Session 1, four presentations gave an overview of the latest research findings related to flexibility from buildings and heating, including how flexibility provision from buildings can work from a technological perspective, how the bidding of flexibility products can work in a market, and how different indoor temperatures impact end-users.

In Session 2, panellists from four sectors (district heating, power grid, building automation, and power production) presented their perspectives on flexibility from buildings and heating. After the panellists shared their views, all participants were invited to join breakout rooms organised according to three thematic topics, namely:

Technology **User acceptance** **Business models**

The discussion was facilitated in each breakout room by the speakers from Session 1. Finally, the relevant topics were summarised in the wrap-up.

The presentations, discussions, and input during the workshop are presented in this report summary.

Session 1A

Testing heating flexibility for intraday bidding in a market pilot

Benjamín Manrique Delgado, SINTEF

Key takeaway— Bidding actions must consider preparation and recovery phases. Based on these phases, the cost of the bidding actions may increase irregularly.

The work presented is a partnership between SINTEF and TrønderEnergi, where the goal is to quantify how, through bidding in flexibility markets, a building can shift its energy demand for space heating away from or towards specific hours. In this research, SINTEF examined the space heating flexibility while TrønderEnergi examined the market side.

One important aspect of space heating flexibility is finding temperature variations that do not change the comfort level of the occupants of the building. In this research, a temperature level of reference was defined, and the optimisation model was allowed to change it by two degrees above. Another aspect of the flexibility related to space heating is that electricity consumption must return to baseline levels after an adjustment period.

Two types of operations were defined that can be associated with bids in flexibility markets. Those are up-response, where the electricity consumption is increased towards the specific bidding hour by increasing indoor temperature, and down-response, done by increasing electricity consumption and pre-heating the building before the bidding hour so that electricity consumption can be decreased in the bidding hour.

To calculate the benefit of bidding in flexibility markets, a baseline was considered by estimating an optimal operation of the building temperature control system, focused on cost reduction, while keeping comfort levels within the established limits. The financial gains or expenditures in the flexibility market must be contrasted with additional costs or gains associated with restoring comfort levels in the recovery phase of the operation and with any actions in the preparation phase.

An initial calculation quantified the maximum amount that can be earned in the flexibility markets while keeping the space temperature of the building within the comfort limits. Then, the model was used to calculate the maximum up- and down-responses within the same comfort limits. This was used to construct a curve which revealed that for down-response, the costs outpaced the electricity consumption decline in a non-linear relationship. A linear relationship was found for the financial gains associated with increased electricity consumption for up-response. Another finding is that, in this example calculation, up-response did not require a recovery phase.

Recovery and preparation trajectories for up- and down-response are not always the same and vary according to the granularity of the bid. Volumes that can be shifted are very dependent on the energy efficiency of the building. Finally, bids can be complex, and optimal strategies require comparing several bids in different time intervals to achieve the best outcome.

Answering a question from the audience, it was clarified that this example does not consider the peak cost in a month, which could exacerbate the cost of using building flexibility.

Session 1B

Activating building energy flexibility with predictive real-time control and thermal storage

Laurent Georges, NTNU

Key takeaway— Model-based control can be applied to unlock the energy flexibility potential without compromising energy efficiency.

Usually, buildings' controls are intuitive or expert-based rules that can also be applied to thermostatic control. Those rule-based controls can be used, for example, to decrease the indoor temperature during night-time to save energy.

Rule-based controls are not ideal for making the building energy flexible. They can cause an increase in energy consumption while attempting to do so, for example, by having high consumption to keep high storage levels or consuming electricity outside of the ideal time. To make the rule-based control efficient, the simplicity associated with implementing rule-based controls is compensated by a significant amount of work required for fine-tuning it for each building.

Model predictive control is a more advanced form of control where an optimisation control algorithm makes the decisions. This control algorithm represents the building's thermal dynamics. It uses inputs such as indoor and outdoor temperatures, solar irradiation and the predicted price for the next day, which are added as boundary conditions for the optimisation problem.

The technology to implement model predictive control already exists, and the current research aims to lower its costs to enable market penetration. The starting point is creating a model, as this is the most time-consuming task related to the model predictive control design. When the building's thermal mass is used as energy storage, the model relates the heating power of the building to the temperature inside it. Therefore, one can estimate how much the inside temperature will change by varying the power consumption. Model creation can follow different strategies, from transparent physical-based models to black-box (machine-learning) models. The current work uses data-driven grey-box models, which are a mix based on data and physics.

This research was done in ZEB Living Lab on the Gløshaugen campus in collaboration with Aarhus University. Model predictive control was implemented in a low-cost setup, which is easily replicable. The optimisation objective was to minimise electricity used during peak hours, and it had a horizon of two days. The baseline for comparison is a constant set point where the temperature inside the lab is kept the same for the time horizon. Results show a significant reduction, of more than 80%, in electricity usage during peak hours. To compensate, there is a slight increase in energy consumption by the building, at around 5% of the total.

The trust of occupants is a critical research question. A key point of discussion is the level of automation used by the system. A fully automated system can be optimised for energy flexibility but is less comfortable for occupants. An opposite approach would let the occupants fully control the temperature, but this may lead to inefficient use of energy flexibility. In addition, occupants might lose the incentive over time to participate in the decision-making process. A good compromise would involve some of both approaches, with a "user in the loop" control strategy.

An extension to the current model is to be able to account for different room temperatures inside the same building. To reduce the cost related to the control model identification, another relevant research is to automate this process in part or entirely. Occupants should also be better considered, and as the occupant behaviour cannot be easily modelled, they represent a source of uncertainty for the model identification and the controller. The influence of this uncertainty should be quantified and integrated into the model predictive control. Current research tends to oversimplify the heating system. This is something that should be improved, especially in non-residential buildings.

Session 1C

Practical challenges toward the data-driven application of real-life buildings

John Clauss, SINTEF

Key takeaway— Know what you measure! Data quality is of the utmost importance for the implementation of data-driven applications.

There are several typical issues in high-level data collection on building heating flexibility. Limitations of building automation communication protocols can reduce the amount of data that can be automatically collected. Interruptions in the communication of data transfers may lead to erroneous data being registered. Therefore, data quality verification, e.g., removing flat liners, must be implemented into the control pipeline. The robustness of the application programming interface should be tested, and a fall-back plan should turn the automation into business as usual while changing heating set-points.

Regarding data-driven control for building operations, it is known by experience that the system does not work as expected. Many are the challenges related to this, such as the ventilation and heating system working against each other (changing one affects the other), poor commissioning of ventilation systems and/or hydronic systems (circulation pumps), sensor placement-related challenges (e.g. lux sensors for solar shading control), malfunctioning regulators which might present no response or respond out of the measurement interval, malfunctioning valves in the hydronic system, among others.

Challenges in data-driven maintenance are also abundant. They can be categorised into system and modelling challenges. System challenges for data-driven maintenance are the level of instrumentation (e.g. having only one energy meter for several heat pumps), correct labelling and dependency of parameters. Modelling challenges are baseline estimation/benchmarking, detection of data outliers and anomalies, and interpretability of the results. Once it is understood what is happening in the system, one should work on the service to be developed.

The data required for a data-driven application depends on the task to be solved and variations within the (training) dataset. Modelling is, therefore, not a trivial task. Widespread implementation of data-driven applications is also not trivial, as each building is different. More focus should be put on ontologies and interoperability. Malfunctioning devices and communication protocol limitations are significant technical barriers for data-driven applications, and data cleansing is time-consuming.

Data quality is of the utmost importance. It is essential to gauge if data is reliable, not only easy to be collected but also trustworthy. Bad data can cause unnecessary delays in modelling and influence the necessary quantity of data. It is also essential to consider whether the variation in the training data set is high enough so that models can be developed that can predict a specific output over a wide range of possible inputs.

Session 1D

Dynamic thermal comfort in buildings

Matteo Favero, NTNU

Key takeaway— New knowledge of human reaction to a dynamic thermal environment regarding asymmetric limits for temperature drifts and ramps, and distinct discomfort mechanisms for space heating and cooling processes.

Thermal comfort is 'the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation' [ASHRAE Standard 55].

Thermal comfort is Experienced through several conscious and unconscious interactions in three areas: physical, physiological, and psychological. Adaptative thermal comfort models and Fanger's PMV/PPD model are the standard models used to estimate thermal comfort. Both predict the mean thermal sensation for a group of people. Those models do not take into account the short-term thermal dynamic of a building. This is important, as steady-state temperatures are usually the exception rather than the rule in buildings.

ASHRAE Standard 55 classifies temperature variations as temperature drifts and ramps, defined as 'monotonic, non-cyclic changes in operative temperature' and temperature cycles, which are 'repeatedly rises and falls of operative temperature with a period not greater than 15 min'. The standard also establishes temperature change thresholds for the average person based on the ratio of temperature change and exposure time.

An experimental study was conducted to test the thermal comfort limits used by ASHRAE Standard 55. The experiment exposed participants to various temperature change rates based on the previously defined boundaries. Participants were allowed to communicate by pressing a button when the temperature was uncomfortable, and then the examiners would take action to restore comfort conditions. The experiment was conducted in an office-like environment; the participation was voluntary and approved by the Norsk senter for forskningsdata, with reference code 525790. This experiment was documented in a PhD thesis.

The results from the experiment show that there are different reactions to temperature change, depending on whether it was increasing or decreasing. For discomfort related to a cold environment, 94% of time measurements for user discomfort happened before the expected time given by the current standard. When the environment was heated, 48% of the responses happened before the time estimated by the current standard.

A survival analysis further shows that people are more tolerant of heating than cooling variations. Also, per the current standard, people are more tolerant of a lower variation rate than a greater one.

The standard models consider an average perspective, and thermal comfort is not a one-size-fits-all measure. A new paradigm looks at individual preference through personalised environmental control systems [IEA EBC Annex 87]. Personalised controls are used to condition the temperature of the area where the person is, in contrast to environmental control systems, and can be used to relax the temperature requirements of the ambient zones under the assumption that the occupants will be spending most of their time at the individually conditioned workstations.

Personalised environmental control systems are not designed initially to be an energy-saving or energy-flexibility component, but with more research, it could be a viable solution. Open questions are the changes in building codes and regulations needed for the implementation and how those controls can scale up.

Session 2A

Panel discussion

Moderated by Igor Sartori, SINTEF

Ella-Lovise H. Rørvik, Aneo

Born from a collaboration between Trønderenergi and HitecVision, Aneo is an investment firm focusing on renewable energy production, electrification and energy efficiency. Aneo is part of the +CityxChange project, generating control signals for flexibility trading. Flexibility will be a more significant part of electricity markets; therefore, Aneo is interested in the limitations and opportunities regarding flexibility.

Tor W Stålsett, Elvia

Elvia, the largest DSO in Norway in grid operations, works with implicit flexibility through tariffs and has many flexibility projects, including an investigation on how demand response can provide security of supply for the grid. Building flexibility is a very promising area for Elvia.

Sjur Usken, Clevair

Clevair develops algorithms allowing the buildings to optimise energy consumption according to outside weather variation. One of the primary motivations for this work is to curb CO_2 emissions from buildings, which represent 36% of global CO_2 emissions in Europe.

Jon Iver Bakken, Hafslund Oslo Celsio

Celsio is the largest district heating company operating in Oslo. It acts in the customers' interest to avoid electricity consumption during peak hours. Celsio aims to optimise the integration of lean heat with the production portfolio. The company is also interested in long-term flexibility, specifically in how the buildings are built regarding energy efficiency. New buildings should be constructed with water-based flexible heating systems that allow the future choice between different technologies.

Question:

What is missing for building flexibility to be used as a large-scale application?

Ella-Lovise, Aneo	It is important to understand how much time is needed to model all buildings and different types of assets. Getting data-driven approaches to identify building flexibility is one of the main things that stand in the way of making this on a larger scale. Research in innovation projects is really needed, for example, into markets for flexibility, what type of responses are available, and how the flexibility will be used, now and in the future.
Tor Stålsett, Elvia	The technology side and the ability to integrate different technologies and make them communicate effectively make for a significant challenge. If something is to scale, then a lower cost is needed, as well as the ability to integrate it in a simple way.
Sjur Usken, Clevair	Incentives. The stakeholders are different from the ones that get rewarded. Also, there is insecurity about the technology that will become dominant and the risk of lock-in. But if those investing in building flexibility are not getting paid for it, then there is no use. This is the challenge in commercial real estate. For example, in some cases, it is not the building owner that pays the electricity costs, and they are not incentivised to do anything about it.
Jon Iver, Celsio	Incentives must be on both the customer's and the energy providers' sides. There must be a win-win situation. Also, there is a question of how tariffs are made. Celsio is looking at the lean-heat concept, and there is a lack of resources and person-hours, which makes it impossible to implement on a broad scale.

Question:

What is in there for you? How do you see that space heating flexibility will help you make money?

Tor Stålsett, Elvia	It is a tricky question as it is easy to see value from the macro perspective. About 50% of electricity consumption in Norway is used for warming. Even in small quantities, changes in peak load will change the need for investments. However, tracing it down to the end-costumer, the building owner, shows a need to work through the complex value chain that needs to be stretched out.
Ella-Lovise, Aneo	Aneo is looking at flexibility markets, and at the current stage, technology development for joining a flexibility market costs more than the possible profit of joining it. A change is needed, but we believe that, as flexibility is required in the future, it should be more profitable to enter these markets.
Jon Iver, Celsio	The final customer will gain indirectly in the long run as grid tariffs lower. In Celsio, using smarter heat allows us to use cheaper energy sources instead of starting up expensive biogas fuelled boilers, making electricity more affordable for customers.
Sjur Usken, Clevair	The cost of having the system not running optimally is CO_2 emissions. One ton of CO_2 costs 800 or 900 kroner per day. The current technology to capture those emissions using CCS costs 6 to 8 thousand kroner. There is a fundamental mismatch. We are missing the 1.5 degrees goal; others are paying for this because of climate change and compensations.

Session 2B

Breakout rooms

Researchers and partners teamed up in smaller groups to develop their perspectives on different thematic areas related to flexibility from buildings and heating.

Room #1: Technology

Which technologies are currently immature/missing (if any) on the building side to enable building flexibility? Which technological challenges are crucial to overcoming to enable building flexibility?

The first missing item to be mentioned was the interoperability of technologies, which pose challenges arising from the use of non-standardised naming conventions for different parameters measured. The second challenge concerns the possible limitations of building automation communication protocols, presented in section 1C. This was followed and coupled with the need for low-cost modelling to improve scalability.

Multi-zone control connected to hydronic systems can be extra challenging. More experience and know-how should be collected and disseminated on the best practice, like the need for a proper sensor placement (for example, concerning stratification).

Expert knowledge about local room control is still required for building automation implementation. Relevant development questions may arise, such as: will the occupants be able to set the room temperature themselves, basically overwriting the set point from the system?

Another challenge is the difference in thermal comfort perception by gender. Also, many companies that propose controls are already established or are spin-offs; however, the performance should be investigated regarding energy efficiency and flexibility trade-offs.

A final challenge is to link the district heating and the electricity grid.

Which stakeholders can/should provide the technology to coordinate/enable building flexibility?

On the building side, building automation companies or third-party companies could implement the technology. A collaboration between stakeholders is needed, ranging from end users to aggregators and flexibility market providers.

Room #2: User acceptance

What are the most important criteria for users to embrace the provision of flexibility?

People should feel ownership; if they can participate directly, it would help with acceptance. For example, schools or other public spaces could have a screen showing the occupants' information regarding the outcome of flexible actions, and users could interact to obtain more information. Even so, it might become repetitive over a more extended period. If the system has a channel to receive feedback, then it could learn from usage.

Feedback, information display, and notifications can be received directly on the phone. This could help with education and knowledge of options, which are also important. The frequency of the messages should be sufficient to transfer knowledge without annoying the users. Visualisation is essential, rather than opaque control. People can accept automated decisions, but knowledge helps with the long term.

What are the most important reasons users resist the provision of flexibility? What is the required involvement from end-users (if any) to enable building flexibility?

One crucial aspect is privacy. Temperature or other innovative measurements can be used to know how many people are in each house at each moment, for example. Pre-heating could lead to a distortion in user comfort perception, which should be done with care for this aspect.

Willingness to pay or to receive is absent from the current discussion. One reason might be that when people see their money going into the system in real-time, their comfort threshold can be changed to save money. But this ultimately leads to discomfort, can have long-term health impacts, and cause a drop in productivity. Money does not provide the correct incentive in that case. It does not make sense even from the company's perspective, as the salary cost is usually higher than the electricity cost.

Education and knowledge can get users on board with building thermal flexibility. Service providers could associate home heating flexibility with air quality monitoring, for example, and it could provide a non-monetary incentive for user acceptance. Yet, the user must know why automated control is important.

Room #3: Business models

What does it take to scale up, and how to make money in the flexibility market?

Requirements for scaling up are better modelling, communication between technologies, correct incentives and enough human resources. Data is crucial, sometimes data is lacking, and then it is impossible to scale up.

Peak load reductions are a crucial implementation, which is evident at the macro level. The complexity lies in how to fit small assets into the big picture. Currently, the cost of technology development is higher than what is being paid by the market.

The final consumer will experience gains due to a long-term reduction in the grid tariff. More smart use of resources can lead to cheaper energy sources that will also benefit grid operation due to the better utilisation of existing assets. To enhance the profitability of building flexibility, CO_2 emission costs should be internalised in the market.

Flexibility can be a tool to help operational planning (short time frame), and it is different to look at strategic 50-year investments. In the latter, the reliability aspect is more crucial. Nevertheless, long-term and short-term are focused towards the same need.

Which stakeholders are most interested in buying flexibility from buildings?

There is indirect competition for flexibility between district heating and the electric grid. If a building is connected to the district heating grid, it will not explicitly use electricity for heating.

Building owners are scared that "flexibility providers" can control too much. However, if flexibility is done correctly, the occupants will not notice it. Technology can run a building's thermal controls more dynamically and compensate for the difference between indoor temperature and outdoor conditions. Those systems can be optimised towards the ASHRAE standard of indoor air quality. If indoor air quality sensors are used inside current buildings, then the occupants could have an understanding of what is achieved with the current technology and can become invested in the solution.

A related question is: how much are companies willing to let end-users control operation that is grid operator responsibility? A DSO, looking beyond R&D, will always choose the solution that will give the lowest grid tariff. If it can trust demand response, even if some of it is not well tested so far, if it is cheaper, then it will be chosen. Many stakeholders disregard that the grid is already flexible. A top-down approach is common for the DSO, but it is also possible to solve from the bottom-up.

Which markets are most important for buildings to sell flexibility?

It depends if the flexibility should be oriented towards local bottleneck or national transmission. Without extra funding, some DSO would not operate in the flexibility market.

Flexibility markets exist already, as Statnett buys flexibility. Market entry is the barrier, and smaller players tend to become significant in new markets. Nevertheless, incentives are crucial.

Concluding remarks and future steps

The fourth workshop in this use case focused on Buildings and heating flexibility and brought the perspective of the provision of flexibility from buildings and the end-consumer. The research currently being done in this segment illustrates many challenges for its implementation, highlighting that this market is still developing while showing great potential.

Many electricity sector participants are interested or have stakes in building flexibility, as shown by the diverse participation on the panel. The profitability of those flexible operations is still uncertain. Still, the correct incentives allied with lower costs in resources and entry barriers could mean good outcomes for market participants investing in the technology and society since flexibility is in high demand.

The end-user comfort and participation are critical for realising this flexibility potential. User engagement and education should be a focus for the successful implementation of profitable building flexibility operations.

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