Shifts and optimisation of energy use through smart energy management software and tools

As it is presented in the first two chapters, there are several challenges in optimising the end-user side. Having in mind the different control points outlined above, you will read in this chapter about ways to manage the energy flows in the building in a more efficient manner.

Control technology overview

4.4 of D5.3
In this section we will provide an overview of the different types of ICT related solutions aimed at controlling the heat system. We will also address ICT tools that are aimed at changing user behaviour as well as diagnosing the system. In Celsius Deliverable 2.1 (**check if file is uploaded and add link**), several strategies for influencing end user behaviour concerning household electricity consumption have been outlined, in which a few examples of ICT tools have been provided. The section includes links to deliverables that show examples for visualising energy consumption and controlling the actual temperature. We will start with an overview of control technology in the utility room, level 1 in the district heating system.

Control technology in the utility room

In terms of the heat exchanger, ICT based solutions for controlling the energy outtake from the district heating network has long been the norm.

There is however a great variation in the capabilities in these kinds of control equipment among the most simple ones (usually older ones) the heat exchanger can only be controlled with a linear correlation to the outdoor temperature. This is done by setting two data points that maps (1) an outdoor temperature and (2) what the user wants the outgoing temperature to be from the heat exchanger and in to the system. With that there are a lot of options for control equipment that can:

- control the mapping with multiple set points
- use additional sensors for outdoor or indoor temperatures.
- be programmed with or calculate delay factors for making use of the stored heat in the building.
- use learning algorithms to learn the response time for control changes to keep the indoor temperature even.
- use schedules to lower temperatures during certain hours (most commonly during nights).
- allow remote controlling of temperatures in order for the user to make manual adjustments.
- use weather forecasts to anticipate temperature changes and act in advance.

For a detailed review of available commercialised systems, please refer to CELSIUS report D5.3, section 4.4.1.**link to the file**

Within the Celsius project, the Short term storage demonstrator (GO1) aims at partly decoupling the heat supply from the outdoor temperature. The outdoor temperature sensor is steered to optimise the regulation curve for the flow and temperature in the heating system. Using a trial and error approach, this control method provides within a few adjustments a steady indoor temperature at all times of the day and throughout the year, with fewer peaks in the production.

Control technology for hydronic balancing and the local network

When it comes to the hydronic balancing, control equipment is often mechanical. The flow is calibrated either by adjusting a valve on the return pipe on the radiator or with valves in the local network. On private houses or housing cooperatives this is usually a static calibration, which is set once after the system is installed and then left alone. However as houses grow older there often emerge a need for replacing heat pipes or radiators or other equipment in the system. Other factors involve tenants or members of the housing cooperative taking initiatives and changing the setting or balancing valves in their apartment. Since calibrating the systems is done with all the thermostat valves open this requires access to all apartments on several occasions. If radiators are replaced several times per year the process of re-balancing the network very quickly becomes unfeasible.

A way to solve these issues can be to use valves with pressure feedback so called ASV (automatic balancing valves) (figure 3). These valves will close once a certain pressure is reached on their down side. In this way they will maintain a constant pressure in the section they control regardless of what happens in another part of the network (as long as the global system pressure doesn't become lower than the pressure the valve is set for). In this way a large heating system can be divided into independent sections that can then be balanced individually. This is of course not an ICT solution but rather a mechanical solution. In terms of ICT solutions any valves can generally be fitted with an actuator for remote control. In case of an ASV being used, the actuator would then control the pressure on that particular sub-part of the system. While this is technically possible the cost benefit factor of such a system will have to be taken in to account in order to determine if it is a cost effective solution.

Such a solution would enable the housing cooperative board to only adjust one house or apartment when receiving complaints, instead of adjusting the whole system - if it could be integrated with the eGain solution or similar products. Although dynamic balancing of the local networks is uncommon in Swedish homes, it seems to be a strategy more commonly applied in the USA. There are quite a few examples of zone controller actuators on American product sites.

Climate control technology in the living space

Since modern digital thermostats usually implement control schemes that are not only based on the surrounding temperature the word ‘controller’ rather than ‘thermostat’ would possibly be more accurate to use when referring to these solutions. The term actuator is often also used in relation to electronic control of the radiator. The term usually refers to a simpler form of control mechanism consisting of an electrical motor and sensors for determining the position of a throttle. We will use the term radiator controller in this review to denote an electronic device fitted onto the radiator (an actuator, digital thermostat or something even smarter). We will use the term zone controller unit to refer to wall mounted solutions controlling the temperature from a central location in the room or an area. The term zone controller is on some websites used to denote the actuator and valve controlling the flow of heat to a particular zone; we will refer to those as zone controller actuators or zone controller actuator valves.

When it comes to hydronic heating in private homes (both apartments and single houses) the most common approach (in Sweden) is still to apply mechanical thermostats fitted directly on the radiator. In commercial buildings like office spaces it is more common with electronically controlled actuators that are controlled by a wall thermostat. In terms of products however there has in recent years been surge in heat orientated ICT solutions aiming for the homeowner market. These products include digital radiator controllers that sometimes are used in connection to zone controller units that provide more advanced features.

The strategies for controlling the heat in the living space with these digital tools include many approaches that can be found in the examples with the DUC’s. This includes:

- The use of learning algorithms to learn the response time for control changes to keep the indoor temperature even (Machine learning).
- The use of schedules to lower temperatures during certain hours (most commonly during nights).
- Remote controlling of temperatures in order for the user to make manual adjustments.
- The use of weather forecasts to anticipate temperature changes and act in advance.

They also include strategies like:

- Using the users GPS position to determine when temperatures could be lowered or not. (Geofencing or location awareness)

- The use of learning algorithms, motion sensors and user input to determine what the temperature should be. (Context awareness)

For a detailed review of systems, please refer to CELSIUS Deliverable 5.3.

Most of the products described in the Celsius deliverable are better suited for one of the two scenarios, but some can be used in both cases. Some of them have special features when the building is supplied by a DH network.

User feedback and individual metering

4.4.4 in D5.3
A number of companies offer a system to measure energy use by individual apartments and collect that data to produce invoices for each tenant. This is typically referred to as IMD (individual metering and debiting).

Most of these companies offer a product range consisting of both wired and wireless sensors data collection units and back-end systems for performing calculations and producing invoices to the customers. Since these systems require extensive installation procedure with pipes being cut and so on they are usually more appropriate for cases when they can be installed when the building is built or when some major renovation is performed.

In some cases the companies also offer non-intrusive measurement methods more suitable for retrofitting.

To debit the tenants by actual energy used is often seen as unfair when introduced into existing buildings where people previously paid by the square meter. With this system, some apartments, which have more outer walls, will get higher bills. Another approach is instead to measure the indoor temperature and debit the tenants according to the temperature they have set their apartment to. For every degree the tenants add to their indoor climate they will pay an additional sum each month. This strategy can also be seen as unfair since a tenant keeping a window open to vent out the heat will be registered as having a low indoor temperature.

For a detailed review of available systems and apps, please refer to CELSIUS report D5.3.

Energy audits

The main problem with motivating an investment in energy efficiency measures is to determine, in advance, what kinds of savings can be gained. If there were a reliable way of estimating this in advance it would obviously make the decision for these kinds of measures much easier and thus increase the potential market.

A diagnostic service usually consists of some kind of hardware that can be used to log temperatures on a site in different houses, apartments or rooms. After that the data needs to be analyzed and translated to an energy savings potential or diagnostic of the calibration of the system. As a third step, users would ideally be able to apply these measurements to a particular solution in order to get an estimate of the savings or even particular settings for that solution.

Closely linked to the Climate Agreement strategy, a simple energy audit method is being developed in Gothenburg.

Data Collection

In terms of logging room temperature, there is an abundance of temperature loggers available at a quite affordable price. Deliverable 5.3 (**add link to file**) provides ideas of products with their price range.

When it comes to determining if the system is balanced, temperature readings are mostly done manually. One strategy is to measure the temperature difference between the incoming pipe and the outgoing one on the radiator. A low difference will be an indication of the flow being too high; a high temperature difference is an indication of the flow being too low. To perform this measurement a preferred method is to use a contactless IR-thermometer.

In most cases the analysis of the collected data seems to require a professional in the area of hydronic heating systems. Even if specific mathematical software are often used, an energy audit still seems to involve a lot of experience based knowledge. When talking to experts in the area there seems to be a number of rules of thumb that are used. For instance, if the forward temperature can be lowered by 1°C it will result in a 7% energy reduction and so on.

When it comes to the next step to predict the effects of a solution on a system we have not found any good solutions. Such predictions would need to be based on empirical data as control algorithms often are kept secret by the companies selling the control technology.

Discussions

When it comes to the area of controlling heating systems, there is a range of ICT solutions available to save energy and increase thermal comfort in the home. The area of smart room controllers, aimed at private households, appears to be a particularly fast growing area in this range of ICT tools. Many of these solutions are also a bit immature in their technology as some of the reviews on them have pointed out. Predicting the needs of humans in a technology solution, for example the area of context awareness, is often a challenge for engineers. The development with these solutions is, however, still interesting since many of these solutions also aim to include the user behaviors in their energy efficiency strategies in addition to other more traditional control approaches. Besides unlocking a potential for even greater energy savings than what could be achieved with just normal control technology, these systems also open up for solutions that can negotiate between user needs and conditions in the district heating network and thereby lessen the effects of peak loads. The zone controllers are so far mostly aimed at single-family houses, as it is hard to see how they could be economically motivated for retrofitting a housing association. For this they would probably have to become even cheaper. But for these kinds of technology to be interesting for a housing cooperative the solutions need to have both the robustness of the systems offered to commercial buildings as well as a price tag that appeals to single family houses. With robustness we anticipate issues like having to change the battery in several hundred apartments or wireless communication between all the controllers causing network collisions and bad reception for neighboring apartments.

In terms of user behaviors, IMD is also an interesting field; although in a retrofitting scenario there are still some real issues connected to it. One of these is how to distribute costs to the different tenants in a fair way and prevent the abuse of such systems so they cannot be cheated. The whole IMD area is also facing the problem that if all of the incentives are directed to the tenant, the housing cooperative or the landlord will lose its incentive to perform energy saving measures. In this regard the strategy of allowing customers to buy a comfort level rather than energy is a rather appealing one if they can be made fail safe. That is including penalties for windows kept open, detection of ice cubes on sensors and so on. When the tenants pay for comfort rather than the actual energy used they will still have the incentive to save energy while the organization responsible for the overall function of the house (the landlord or the housing association) would still be motivated to perform further energy efficiency improvements when feasible.

So what is then lacking in terms of ICT solutions for district heating? We have identified three areas where improvements can be made. These include (1) diagnostics of existing systems and simulation of the effect of the solutions offered in the market, (2) flow control of individual houses in large building cooperatives and (3) we also lack applications which integrate the whole chain from end-user to heating central in large systems.

(1)When many of the solutions discussed so far are restrained by hardware cost (e.g. the room controller is too expensive for multifamily houses, IMD needs cheap non-intrusive sensors) the area of diagnosing the heat system is rather limited by a lack of appropriate information and data analysis software. As we touched upon earlier, this area is crucial in order to stimulate the deployment of the other control related technologies as well as enabling the administrators of a local heating system to adjust the system properly. Today there are several energy consultants that offer measuring and adjustment of heating systems as a service. The existence of a simple form of do-it-yourself tool could however greatly reduce the threshold of housing cooperatives or homeowners to get information about their system. Having this information could act as a bridge to later hire a more expensive consultant. Among the available Apps we found related to hydronic heating systems they are more about building a system rather than maintaining it. Anticipating the effects and distinguishing between the different energy optimization systems is also hard since the control algorithms are kept a secret. An online resource could in this case be a tool to visualize reference data from other sites where a specific technology has been implemented.

(2) When it comes to our second point we could see that many of the smart algorithms for controlling large systems such as eGains' solution will lose many of the benefits it usually provides if it cannot control houses individually as in the case with several houses and one heat central. A cost efficient solution for remote controlled valves that can integrate with these kinds of solutions is therefore a second important technology.

(3) As the third point we would like to point out the obvious benefit that combining the IMD system and its sensors with the control system would bring. Today IMD systems are sold as one kind of solution and energy optimization system as another. In both eGain and ERABs solution the systems require temperature sensors to be placed out in the different apartments. If we were to integrate solutions like the one from eGain with the one from BKAB where tenants pay for comfort we would only need one set of temperature sensors and would drive two energy efficiency services.

Such a strategy of collaborating around sensors in an open data environment has long been a research subject within the Internet of Things research area. In this area it is envisioned that also other services will coexist and share hardware. Examples are that a motion sensor can be used for both lowering heat as well as for a burglar alarm service. In the example with the Google Nest we can already see that Google is trying to build a service platform around the Nest. In addition to the thermostat they are also providing smoke alarms as well as integration to washing machines etc. These service platforms should however ideally be open to any manufacturer or sensor.

Conclusion

The overall conclusion in terms of ICT solutions for district heating and homeowners is that there is a lot going on. During the last year we have seen a large number of products starting to appear in this area. The potential of these solutions will be even larger in the future when they are able to provide even more cost efficient control solutions and also integrate user behaviors, zone controls, heat exchange controllers and even the district heating production in the tasks of optimizing energy use.

But there is also a missing piece. It is impossible for the users to understand what the offers from the different service providers actually mean, and even harder to understand what they would mean for their system in particular. This points to the conclusion that more open solutions or different forms of energy audit solutions that could both diagnose heating systems in a simple fashion and also provide information on how the solutions would perform in that particular system would be a good way forward.

Shifts and optimisation of energy use through thermal storage

Chapter 6 , D5.2 also part of Chapter 3, D5.2

In the context presented in the first two chapters, thermal storage on the end-user side is a possible means of optimisation of network performance. The underlying principle consists of storing energy at times when the overall network load is lower and then using it during the load peaks. This has already been implemented in some networks at the utility level but there is a potential for further performance improvement by storing energy at the end-user side.

Such a scheme has been encouraged in some places by introducing dynamic pricing or time slot dependent pricing, asking for higher tariffs during peak hours and offering lower tariffs during night and lower heat demand hours. The main obstacle for implementing such technique is often the need for substituting heat metering equipment with systems registering data hourly (see the previous chapter for possible solutions). Furthermore the appropriate billing method is necessary.

The following sections explore different types of end-user side storage: dedicated thermal stores, short-term storage in building structures. Finally the benefits to the electric grid are outlined.

Physical demand side stores

3.2 D5.2 All the introduction of 3.2 sets the context for demand side energy management and some pointers towards reasons for using demand side storage - these pointers were used to build the motivations paragraphs above.

Physical demand-side storage is a relatively uncommon strategy, although it could become a diffused practice in case time slot dependent pricing was broadly implemented.

Within Celsius, heat buffering at the user premises is present in one of the Cologne demonstrators, CO1 waste heat recovery from sewage water; the demonstrator page does not go into any detail about the buffer characteristics. A water buffer is present to allow smooth operation of the heat pumps having, at the same time, the possibility of delivering a higher power rate to the served schools thanks to the heat storage. Such system might be a good example of water storage aimed at de-coupling peak heat demand of an existing building respect to the peak price time slot of a DH system, keeping the rest of the system very similar to the pre-existing one.

Heat buffering can also be achieved without having a dedicated store but by using the thermal capacity of the facility to heat, e.g. the water in a swimming pool or the structure of a building, see the next paragraph.

Add features of chapter 6 D5.2?

Short-term storage in buildings

4.2 D5.2
In the Gothenburg demonstrator Buildings for short-term storage, demand side storage is provided by the building structure. Using the heat storage capacity of buildings is one way of managing heat load variations without installing an extra physical energy store. By installing equipment that allows the district heating operator (in this case Göteborg Energi) to adjust the amount of heat delivered to a building at certain times of the day, the building can be “loaded” and “unloaded” with heat, thus contributing to shift heat demand from peak hours to hours with lower heat demand.

Peak load reduction technology

The ability to store heat in a building is based both on the thermal characteristics of the building materials, i.e. their capacity to store heat, and the acceptance of slight variations in indoor temperature. In a building that is heated to the desired indoor temperature and at steady-state, i.e. the heat losses to the surroundings are balanced by the heat provided by the district heating via a space heating system, heat can only be unloaded by temporarily reducing the heat supply. Once the heat supply is reduced, the indoor temperature will start to drop, but when it does, all materials (walls, floor structures etc.) will start to release their retained heat. The retained heat will make the indoor temperature drop only slowly. The technology used in the Celsius demonstrator in Gothenburg takes advantage of this fact and, if the technology is applied correctly, the residents shall not even notice the small changes in indoor temperature. In order to reload the heat that was “borrowed” from the building during peak hours, the district heating operator can increase the heat supply slightly during other parts of the day, thus maintaining the heat balance over the long run.

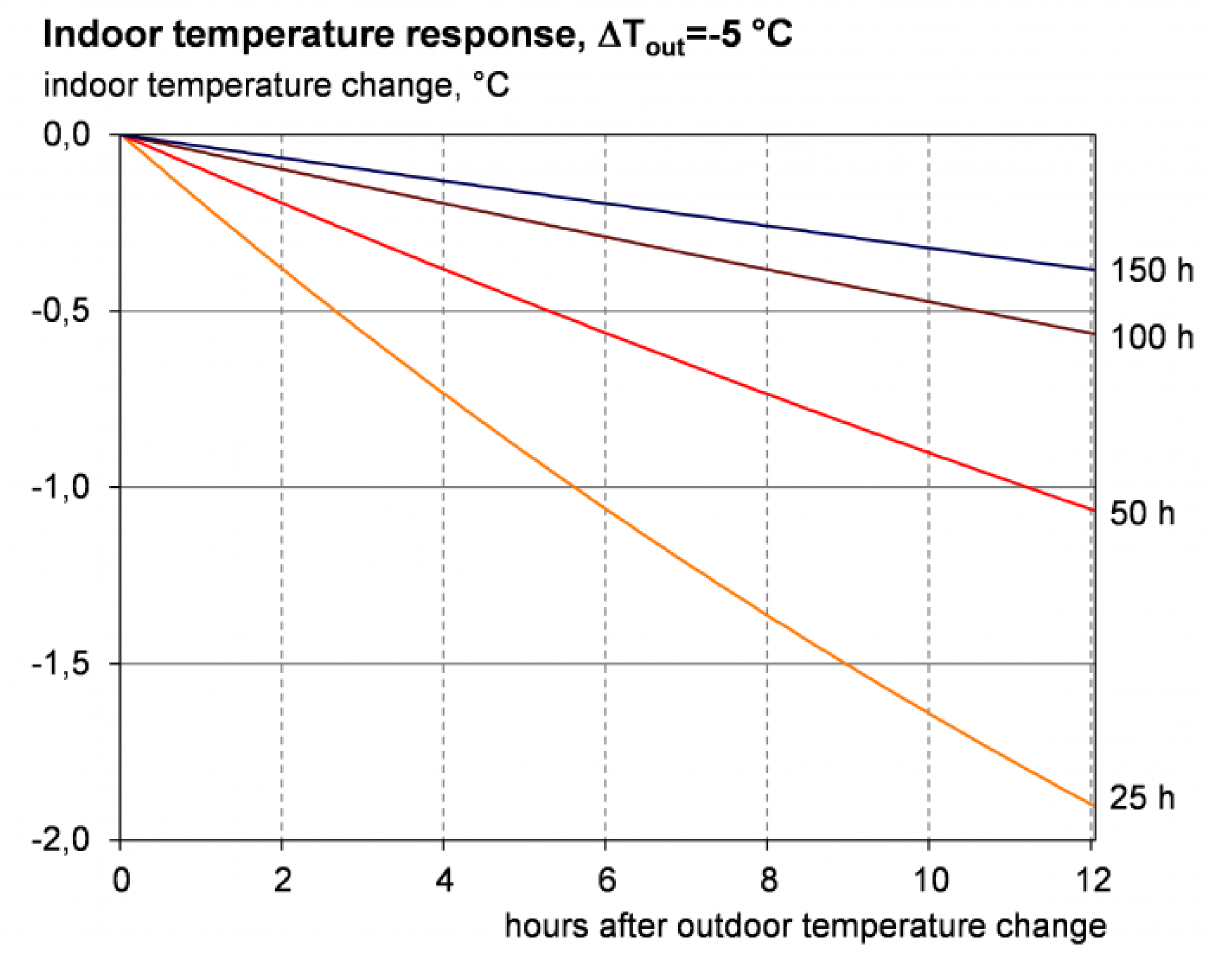

Figure 3: Theoretical change in indoor temperature after a sudden change in outdoor temperature of -5 °C and no heat supply to a building with a time constant of 25, 50, 100 and 150 h

The ability to store and retain heat is dependent on the materials used and varies from building to building. For example, a building with heavy construction materials has a higher capacity to store heat than a light building, and the temperature will drop more slowly. A parameter used to describe this characteristic of a building is the time constant, where a high time constant means that heat is retained for a long time and the indoor temperature will drop slowly. This is illustrated in Figure 3, where the theoretical temperature drop for buildings with different time constants is shown.

In practice, the heat supply changes to the buildings are achieved by manipulating the outdoor temperature sensor signal. This way, no adjustments are needed in the buildings' control system; they are only "made to believe" that the outdoor temperature is either higher or lower than it actually is.

Results from feasibility tests

The Celsius demonstration of this technology is expected to start during the winter of 2014/2015. There are thus no results yet from this demonstrator. However, Göteborg Energi has already performed small-scale experiments and tests of the technology; from which results are available.

One study focused on field measurements of time constants[10]. In previous feasibility studies of the potential of this technology on system level, the average time constant was assumed at 100 hours. The field tests confirmed that this was no underestimation; most buildings had time constants well above that. Even wooden buildings had an average time constant of 102 hours.

Göteborg Energi has tested the technology in real buildings in order to evaluate the effect on indoor temperatures, DH return temperature, achieved heat power reduction and heat power response, as well as to find optimal settings for the modification of the outdoor temperature signal. Evaluations of results from measurements and tests with different test cycles on a number of buildings showed that [11] : • The indoor temperature dropped by 0.18-0.8 °C, which was not more than natural variations. • The heat power reduction was in the range of 10-13 W/m² or 17-21 W/m² building area, depending on the induced change in outdoor temperature (up to ±7 °C from the actual outdoor temperature was tested). Larger induced change gave larger power reduction.

Other tests by Göteborg Energi have also shown that the changes in indoor temperature are small and should not affect the residents' perceived comfort. However, the heat power reduction was found to be smaller than the theoretical value (40-80 %). One explanation could be that well-functioning thermostats counteract the effect of reducing the heat supply, since they do their best to maintain the indoor temperature. From a DH perspective, the return temperature from buildings was affected when applying the technology: it was reduced somewhat during loading and increased somewhat during unloading.

Large-scale replication potential

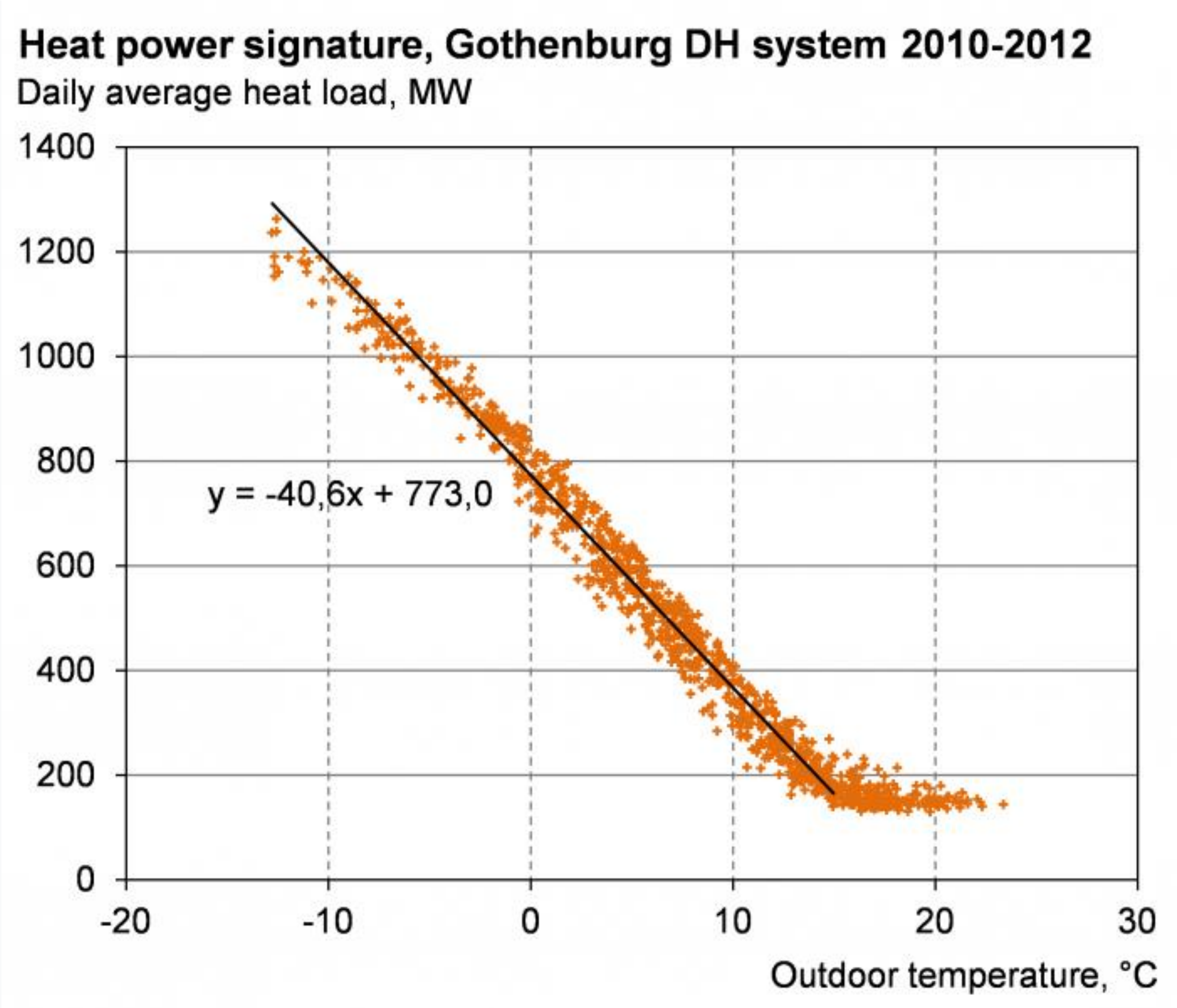

Figure 4: Heat power signature for the Gothenburg DH system. Average daily values from 2010-2012. The linear trend line is based on values up to 15 °C.

Göteborg Energi has been investigating this idea for a number of years, based on preliminary estimations that showed a large potential to store heat in buildings. The limit is set by how many buildings are used for heat storage, and how much the indoor temperature is accepted to change. One way to estimate the large-scale potential is to calculate the approximate outdoor temperature dependence. Figure 8 shows the heat power signature for the Gothenburg system, indicating a heat demand of roughly 40 MW/°C. As mentioned above, the induced outdoor temperature changes used in Göteborg Energi's tests of the short-term storage technology was up to ±7 °C during 9 hours without causing noticeable changes in the indoor temperature. With these assumptions, if 100 % of the heat load was available for heat storage, the daily heat storage capacity would be about 2500 MWh and the unloading rate approximately 280 MWh/h (at outdoor temperatures up to approximately 8 °C). Using the results from section 4.1 in deliverable 5.2 **add link to file**, this means that if an implementation rate of 50 % of the heat load is possible to reach, this technology has the potential to eliminate 99 % of the daily variations in the Gothenburg system. On the other hand, if the technology is targeted at predominantly reducing peaks during periods of high demands (cold days) in order to avoid starting certain peak boilers, a smaller storage capacity could suffice. For example, the coldest day 2012 had a daily variation of only about half of the maximum value (630 MWh compared to 1200 MWh), being possible to eliminate with an implementation rate of 25 % using the assumptions above. Also, at lesser implementation rates, the storage would still reduce the peaks, albeit not eliminating them.

It should be noted that these results are theoretical estimations and that the actual potential may be reduced by a number of factors, including reduced heat power reduction due to well-functioning thermostats (as mentioned above) and the fact that not all buildings are suitable for short-term storage, for example buildings with supply air that is pre-heated by the same system as the space heating, in which a heat power reduction could lead to uncomfortably cold air from the ventilation system. However, the potential may also be bigger, since some heavy buildings could probably tolerate larger reductions than the ones used in Göteborg Energi's tests, and possibly the indoor temperature variations could be allowed to increase slightly more. Furthermore, it is not necessary to aim at fully eliminating daily variations; even at lesser implementation rates, the most unwanted variations in terms of economic and environmental impact could be reduced. The optimal implementation rate should thus consider a number of economic and environmental parameters, not within the scope of this report. However, from the estimations presented above, it can be concluded that the potential for peak reductions with a large-scale implementation of this technology is very large.

More results with this scheme are presented in the last chapter below

Thermal storage and demand-side management of the Electric Grid

only abstract of chapter 6, D5.2. Detailed info referred to the Deliverable.

This chapter analyzes the possible evolution of the use of thermal storage and more in general of the use of electric devices to produce useful thermal energy as tools to shave peaks and save energy on the electric grids.
The gradual shift of electricity production from mainly fossil fuelled, easily manageable power plants to renewable sources with production patterns not in line with demand profiles calls for smart grids, able to dynamically manage energy from these sources thanks to electric storage and to the time shift of several electric uses accordingly with energy availability.
Thermal services (domestic hot water production, space heating and space cooling) are among the electricity uses offering the largest potential for demand profile change, thanks to the ease of storing thermal energy compared to storing electricity.
Such profiles could become increasingly interesting also in the field of district heating and cooling, where electric heat pumps are already in use (although not very diffused; two examples are offered by two Celsius demonstrators in London: Capture of waste heat and extension of the seed network in Islington)and where new applications, such as temperature changes for offering multi-temperature services through CO_2 heat pumps or the use of geothermal heat pumps in combination with seasonal geologic storage, could be developed in the near future, to exploit excess electric production at best.

If you would like to go further, Chapter 6 in Celsius deliverable 5.2 (**link to the file**) addresses the following topics:

- Concept, instruments and aims of demand-side management
- EU framework for the use of heat storage systems as a strategy for peak shaving

- Thermal energy storage and heating - including with heat pumps
- Thermal energy storage and combined heat and power