The end-user in the district heating/cooling network

This first chapter presents the situation on the end-user side of the network. You will find the answers to these questions. Why is it worth focusing on this part of the network? What are the possible end-user scenarios? What are the main control points in the physical layout?

Motivations for optimisation on the end-user side

The load for the DC/DH network is defined by the consumption of the end-user. Therefore the performance of the whole network is dependent on the operation of the end-user side. There are several main benefits from optimising the end-user side.

- Reducing the daily peak means that it is possible to decrease the use of more expensive sources of heat/cooling (e.g. gas boilers).
- Moreover, reducing the highest peak over the year reduces the peak to baseload ratio which in turn can lead to one of the following events. The heat/cooling source fleet can be optimised because a lower capacity is required to meet the demand, or the DH/DC can be expanded without adding extra sources of heat/cooling.
- Besides these, changing the shape of the load can lead to a higher penetration of low-carbon heat/cooling sources because some of these are intermittent.
- By having more control on the end-user side it is possible to adjust the temperature of the water to increase the efficiency of the heat exchange both at the end-user side and at the heat source end. The latter can in turn increase the efficiency of the heat source[1].
- Working on the end-user side is a way of involving the occupants who play an important role in the DH/DC network.
- Finally, having all these elements in mind, it is clear that the DH/DC network stakeholders can benefit from this; and it is likely that other organisations such as energy services companies or building companies will tap into this potential for money if the DH/DC network scheme leaves it available.

End-user scenarios

There is a variety of types of end-users that are supplied by DH/DC networks. Out of all the possible ones, the Celsius project has mainly focused on the residential sector.

Single family house

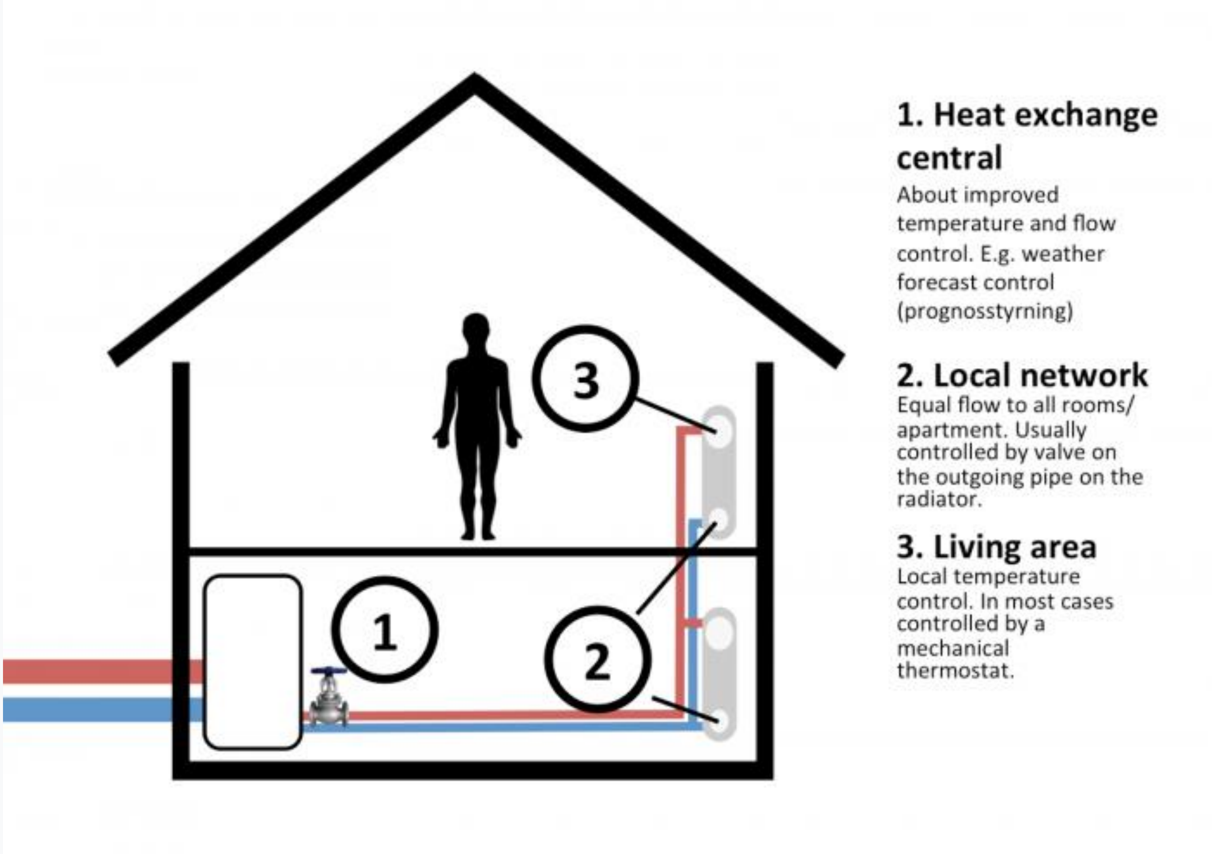

Figure 1: A single family house

In the single-family house the inhabitants usually have their own heat exchanger as well as their own agreement with the energy company that provides the district heating. Since the heat exchanger and its control box is fitted in the house this often allows to place a heat controller in the living space that can communicate with the heat exchanger either through wire or radio. Valves fitted on the outgoing valve on the radiator usually control the hydronic balance, i.e. how much heat each radiator gets. Local mechanical thermostats fitted on the forward side of the radiator control the local room temperature. These will provide local control of temperatures as well as savings when the sun is heating the room through a window. In Sweden the usage of district heating is usually read by AMR technology (automatic meter reading). District heating customers therefore received a monthly bill based on their actual consumption. Often the district heating company will provide statistics on the energy use either on the bill or through an online portal.

Housing cooperative

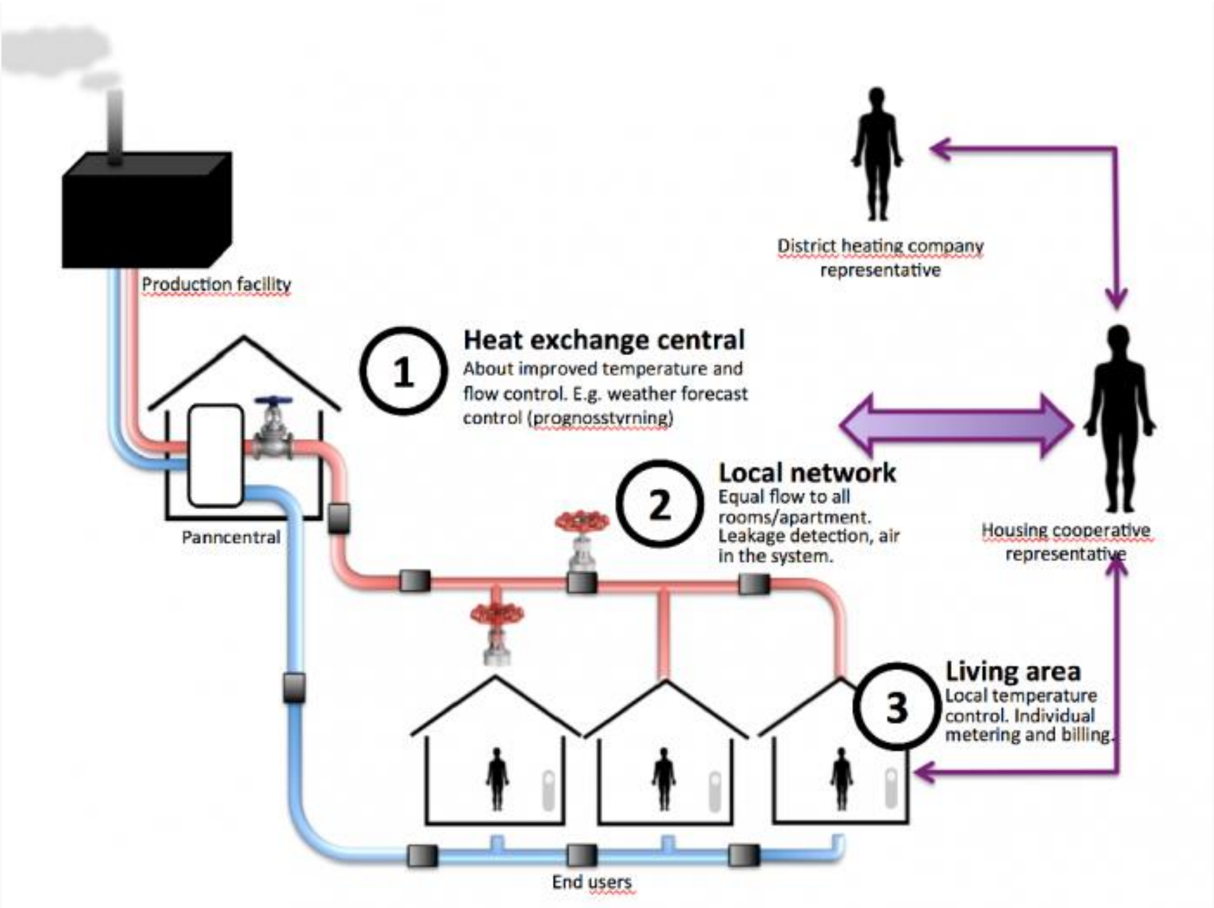

Figure 2 : Heating system of a housing cooperative

The private housing cooperative is a common form of living in Sweden where people own their apartment through a housing cooperative. In this form of living, the tenant governs most basic things about the apartment's interior. Other things like the exterior of a building, the kind of heating system installed, and so on are instead a cooperative decision made either by the housing association's board or by all the members during yearly meetings. In this form the tenants are the users of the district heating but the association is the customer to the energy company. This means that the people using the energy also are generally unaware of the costs connected to the heating of the apartment or their use of hot water (in many cases tenants in an housing association would not even know what kind of heating they have if asked). The most common way to distribute the cost of the heating is to include it in the rent based on the apartment size. Even though the housing associations, just like in the case with single-family houses, will pay heat bills according to the actual usage, however, the tenants will have the same rent all year around.

It is also not uncommon that housing associations own and operate several buildings with a common central heat supply which causes the local district heating network to be both large and quite complex to maintain. Many of the housing associations can also have quite old heating systems. The most ambitious public housing programme ever implemented in Sweden took place between from 1965 to 1974 and produced over 1 million new homes. Many of these homes today owned by housing associations are now in urgent need of renovation and energy efficiency improvements. This raises questions about how to retrofit modern solutions into old buildings as well as how to maintain a heating system that might be changing from week to week as the system is upgraded apartment by apartment or pipeline by pipeline.

Remarks on other possible scenarios

Commercial buildings (offices, shopping centres,...) have different heating and cooling profiles (magnitude ad shape) than residential buildings. The same holds for industrial facilities.

Control points in the local district heating system

A district heating system (in the Sweden scenario) can be divided into three parts (see Figure 1 and 2), (1) the heat exchange central, (2) the local network distributing the heat locally within a building or a building complex and the (3) living space with the radiators and thermostats as the main components. Each of these three areas has one or several potential calibration and control points.

The central heat exchanger

The common medium used for heat distribution in district heating systems is pressurized hot water. In the Swedish system a heat exchanger transfers the heat from the medium in the district heating network into the medium of the local heating system. The medium is in most cases water with some added chemicals to prevent corrosion or colouring to easily detect leakage. In the heat exchanger the amount of heat that will be taken from the district heating network and inputted into the local network or building is controlled by a number of valves connected to electrical actuators. In the most basic setup a control box uses an outdoor temperature sensor as well as a temperature probe into the medium going to the radiators (the forward temperature) to determine how to position the actuators. If the outdoor temperature is below a certain threshold the inlet valve to the heat exchanger will open to raise the forward temperature. If the outdoor temperature is high the forward temperature will be lowered. At +15C the control box typically shuts down the system and also stops the circulation pumps. In this way it will maintain a constant temperature in the house or apartments it is serving. The heat exchanger also heats incoming freshwater to provide hot tap water. This is controlled by another set of actuators and valves as well as temperature sensors measuring the outgoing temperature of the hot water.

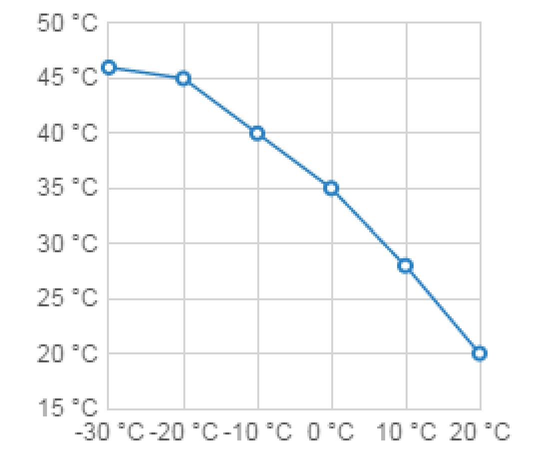

Figure 3: Mapping of the forward temperature in relation to the outdoor temperature

The main problem in regard to the heat exchangers is how to estimate the energy needs of the building. Doing an outdoor temperature to forward temperature mapping will only be a rough estimation of the heat actually needed. This will, in most cases, cause indoor temperature to fluctuate over time resulting in energy waste. In reality the actual need is not only related to the outdoor temperature but also factors such as wind, air moisture, solar radiation, and accumulated heat in the buildings, etc. Modern systems therefore often try to use sensors in the apartment or rooms of the building together with weather prognosis in order to predict the energy need of the building in a more precise manner.

In other words an energy system can be made energy efficient by improving the mapping (i.e. a curve, see figure aside) of the forward temperature with respect to the outdoor temperature. This mapping ought to be as close as possible to the energy need of the building. This is dependent on both the location of the building and a lot of specific factors. It can also be made even more efficient by using even better predictions based on additional data.

The local network

Another important task for a heating system is to balance the temperature so that all rooms or apartments get the right amount of heat (Hydronic balancing). This can be a particularly big problem if the system is large as in our second scenario (on Figure 2 higher up). In many cases, this balance is achieved by adjusting valves fitted on the return pipe of the radiator (opposite to the thermostat). However, if the network is large and spanning several buildings, additional control points are usually needed. In those cases different valves in the system are used to control the flow over different zones. A bad adjustment of these valves will lead to an unbalanced distribution of heat, causing some apartments to become too cold while others, at the same time, will be too hot. In the scenario with a housing association as described above this will generally cause complaints from the people experiencing cold apartments causing the overall temperatures in the system to be raised.

Problems with an unbalanced system will be most severe during cold days when all radiator thermostats are open. In that case, the pressure in remote parts of a local network will drop giving some apartments even less heat during these times compared to the average apartment. In a well-balanced system unbalanced situations can still arise during warmer weather. The reason is that the system is usually calibrated with all of the radiator thermostats fully open. With the thermostats closed in some parts of the system it can cause other parts of the system to get more heat than required. Other methods include the implementation of so-called low flow systems, which in Sweden also referred to as the Kiruna model (after the city Kiruna in the north of Sweden). In these systems the flow of the medium is lowered and the temperature increased. This produces a more even pressure distribution/flow throughout the system. The reason for this is that the resistance between the pipes and the fluid is very small if the fluid is flowing slowly with a low pressure. When the pressure and flow are increased the resistance from the pipes increases exponentially causing the pressure to drop faster throughout the system.

The radiator

The radiator thermostat provides a third and important control point in the heating system. A normal mechanical thermostat that is calibrated and functioning well can often reduce the energy use with up to 30% compared to systems without thermostat or with one that is not working properly. With hydronic heating the most common thing is to use mechanical thermostats fitted directly into the radiator. In commercial buildings electric actuators connected to a central room control are however also quite common. These systems are generally more costly but have several advantages over mechanical systems. The advantages include more accurate control of the room temperature and easier interfaces for the user. In an office environment where there can be as many as ten radiators in the same room it is not feasible for the user to set the temperature by turning handles on each radiator. Electronic systems also have an advantage of not deteriorating in the function over time as mechanical systems do. While it is very important that the mechanical thermostat is positioned at the right distance from the needle or throttle that controls the flow to the radiator, electronic ones will often self-calibrate the distances needed to close or open the flow to the radiator. Many of the electronic systems also have built- in functionality for running the needle in an out from time to time in order for it not to get stuck by corrosion in the valve.

Social and economic features at the end-user level

7.1 and 7.2 of D5.2 This chapters provides insights into the actual situation at the end-user level and how this can interfere with optimising the performance of the DH/DC network. You will read about the heat load, refurbishment, challenges against and levers for change. End user engagement provides complementary insights into these topics.

Heat load: pattern, variations and magnitude

Pattern and variations

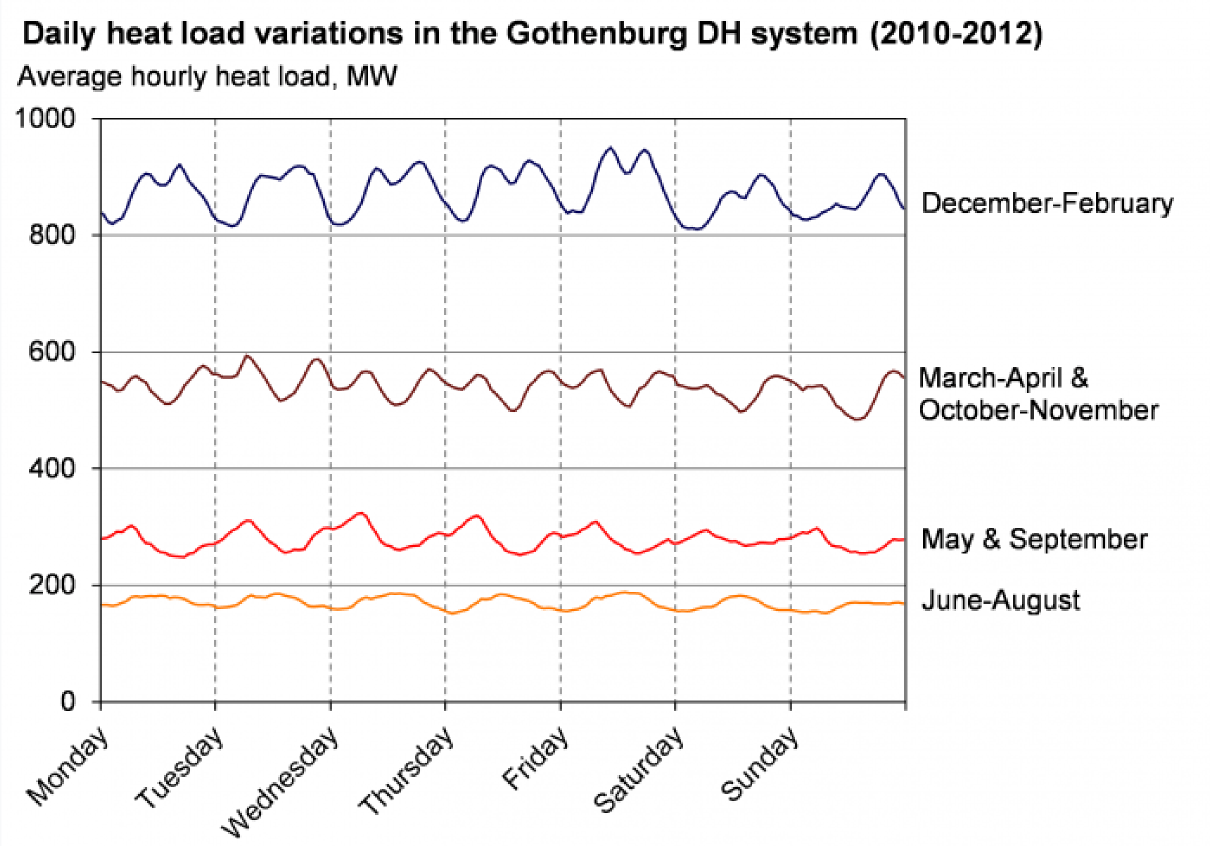

Figure 2: Daily heat load variations in the Gothenburg DH systems, split into four seasons. Average hourly heat load data from 2010-2012.

Heat load in district heating varies both along the heat season, depending mostly on external temperature, and along the day, due to user requirements (i.e. desired internal temperature is lower during the night than during the day and optimal internal temperatures during the day depend on the real occupation of homes and buildings), to weather conditions and to the domestic hot water use patterns. These variations are visible in Figure 2. **add link to file** Section 3.1 in Celsius Deliverable 5.2 provides an illustrative case study for Gothenburg.

Variations in the network load, and especially the peaks lead to a higher economic and environmental cost of heat production. Peak boilers have to be used usually. For many reasons, removing the production peaks would benefit to the network performance. One of the solutions lies in storing energy at times when the 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. Furthermore the appropriate billing method is necessary.

The effect of refurbishment on the magnitude

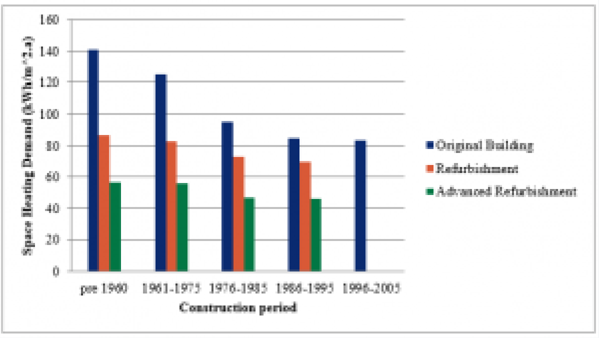

Figure 3: Theoretical potential of refurbishment on southern Swedish residential buildings space heating demand

An obvious deterministic driver of individual heat demand is the quality of the building stock and the energy efficiency of construction materials. Buildings with higher energy efficiency exhibit lower space-heating demand as a result of their increased thermal insulation. Thus some of the benefits highlighted above, namely the ones related to the magnitude of the load could be obtained by refurbishing building envelopes. Energy efficiency is expected to have an impact on future heat demand and is a key parameter of the deployment of demand side management schemes based on short-term storage in thermal building envelopes. A building designed for short term storage in its thermal mass allows for more flexibility in the thermal energy supply and control of the building. One way to reduce energy consumption in the single buildings is through refurbishment of the existing building stock. A considerable number of studies have been put forward in order to assess the potential of refurbishment and renovation for residential buildings. The studies include some European initiatives like the TABULA project (Typology Approach for Building Stock Energy Assessment, 2010a, 2010b), EPISCOPE (Energy Performance Indicator tracking Schemes for the Continuous Optimization of refurbishment processes in European housing stocks, 2013), “Europe’s Buildings under the microscope” by the Building Performance Institute Europe (Buildings Performance Institute Europe - BPIE, 2011). According to the model-based TABULA web-tool it is estimated that there is an energy saving potential of up to 60% in the renovation for buildings in southern Sweden cities like Gothenburg (Figure 3). Some more specific studies have been carried out at Goteborg Energi with respect to a range of refurbishment options such as double glazing windows replacement, enhanced wall insulation and the use of micro-grid thermal collector. The use of solar collectors has an impact on the need for district heating hot water consumption during the summer. In some instances, solar heat has been used in combination to large scale heat storage in the system as a way to decrease peak time consumption. solar thermal collector. These aspects are discussed in section 7.2 of **Celsius deliverable 5.2**[2]. As refurbishment does not only change the space heating demand of the building but also changes the thermal mass of the building, it should be taken into account when modeling smart energy management methods, which is the case in Chapter 6 below.

Refurbishment case study: Effect of building energy efficiency technology in Gothenburg

5.2 of D5.2

Space heating demand and gap to current standards

A well thought-out, long-term rationalization plan based on the survey of different types of buildings and coordinated with existing maintenance planning is necessary in order to achieve a significant level of energy efficiency in buildings. In order to achieve the Swedish national environmental objectives it is estimated that the annual energy consumption in the building sector should decrease by 30 TWh by 2020 and by 75 TWh by 2050. A large proportion of the Gothenburg building stock was built in the 1950-1975 period. It is possible to take the opportunity to tackle the energy efficiency enhancement of these older buildings as part of their normal renovation cycle. Typically, these houses constructed during the 1950-75 period are similar in terms of energy efficiency and were built with minimal energy efficiency requirements. This constitutes an advantage for a possible fast impact on the entire construction sector. The buildings typically have the following properties:

- 10 cm insulation in exterior walls and 15 cm for ceilings, compared to nowadays' 20 cm and 40 cm standard;
- Balconies and supporting walls are major thermal bridges with only a thin insulation layer behind the façade's cladding;
- The windows U-value is about 3.0 W/m2/K, compared with the current construction standard of around 1.2 W/m2/K;
- Natural ventilation systems are prevalent in the houses built before 1961. Heat recovery ventilation systems are uncommon in buildings built prior to 1975. Exhaust fans often show poor efficiency leading to unnecessary electricity consumption;
- Hot water usage is high;
- Individual meters for electricity are non-existent so the user has no financial incentive to save household electricity;
- The average energy consumption for a typical apartment building is 150 kWh/m2 [3].

Aggregate effect of refurbishment

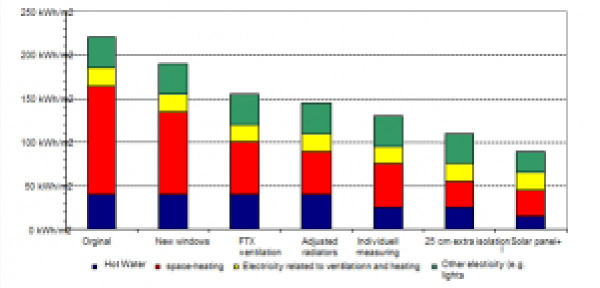

Figure 4: Impact of different energy efficiency measures on residential buildings in Gothenburg

It is evident that refurbishment will have a direct impact on the heat consumption of a given building. However, it is important to be able to quantify the overall impact of energy efficient measures. In a city like Gothenburg, this will primarily involve the quantification of the rate of refurbishment of the building stock. A possible way to perform this analysis would be the use of agent based models in order to survey the emerging behaviour, i.e. the collective impact of individual houses refurbishment on the overall heat load. In order to address these energy efficiency shortcomings, Swedish municipalities like Gothenburg have engaged in a holistic approach for energy reduction which was outlined by the Swedish ventilation association (Svensk Ventilation, 2008): 1. The first measure towards improved energy efficiency naturally consists of achieving a better insulation of the building envelope. 2. The second step consists of bringing improvements to the ventilation system. Energy reductions must never happen at the expense of the comfort of the occupants. 3. Once these measures concerning the building envelope and ventilation system have been achieved, it is necessary to adapt the heat supply system (radiator system) to the new heating requirements needed in every room. 4. Afterwards, it is also beneficial to investigate energy savings that can be derived from the enhancement of the hot water systems. 5. Eventually, some additional measures such as individual metering and the implementation of solar thermal panels can be implemented. These steps are described in more details in section 5.2.1 of deliverable 5.2 **link to file**.

Figure 4 gives an overview of the heat saving achieved through the subsequent implementation of the aforementioned energy efficiency technologies. The measures are essentially re-design features.

Context at the building level

What types of end-users are targeted in strategies for end-user efficiency? And who is responsible for managing the heating of a building? These questions can be answered differently in different contexts. For example, various end-user segments can be distinguished for apartment buildings in the CELSIUS project, eg. house owners, private building owners, housing corporations, etc which need different incentives and intervention strategies if they are to adopt energy conservation technologies or change their behaviour. Such incentives are usually based upon individual metering, by providing users with their uptake of a certain resource, like electricity. Several individual metering options for managing household energy consumption are available on the market (eg. Apple's Homekit, The intelligent NEST heating meter, Energy Aware Clock for electricity, see also Celsius D2.1 and D5.3 **upload the files and insert the link**), as well as the Swedish National Energy agency providing general household-related tips on their website to address energy management in a dwelling.

Challenges related to the operation of building-level energy systems

Currently there is no option, at least in Swedish apartment buildings, to calculate the individual uptake in terms of heating and hot water uptake, which reduces the possibilities for end-users to take into account the effect of their actions and relate this to their uptake. There are other important differences though between individual behaviour oriented approaches for reducing electricity uptake and reducing heating uptake in apartment buildings connected to the CELSIUS district heating systems. The district heating system is very difficult to regulate to meet changes over the day. The production systems have high inertia, which is also the case with the customers' heat usage, due to the fact that the buildings themselves can store energy.

Another important issue is the fact that end-users are actual people with different ideas of building management and daily household practices, which are often not taken into account. Such social factors especially in the context of decision-making, communication and social groups in the building cannot be readily accounted for in the technical approach of heating management system optimisation.

Levers for change

In Swedish apartment buildings it is the building owners or housing cooperatives of the apartment buildings, not the residents themselves, who take decisions on the temperature level in the whole building. Through addressing the need for optimisation of the system and a reduction in the indoor climate temperature, as well as social responsibility for the environment, also as citizens and co-owners of a building, they may become aware and proactive towards adoption of energy reducing strategies. The decision to change the temperature is therefore also a collective one with different mechanisms and incentives for change than those, which are only partly individual oriented. At least the mechanisms for change through personal gain and awareness incentives seem to work differently and through different types of actors. It seems more beneficial to look for heating management processes that support creating variation in indoor climate combined with optimisation of the district heating system. Therefore, in the next sections we have addressed the optimisation and management of the building rather than focusing on individual factors. Hence in this article we also address other types of optimisation methods than technical functionality to explore strategies for end-user efficiency. We started our investigation with a demonstrator, Climate Agreement (GO2), from the Celsius project and interviewed several types of actors, with the aim to understand how they manage and control the heating system in the buildings. This research is presented in the next chapter.