# Trabajo Fin de Máster

Título del trabajo: The flow impact on a radiator system

English tittle: The flow impact on a radiator system

Autor/es

Juan Antonio Catalán Solsona

Director/es

Guillermo Hauke
Roland Forsberg
Taghi Karimipanah

Master Universitario en Ingeniería Industrial

ESCUELA DE INGENIERIA Y ARQUITECTURA
2016

FACULTY OF ENGINEERING AND SUSTAINABLE DEVELOPMENT

Department of Building, Energy and Environmental Engineering

# The flow impact on a radiator system

## A case study in district heating system

Juan Antonio Catalán Solsona

June 2016

Student thesis, Master degree (one year), 15 HE
Energy Technology

Master Programme in Energy Systems

2015/2016

Supervisor: Roland Forsberg, Taghi Karimipanah
Examiner: Shahnaz Amiri

# Abstract

Most buildings are warmed up using district heating in Sweden. That process consists in obtaining the thermal energy in high efficiency from plants and transport it to the customers, using water flowing through the pipes. Radiators with thermostatic valves in a building give the possibility to save the energy consumption and they are designed to achieve a pleasant indoor temperature. These radiators are connected with the district heating system.

There are two principal methods for balancing radiators in a heating system: low flow and high flow. Some specialists say that it is possible to save energy applying a low flow method. Some others disagree with this method because it has some disadvantages such as the difficulty of integrating it with alternative energies. Finally, it is necessary to analyse each case separately to know which method is better.

In this Master Thesis, the flow impact on a radiator system has been studied and analysed. This study has been realized in a particular building connected to a district heating system. The aim of the project is to compare the performance using traditional high flow and low flow. For doing that, some measures in the building have been taken to design the network radiators system. TVAROR is the simulation software that has been used to simulate and solve the modelled heating system.

The system has been tested with a configuration of 70/40°C (Supply and return temperatures in the radiator) for low flow and 60/45°C for high flow method. Two different periods have been chosen for the simulations, but both of them during March. For this period, three different calculations have been carried out to know which method is more profitable, which are: the mean temperature inside in the building, the effect of the pump and a comparison between real and theoretical temperature curves for a radiator system.

Lastly, it has also been discussed the main results obtained in each calculation. The main conclusion is that it is more efficient to use the low flow balancing method for this particular building. However, it must take into account that the low flow method can have some problems. One of them is that if the water mass flow rate is very low, the pump gets dirty due to sediments. Besides, the pump generates more noise because of it is necessary to strangulate more the valves. When the valves are more strangulated, the radiator valves also will have more dirt due to sediments.

# Acknowledgements

Through those sentences I would like to express my thankfulness for all the support that I have received during this Master Thesis.

In first place, I would like to express my sincere gratitude to my supervisors Roland Forsberg and Taghi Karimipanah for all the knowledge that they have transmitted to me and their support during all these months.

Moreover, I would also like to thank Magnus Jägbrant from Akademiska Hus for helping me with the instrumentation needed in the experimental measurements and give me the opportunity to stay in his installations.

Last but not least, I want to thank my friends that I have met during this experience and to my family and partner. It would not have been possible without them.

# Table of contents

# 1 Introduction

## 1.1 Background

Heating systems in buildings are designed to achieve a pleasant indoor temperature. In Sweden, the most of the buildings are warmed up using district heating [1]. A heating system in a building is made up for the three parts: heat production, piping network (distribution) and heat supplier.

The heat production can be obtained from the industry in the form of heat recovery, which otherwise it would have been lost. The heat production is produced with a high efficiency in central plants and they emit less emissions to the atmosphere than other alternatives [2]. The piping network can be divided into a primary and secondary system.

The first ones include from the heat production to a heat exchanger that is situated in each building in order to transmit the energy from the primary line to the secondary line [2]. The secondary systems include from the heat exchanger to the radiators and it is included every pipe and different type of valves. This master Thesis focusses on this point. Figure 1 shows schematically roughly the district heating system.

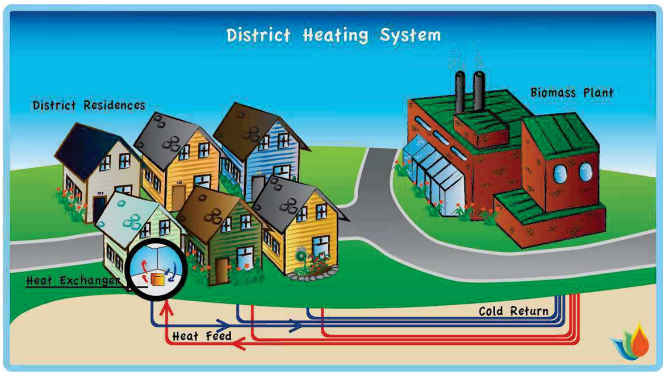


*Figure 1: district heating system [3].*

The design of supply/return temperatures has been changing over time. In the past, the temperatures in use were 90/70°C or 80/60°C. In the following years, it has been preferred to use lower temperatures, for instance 60/45°C or 55/45°C [4].

Nowadays, there are two ways for working in the radiator systems: high and low flow. The first one is the most common and has a temperature difference about 10°C, which leads to a higher flow. The low flow systems on the other hand have received both support and opposition.

Against low flow systems, new sources exist like solar collectors, which work better with lower temperature. As for positives, if the Thermostatic Radiator Valves (TRVs) are working with low flow systems, it is possible to reduce the power of the pumps and reduce overheating. Thus, less heat is consumed and a lower return temperature is obtained [5] [6].

In these times, because of increasing of greenhouse effect, business competition and increasing of energy demand, the research of the Radiator Thermostat Valves (RTVs) and low flow heating systems have become an important part to improve the environmental and the system performance [7].

## 1.2 Objective

Companies are aware of the significance of using energy efficient methods. That, together with the possibility of increase the benefit make them interested in research. The primary goal of this Master thesis is to compare the flow impact on a radiator system. For that, the energy savings between using traditional high flow and low flow methods are compared and the best option is chosen. This means, calculating the system efficiency with different flows and demonstrating which is more economical. The flow is adjusted by pressurized valves in the supply pipes. For that resolution, software TVAROR is used.

## 1.3 Limitations

Practical testing requires a too expensive and qualified measuring equipment, which was not available for this work. Before writing about the rest of the limitations, it is interesting to show the Figure 2, where the heating network can be seen.

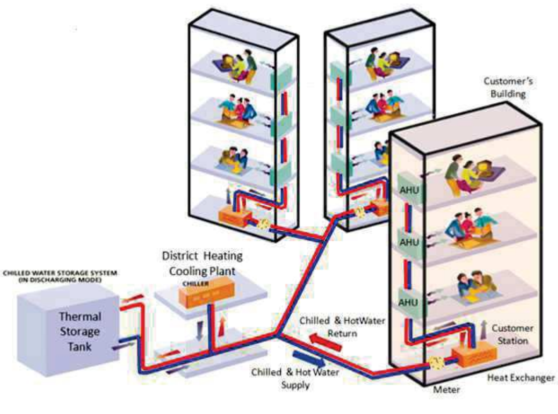


*Figure 2: district heating network [8].*

Because of the model is just about a building, only the local regulation in heating system is studied. Thus, the primary line is omitted. The same occurs with the system that works in the form of shunt and main valves, which can lead to carry an investment costs or similar that have not been audited. This is because just one building is going to be simulated and the main valves dependent of the whole system.

Another boundary is that the valves could have a small leakage, but this can be considered negligible.

For the case with less flow there is a limitation and this is that the main valve has real limitations because it is impossible to close the valve until it wants. Because if it closes the valve too much the system could have not enough water. For this reason, it has been decided that the flows for both cases will be 150 % of nominal conditions. This thesis compares the two flows, since when they are comparing two values between them, the result is zero.

# 2 Theory

In this chapter some definitions and concepts are described to understand the rest of the work. However, some basic concepts are not explained in this section because it is assumed that they are known by the reader. For more basic concepts relating to this Master Thesis, see Trüschel (1999) where theory of hydronic heating systems are fully described.

## 2.1 Heating system operation

The efficiency and performance of the heating system depends on system modelled and its control. In this work the control of the heating system is not studied, it focusses completely on the analysis of the modelled system. Before analysing the system, it is interesting to understand its design. The better the design is known, the easier it is to study and analyse it.

The operation of the heating system can be seen in the schematic Figure 3 and it is described below.

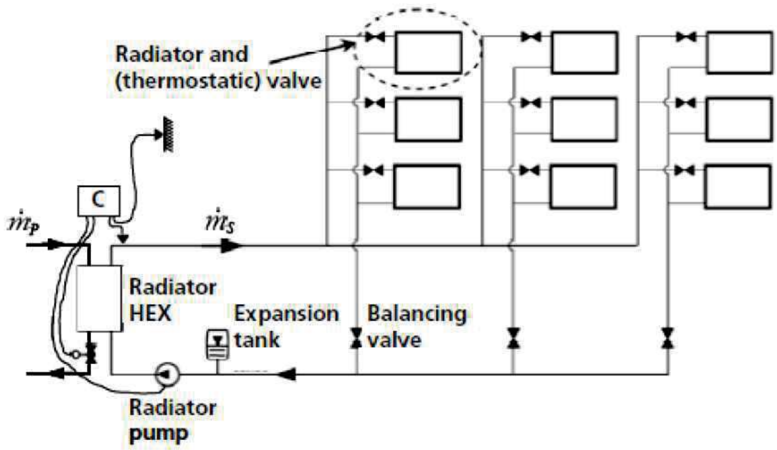


*Figure 3: schematic picture of a space heating system connected to district heating.*

This figure shows mostly the secondary line, since it is that has been studied in this work. The heat exchanger is the device responsible for connecting the primary and secondary system, which enables energy transfer between both systems. The temperature of the water from the district heating depends directly on the outside temperature, Tout. In the main system it can also observe the primary water flow, $\dot{m}p$, which is regulated by a valve in charge.

In the secondary line, the secondary water flow, $\dot{m}$s, is controlled by a local pump. To control pressure variations in the network, it is useful to use the expansion tank.

In heating systems, the differential pressure usually decreases as the water flow is leading through the radiators. There are several reason why this phenomenon occurs, but there are two main reasons: the friction that occurs within pipes (dynamic pressure) and the height difference between the pump and the radiator (static pressure) [10]. This is explained in more detail in section 2.3. To minimize the lost pressure, balancing valves are used. These valves are typically placed in its standard (right) position when the radiators are installed in the building. With the help of these control valves it can also be changed the flow of water passing through the radiators. Thus it is achieved cope with fluctuations in room temperature, $T_{room}$.

## 2.2 Radiator

The heat released by a radiator can be divided into radiation, convection and conduction. The heat due to conduction, is generated by transmission between two solids. The proportion of heat transport caused by conduction can be assumed negligible compared to convection and radiation because this type of energy is not big when a gas is involved. The relationship between convection and radiation depends on the design of the radiator and radiator temperature levels.

$$\dot{Q}\text{radiator} \approx Q radiation + \dot{Q} conv \quad (1)$$

Where:

$Q$radiator: total power by the radiator [$W/m^2$]

$Q$radiation: power by radiation [$W/m^2$]

$Q$conv: power by convection [$W/m^2$]

Radiation is the transmission of energy due to electromagnetic waves through a material or through a space due to their thermal agitation.

$$\dot{Q}\text{radiation} = \varepsilon * \sigma * (T^4\text{radiator} - T^4\text{room}) \quad (2)$$

Where:

$Q$radiation: heat because of radiation [$W/m^2$]

$\varepsilon$: emissivity factor

$\sigma$: Stefan Boltzmann's constant ($5.67*10^{-8}$ $W/m^2 °C^4$)

Tradiator: temperature of radiator [°C]

Troom: room temperature [°C]

The fundaments of natural convection are based on density differences. When the radiators heat the surrounding air, this starts to rise because its density decreases. Thus, it is possible to leave space near the radiator, which deals with more air.

$$\dot{Q}conv = \dot{m} * h * (Tradiator - Troom) \quad (3)$$

Where:

Qconv: power by convection [W/m$^2$]

h: convection coefficient [W/m$^2$°C]

Tradiator: temperature of radiator [°C]

Troom: room temperature [°C]

According with the water mass flow, the energy balance is:

$$\dot{Q}= \dot{m} * cp *(Tin - Tout) \quad (4)$$

Where:

Q: power from the water to the radiator [W]

$\dot{m}$: water mass flow [kg/s]

cp: specific heat of water [J/kg°C]

Tin: temperature of water at radiator inlet [°C]

Tout: temperature of water at radiator outlet [°C]

It is important to know the heat power required of each radiator. The heat power depends on several factors such as: the weather where the building is built, the design temperatures, its insulation, the kind of building (residential, apartment, office…). In addition, radiators must be designed oversized to ensure that this well sized for the coldest days.

## 2.3 Balancing

The purpose of the balancing is to establish the correct flow through each radiator in the system. It is very important to make this correctly because it affects how the flow is distributed through the different radiators and branches. However, the balancing does not only affect the distribution of flows across the system, but also affects the heat release components and their properties.

$$\Delta p_{\text{total}} = \Delta p_{\text{radiator}} + \Delta p_{\text{pipes}} + \Delta p_{\text{valve}} \quad (5)$$

Where:

$\Delta p_{\text{total}}$: pressure loss in the system [Pa]

$\Delta p_{\text{radiator}}$: pressure loss in the radiator [Pa]

$\Delta p_{\text{pipes}}$: pressure loss through pipes [Pa]

$\Delta p_{\text{valve}}$: pressure loss across valves [Pa]

To get a fluid running through a pipe, it must have a pressure difference. It is also interesting to note that the flow amount is limited by resistance. Pressure loss is due to energy losses such as: losses due to big changes in speed or losses produced by direction changes (elbows). All of these factors affect the flow and determine whether the flow is laminar or turbulent depending on the Reynolds number. The Reynolds number is non-dimensional:

$$Re = \frac{\rho v D}{\mu} \quad (6)$$

Where:

Re: Reynolds number

ρ: water density [kg/m$^3$]

D: inside pipe diameter [m]

μ: water dynamic viscosity [Pa*s]

For calculations, a limit number is set to determine whether the flow is laminar or turbulent. It is estimated that a flow is laminar when Re=< 4000. While the flow is turbulent when Re> 4000. In reality, this does not happen suddenly, there is a large range of transition where it is uncertain whether the flow is laminar or turbulent. However, in practice as a result of suspended particles in water that increase the roughness of the pipe, elbows and branches a turbulent flows usually occur. The magnitude of the flow is determined by the relation between the differential pressure and the flow resistance. The following expression shows this relation and is valid only for fully turbulent flow:

$$q = \sqrt{\frac{\Delta p}{k}} \tag{7}$$

Where:

q: flow [$m^3/s$]

$\Delta p$: differential pressure [Pa]

k: flow resistance [$Pa/(m^3/s)^2$]

In heating systems, a circulation pump is used with the purpose of creating a pressure difference. This pressure difference generated by the pump is the driving force of the flow, which gradually decreases if the distance of the radiators is further away from the pump. That means that the pressure difference will be lowered as radiators are further from the pump. This can be seen in Figure 4.

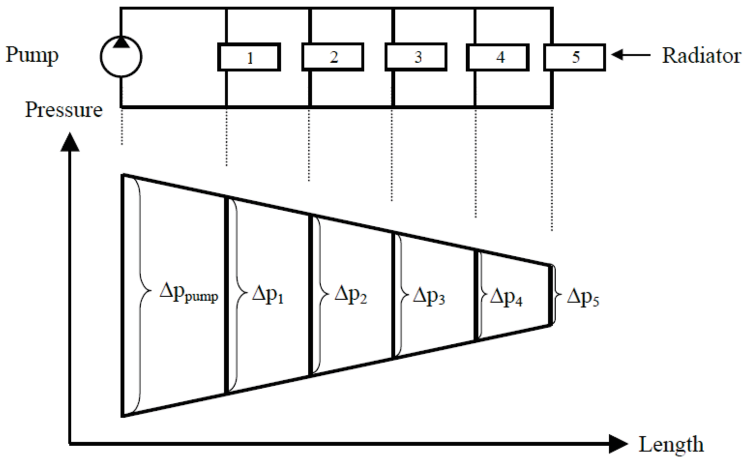


*Figure 4: differential pressure in a heating system with five radiators.*

As the flow through all the radiators are the same, there must be different flow resistances for each radiator. For example, there needs to be through radiator 5 a less flow resistance which through radiator 1. To achieve this balance, the balancing valves must be opened or closed. Thus, the flow resistance is changed.

### 2.3.1 Valve capacity

The valve capacity can be expressed by using the Kv-value and indicates the amount of the flow [$m^3/h$] passing through a valve with a differential pressure of 1 bar. Kv-value is non-dimensional, but is a relative measure.

$$Kv = \frac{q}{\sqrt{\Delta p}} \tag{8}$$

Where:

kv: valve capacity

q: volume flow through the valve [$m^3/h$]

$\Delta p$: differential pressure through the valve [bar]

Kv nominal value is usually the equivalent to full open. Therefore, a pre-setting for each radiator valve must be done to set the Kv-value properly. This pre-setting is different depending on the manufacturer's brand. To adjust low flows very low capacity values are required, such as valve capacities between 0.01 – 0.05.

### 2.3.2 Pump and system characteristics

Heating systems always have a circulation system, in which the water is driven by a pump. The pump is the machine that guarantees the pressure drop in all of the system. The pump characteristic is calculated by the size and the design of the pump, it shows the relationship between the flow through the pump and the pressure increase that have to be provided by the pump. The magnitude of the flow, changes depending on the valves, pipes (material, direction changes, size, etc.) and heat-releasing components. All of these variations influence the pressure drops of the heating systems.

On the other hand, the system characteristic is known as the curve that shows this dependence. The system operating point is the point where the total pressure drop in the system is the same as the pressure increase given by the pump, this can be observed in the Figure 5.

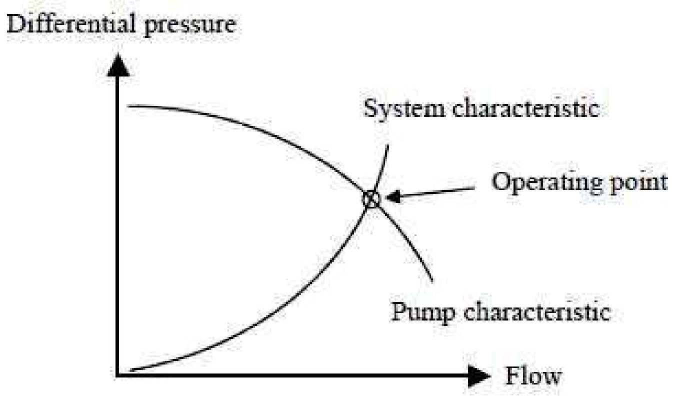


*Figure 5: pump and system characteristics [9].*

The system characteristic curve changes depending on the flow resistance of the system. The lower the flow resistance, the lower the pressure loss in the system for any flow. Therefore, when something changes in the system, also the position of the operating point is going to change, in a new total flow in the system. If the system characteristic is changed there is a new balancing as a result and this is because of the balancing valves are partially more open or closed and the pressure increases or decreases by the pump at the same time. Definitely, the total pressure loss in the system would change. Figure 6 shows an example of how would be a change in the operating point in a system.

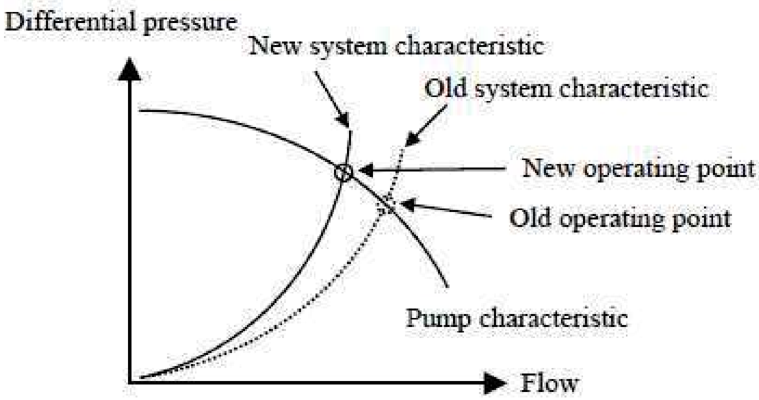


*Figure 6: new system characteristic, changing the operation point in a system [9].*

### 2.3.3 Categorisation of systems

In heating systems there are two different types of systems according to their temperature, the low-temperature and the high-temperature system. Low temperature systems are designed for an average temperature about 50°C, which means that the average temperature of the supply and return is 50°C. While, heating systems that are designed for high-temperature have a maximum average temperatures. The system temperatures are usually indicated by the next way. For example, a 60/45°C system has a supply temperature of 60°C and a return temperature of 45°C.

In heating systems there are also two different types of systems according their flow, the high-flow and low-flow systems. A common balance that was made is based on balancing each valve, one by one, of each branch or group, being them independently in respect of each branch or group. This occurs because the flow is relatively high and therefore the pressure drop between each valve is considerable for the balancing. These systems are called as high-flow systems and some examples of these are: 60/45°C, 80/60°C and 55/45°C.

The first low-flow balancing was made by Östen Sandberg in the 1960s and manages to reduce considerably the flow in comparison to the high-flow system. This new balance allows to reduce the pressure drops between the valves of each branch or group. Thus, each branch or group has almost the same differential pressure and there is no need for each valve of the group are independent as before. Some examples of temperatures are: 70/40°C, 70/30°C and 80/40°C.

Finally, it should be noted that one high-flow and one low-flow system has been analysed in this work and they have the next temperature differences:

- High flow: 60/45°C.
- Low flow: 70/40°C.

## 2.4 Effect in a heating system

One great form to compare which water mass flow balancing is better is calculating the effect in the pump. Thus, it is possible to know which water mass flow method that needs less power to drive the water through the pipes. The next equation is used to calculate this effect:

$$P = \frac{Q * p}{\eta} \quad (9)$$

Where:

P: effect (W)

Q: flow ($m^3$/s)

p: Pressure (Pa)

$\eta$: efficiency (%)

Finally, the next equation is used to calculate the total energy consumed by the pump during all the year:

$$E = P * t \quad (10)$$

Where:

E: energy (Wh)

P: effect (W)

t: time (h)

The heat pump runs continuously, it stops only when the outside temperature is higher than plus fifteen degrees. The exact operating time is hard to come by, so it can make an estimation of how many hours Gävle has a temperature below 15 degrees. It has been estimated that there are about 10 hours per day during summer station (three months) with a temperature higher than 15 degrees. Thus, it can be estimated about 7740 working hours for the pump.

## 2.5 Thermostatic radiator valves

The purpose of thermostatic radiator valves is to regulate the heat output according to the set room temperature. Regulation of the valves is done by reducing or increasing the flow through the radiators. In addition, it is provided that by using thermostatic radiator valves energy savings in heating systems are achieved [10] [11]. The thermostatic valve is mounted directly on the radiator and consist of the valve, actuator, controller and sensors in an integrated component [12]. It can be seen an example of a thermostatic radiator valve in Figure 7.


*Figure 7: thermostatic radiator valve [13].*

The mechanical design of the thermostat allows moving the valve plug and produces a temperature change inside the room. When a proper operation with the thermostatic valve is done, these can help to maintain the desired and uniform temperature in the room. Additional heating can be recovered by thermostatic valves and this is important for saving energy [14]. When small changes in the flow cause large changes in the system, it can be said that the energy gain is significant. There are different parameters in a thermostatic valves, which are described in more detail below.

### 2.5.1 Valve characteristic

Each designs of mechanical valves generate different valve characteristics. Depending on the system type, different valve characteristics are needed. The valve characteristic shows the relation between the capacity (kv) and the amount by which the valve is opened (H), and is expressed in percentage [12]. The valve opening (H) represent how much the valve head was lifted. H=0% indicates that the valve is fully closed and kv also becomes zero. On the opposite side, if H=100% denotes that the valve is fully open and therefore kv achieves its maximum value. Nevertheless, in the practice there are usually leakages, which are neglected when the valve is closed. These values can be expressed as a per-unit value, from 0 to 1.

The Figure 8 shows different examples of various characteristic of the mechanical valve, which is the ratio between the capacity value and the valve opening, both are expressed as relative values.

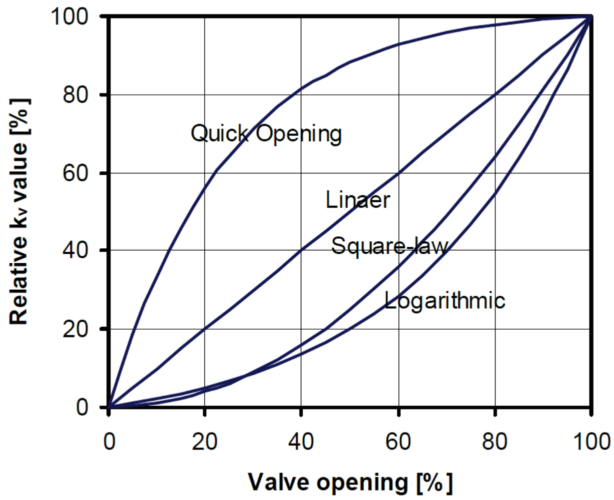


*Figure 8: four different mechanical valve characteristics.*

It is important to notice that logarithmic and linear characteristics are standardized, and the linear one is used in this work. The quick-opening form are used in shut-off valves, they are not usually used for control valves [15].

The flow through the valve depends on the differential pressure across it and its capacity such as in equation 8 that was previously described.

If the differential pressure is constant, the relationship between the valve capacity and the flow is directly proportional. Therefore, it can be said that the valve characteristic has the same aspect, it does not matter if the Y-axis in Figure 8 indicates the relative kv-value or relative flow.

### 2.5.2 Valve authority

The true valve characteristic and the mechanical valve characteristic are the same when a constant differential pressure goes across the valve. However, if the differential pressure is altered, the true characteristic changes, and therefore the true characteristic does not match with the mechanical one. In heating systems is produced a pressure drop across the regulating valve because of the heat demand changes. In this case, the mechanical valve characteristic differs from the true valve characteristic.

The valve authority (β), is known as the relationship between the pressure drop across a control valve when it is fully open and the pressure drop when the valve is fully closed [7].

$$\beta = \frac{\Delta \text{p,fully open}}{\Delta \text{p,fully close}} \qquad (11)$$

Where:

β: valve authority

$\Delta p$, fully open: pressure drop across the valve when is fully open [Pa]

$\Delta p$, fully close: pressure drop across the valve when is fully close [Pa]

The range of the valve authority is between 0 and 1. The value 1 means that the mechanical characteristic is the same as the true valve characteristic, which is almost impossible to get in practice. A design with β=0.5 is common in the practice because the pump that it is needed is cheaper and the requirements are lower.

Figure 9 shows how the deformation, in a linear valve, of the true valve characteristic varies in function of β. When β=1, the true characteristic continues being a straight line, that is the mechanical characteristic for the linear valve.

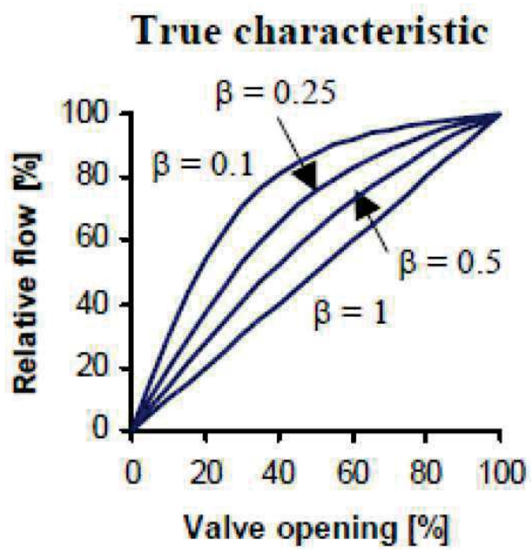


*Figure 9: true valve characteristic [9].*

As can be seen in Figure 9, as the valve authority decreases the dependence of the valve opening on the flow through it is smaller. In this case, it is common to say that the valve authority is poor. By contrast, when β=1 the valve has full control over the flow, because the valve opening changes in the same way as the flow rate changes. The best option is to design a system so that the valve authority is high and thus the true characteristic is distorted less [15]. Although it must not neglect that what matters is the form of the true characteristic.

### 2.5.3 Hysteresis

Hysteresis is the temperature change necessary to overcome the frictional forces, which means that the valve starts to move. Hysteresis may of course be much greater for a valve that has been stopped for a long time, for example, after the summer season [16]. Frictional forces also increase with time with the lubricant aging or if they does not exist. The hysteresis is of the order of 0.25-0.5°C according to the technical data of known suppliers.

### 2.5.4 Max limitation

Maximum limitation of the valve is the temperature that the thermostat is experiencing when the valve is fully closed. When a valve is at the maximum limit, the maximum temperature must be taken into account, which have an effect on the flow very different [16]. Most of the thermostats have a scale for adjusting the closure temperature. Thus, it can make an adjustment to the radiator thermostat, whenever the thermostat is positioned properly, not, for example, behind furniture, curtains or similar.

## 2.6 Theoretical supply and return temperature general curves

Heating system can work with different supply and return temperatures. Figure 10 shows different supply and return temperature curves used in Nordic countries for district heating. It is interesting to know the curves because they are going to be compare with the real supply and return temperature curve.

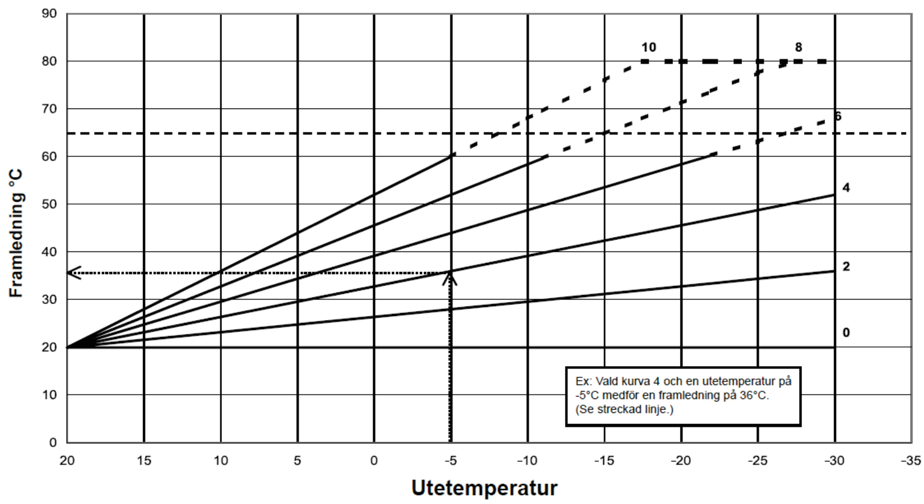


*Figure 10: theoretical return and supply temperature general curves [17].*

# 3 Method

## 3.1 Overall strategy

The main objective of this work is to compare the energy savings between using traditional high flow and low flow method. For that, the method used to calculate which flow configuration is more efficient is divided in different steps:

1. Doing a detailed study of the heating system in the building.
2. Using TVAROR software to simulate the network radiators system of the building.
3. Utilizing some devices to adjust the water mass flow through the pipes.
4. Placing some devices for measuring the indoor temperatures in the building.
5. Comparison between real and theoretical supply and return temperature curves.

The systems which are simulated are 70/40°C for low flow and 60/45°C for high flow. That system variety has been chosen to compare if it is profitable to save energy in the secondary system. This comparison is one of the most common ways to know the energy saving in a District Heating.

The simulation periods for the flow comparison have been selected based on the outside temperature. Cold periods are better for this type of comparison. Therefore, cold period in March, from 08/03/2016 to 21/03/2016. The temperature of these days can be observed in Figure 11.

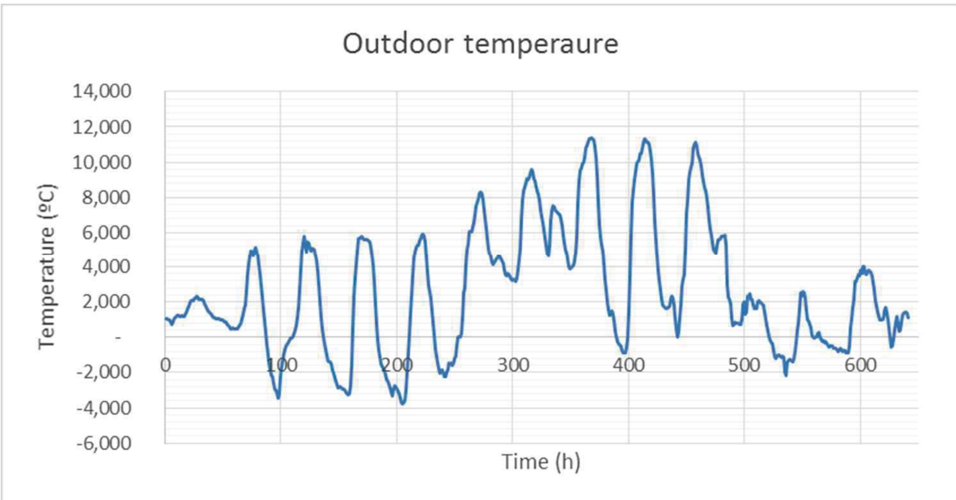


*Figure 11: outdoor temperature in Gävle, 08-03 to 23-03.*

## 3.2 Detailed study of the heating system in the building

For this procedure it is interesting to know the place where this work was made. It was located in Gävle (Sweden) and it is a building close to the University of Gävle. The building is intended for new offices for the Akademiska Hus Company. Figure 12 shows the front facade of the building.


*Figure 12: Akademiska Hus building [18].*

First at all, the company have gave me the building plans, which have been studied. The radiator system plans of the building can be seen in the appendix III. The position of the radiators within the building can be found in these plans, but it is necessary to check all of the radiators system in the building in person because of it could have some differences between the plans and the reality. Some of these differences could be for example: new radiators, new valves, change of radiators, new pipe lines. Besides, it is also necessary to check the installation in person, additional information is required. It is necessary to know all of these additional data because they are going to be used as an input data in the software program.

In the next paragraphs are going to explain which additional information has been extracted due to go the building in person and which tools and methods have been used to achieve that.

The first thing that has been done was to check the material of the all pipes system. Two different kind of materials have been found, most of them were made by iron and the rest were made by copper. Iron pipes were the first material to be used and gradually were changing for copper pipes. A magnet has been used to know of which material were made the pipes because copper is a non-magnetic material.

The second matter that has been done was to check the kind of the radiators to know the exactly heat power output of each. There are various models of radiators and these are the next ones:

- MP XX-XX
- M YY-XXX
- TP Y-XX

Where:

The letter "Y" represents the model of the radiator, for example if the radiators have one or two convection plates.

The letter "X" represents some radiator size, for instance: its height or its width.

Depending on the model of the radiator and its height and width, they will have different heat power output. It is necessary to use the data sheet of the manufacturer to know how much power output have each radiator.

The next thing that has been done was to take different measures between the radiators. That means, measures like: distance of the pipes between the radiators, the possible valves that had between them, elbows, the direction in the connexion between two pipes. For doing that, one meter was used.

The last thing that has been done for the detailed study of the heating system in the building was to create a network of the radiator system. This step was made at the same time than the previous ones. It consists in listing every interesting point in the heating system and relate it to the next ones. In this way, a network is created, representing the real one and where all radiators, pipes and valves are related.

## 3.3 TVAROR software

The next step, once created the network radiator system of the building in paper is to use a software to simulate this network in a computer. The program selected to simulate this network is TVAROR software. SThis program shows the position that the thermostatic radiator valves should have. It must introduce the input data in the program, which are the same as it was written in the paper and the program works really well and fast.

Figure 13 shows one example of how some input data of radiators were introduced, where it is possible to see different model types of radiators.

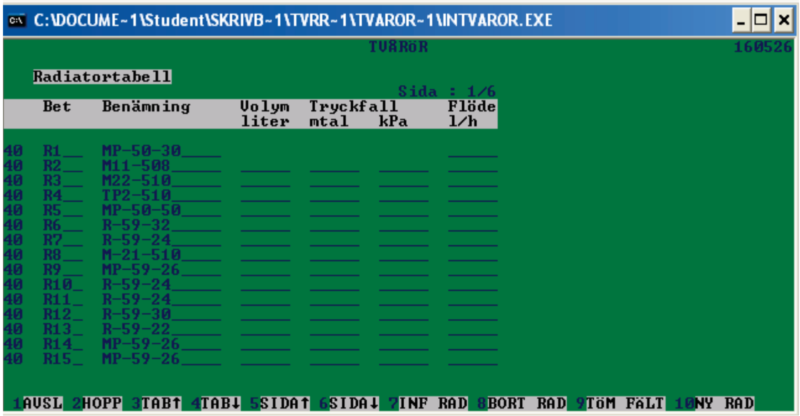


*Figure 13: input data of the model type of radiators.*

In Figure 14 is possible to observe some input data of the heating system network and its connexion through numbers. In this figure, it can see some data, from left to right: number of connexion, the water mass flow through each radiator, the material type of the pipes, the dimension of the pipes, the numbers of elbows, the connexion between the pipes and the number of valves between two points in the system.

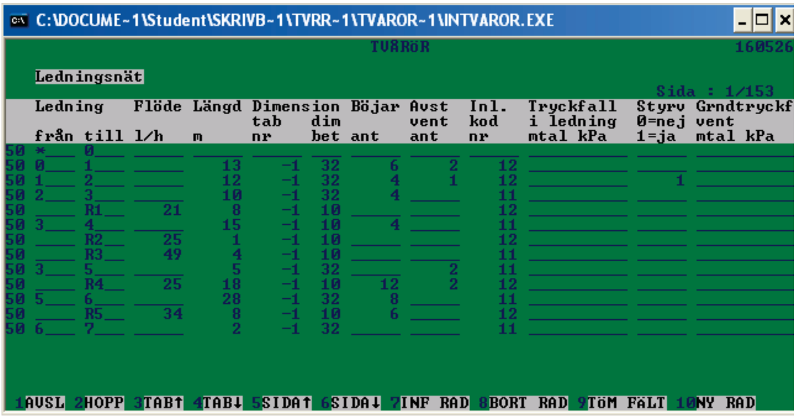


*Figure 14: input data of some connexion points in the heating system.*

Once all of the input data have been introduced in the program, this returns the exact position that the thermostatic radiator valves of every radiator should have and the total water mass flow that should have through the pipes. It can be seen in the Figure 15 one example of how the program shows the exact position that the valves should have (Kv).

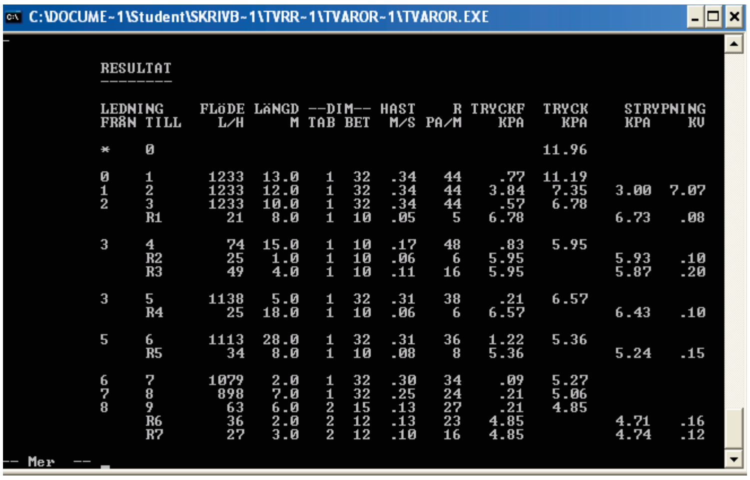


*Figure 15: output data of radiator valve position (Kv).*

It also can be seen in Figure 16 the output data of the total water mass flow and the pressure of the heating system for one simulation, in this case the total water mass flow was 0.3 l/s and the pressure was 12KPa.

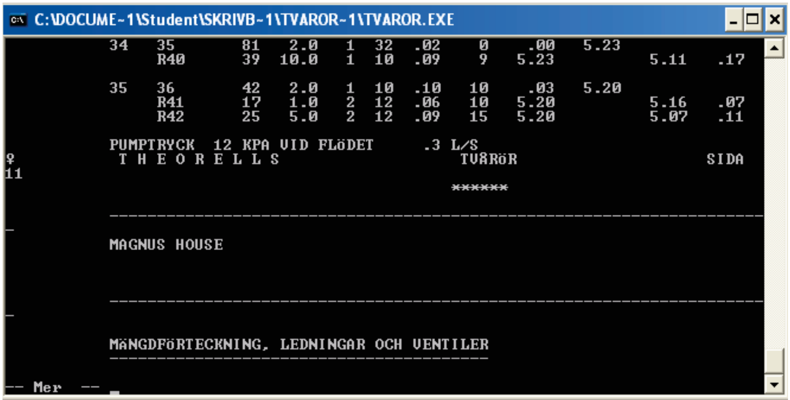


*Figure 16: output data of water mass flow and pressure in the heating system.*

These figures only represents one part of the software code and the output data of the software, but it has been simulated all of the heating system network to get the proper results.

## 3.4 Adjusting the water mass flow through the pipes

Once the results are known thanks to use TVAROR program, it is necessary to adjust the water mass flow through the pipes and change manually the position of the valves on the radiators. The flow is adjusted by pressurized valves in the main pipes with some devices, near the pump. In the next paragraphs is going to explain which kind of devices have been used to make this possible.

As it explained before, two water mass flow have been compared each other to check how affect energetically and economically to the heating system.

The first test has been made with low flow and with a temperature of supply and return of 70/40°C and the pressurized valves have been adjusted according that. It is necessary to do some steps before adjusting the pressurized valves. The first step has been to try different positions in the valve to put the same water mass flow than the program gave as a result. For doing that, one device has been used. This sophisticated device gives back the real water mass flow through the pipes and it must be connected between two points of the same pipe. The Figure 17 shows this device and how it is connected in the pipe.

*Figure 17: water mass flow meter.*

It is necessary to do some modifications to introduce the input data in the device. First, once known the exact position of the valve, there is to change the scale of this value. A book provided from my supervisor has been used to change the scale of this value. To understand how changes of scale was made, one example is going to explain below. The pipe has a dimension of DN 32 and for the first test to get a properly flow, the valve is open to the position 2. It can be seen the line painted in the Figure 18 to understand the scale change of the value, which later is going to be introduced in the device. Thus, the new value to introduce in the device is 1.8 in this case.

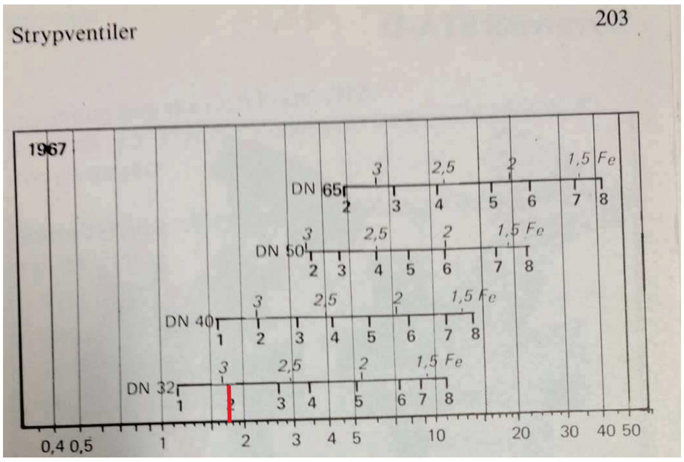


*Figure 18: scale change for the water mass flow.*

After being adjusted the water mass flow in the main pipe, the next step is to change the position of the valves in each radiator inside the building according the results of the program. After making the changes in the valves, it must wait about one week with this configuration to measure the indoor temperature.

The following step has been to change the water mass flow and with a new temperature of supply and return of 60/45°C. The supply and return has been changed from the computer thanks to the heat exchanger. This procedure has been made with high flow and it has been adjusted according to that, repeating the process explained before.

While it was doing the first strangulation for the low flow in the main pipe, it was observed a real problem. Problems occur in reality because there are more limitations than in the program simulations. In that case, the valve, which has to be strangulated, has a limitation because it can not strangulate more than 1.2. It is dangerous to close more than this point because the heating system could be without enough water mass flow through the pipes and radiators. Therefore, the decision that has been taken is to increase the water mass flow to 150% for both cases, high and low flow. The purpose of this work is to compare both cases and therefore there is no problem in increasing the mass flow for both cases, while the two cases are increased the same percentage.

## 3.5 Measuring the indoor temperatures in the building

The next step, which is going to be explained have been made at the same time as the previous one. Once that the water mass flow through the pipes and the position of the valves on the radiators have been adjusted, some devices has been placed inside the building. This procedure consist in placing some devices inside the building to measure the indoor temperature. This procedure has been done twice, once for each case. These devices have been placed in different rooms into the building to get temperatures of different rooms. Some of these rooms are localized in the way that the sun can come in through the windows, so these rooms have to be analysed during the night or when there is no sun.

The temperature gauges have been placed in the rooms for each test for a week. It can be seen in the Figure 19 one of the devices which were used in the test. These devices are very sophisticated, they register the temperature data every thirty minutes for several months or even years. After that, it is possible to download the temperature data in a computer in a txt file format. Finally, the data is converted from .txt. to a xls. sheet to show the results in a clear way.


*Figure 19: device to measure temperatures.*

## 3.6 Supply and return temperature curves

Finally, a comparison between real and theoretical supply and return temperature curve has been made. Thus, it can be known if the real supply and return temperature curve is similar to the theoretical supply and return temperature. In this Master Thesis 70/40°C and 60/45°C is used for supply and return respectively. These supply and return temperatures refer to an outside temperature of -20°C.

In Figure 20 can be seen specific theoretical supply and return temperature curves used in this work. The two blue lines show the curves for a low flow balancing, which mean a high temperature difference in the heating system. While the two red lines show the curves for a high flow balancing and a low temperature difference in the system.

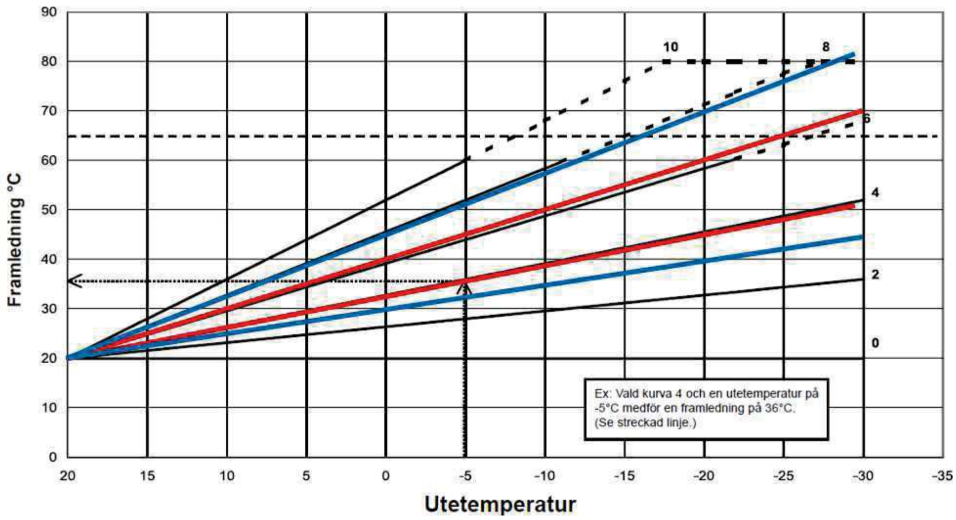


*Figure 20: theoretical supply and return temperature for the heating system.*

For checking if the real supply and return temperature curve is equal or similar than the previous ones shown before, two devices as Figure 19 have been used. One of them measures the supply temperature and the other one measures the return temperature every thirty minutes.

To simulate the real curve, some aleatory points of temperature have been selected from the devices as Figure 19. Three outdoor temperatures have been used to draw a tendency curve, which they have been -1°C, 2°C and 5°C. These temperatures have been selected because they have been the most common outside temperatures. A lot of data has been extracted in txt file from the devices, which have been introduced in a excel file to compare with the values of the theoretical curves. To simulate the real curve, a temperature range of each outdoor temperature has been selected. The outdoor temperature range have been -0.2°C +0.2°C of the number. For example for outdoor temperatures of -1°C, it has drawn the mean value of supply and return temperatures corresponding to outdoor temperatures from -1.2 to 0.8 °C.

Finally, the process that was explained before has been repeated for the outdoor temperatures of 2°C and 5°C. Thus, different tendency curves have been drawn through graphics.

# 4 Results

For the period of time from 08/03/20016 to 21/03/2016, simulations and calculations have been carried out for low and high flow methods. The resulting data of the mean temperature inside in the building, the effect of the system, as well as one comparison between real and theoretical temperature curve for a radiator system.

## 4.1 Low flow

For the first seven days, from 08/03/16 to 15/03/16 were chosen to analyse with the low flow method and a high temperature difference.

### 4.1.1 Mean temperature inside

Figure 21 shows the data obtained for the low flow balancing method in the cold period of March with a 70/40°C. In this figure it is possible to observe both the outside temperature and the mean temperature inside in the building from 08/03/16 to 15/03/16.

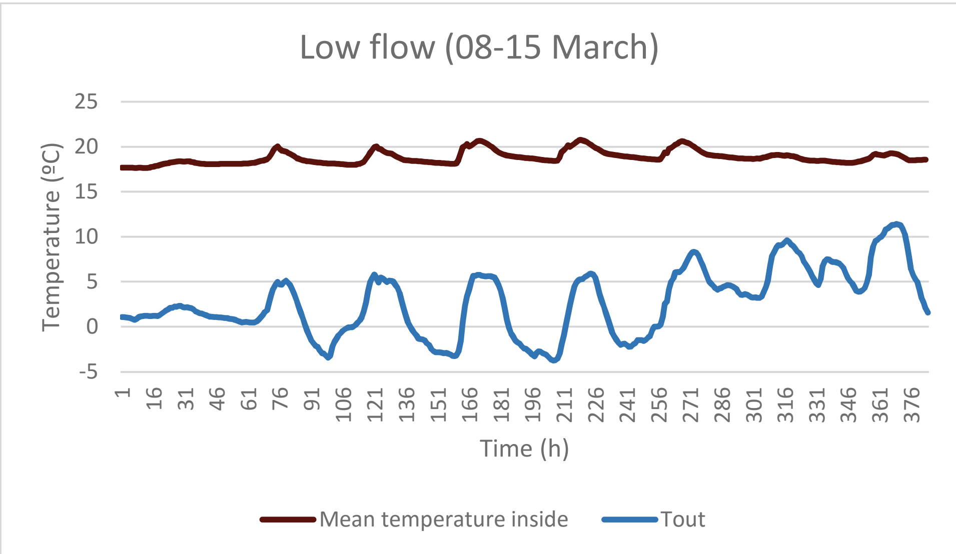


*Figure 21: results of low flow for 7 days.*

### 4.1.2 Effect of heating system

It is necessary to know the water mass flow and the pressure through the pipes to calculate the effect of the system. The output data of water mass flow and the pressure through the pipes have been obtained from the TVAROR. For the low flow method, the power and the energy needed to drive the water mass flow through the heating system have been calculated with the equation (9) (10).

$$\mathrm{P} = \frac{Q * p}{\eta} = \frac{0.26\frac{l}{s} * 8\ kPa}{0.7} = \frac{0.00026\frac{m3}{s} * 8000\ Pa}{0.7} = 2.97\ W$$

$$\mathrm{E} = P * t = 2.97\ W * 7740\ \mathrm{h} = 22987.8\ \mathrm{Wh}$$

### 4.1.3 Real supply and return temperature curves

In this section is going to draw the real supply and return temperature curves. Three outside temperatures have been used to draw a tendency curve, which are -1°C, 2°C and 5°C. Figure 22 shows the real supply and return temperature curves for low flow.

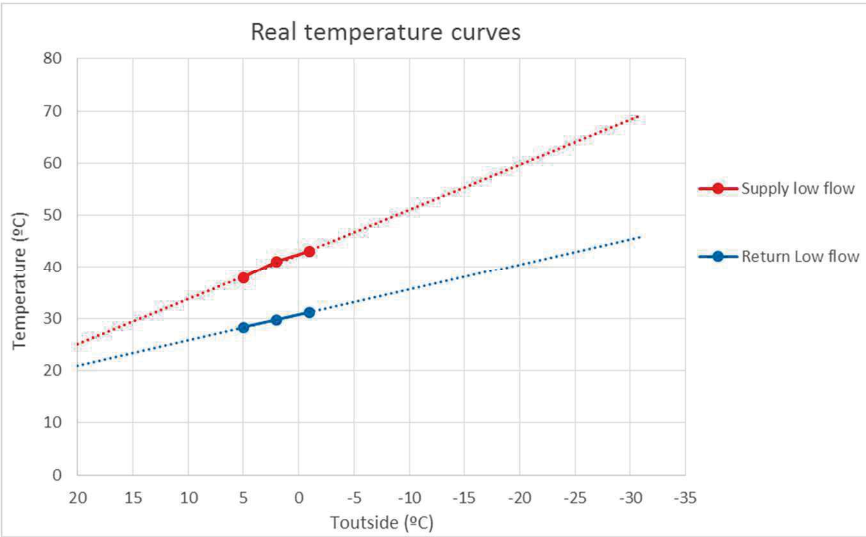


*Figure 22: real supply and return temperature curves for low flow.*

Finally, Table 1 shows the output data of both supply and return temperatures for the outside temperatures selected. In this figure is also possible to see the temperature difference for each outside temperature with a low flow balancing.

*Table 1: points of temperature with different outside temperatures for the low flow.*

| LOW FLOW | Supply (°C) | Return (°C) |
|---|---|---|
| Tout (-1°C) | 43,07 | 31,18 |
| Tout (2°C) | 41,09 | 29,73 |
| Tout (5°C) | 37,90 | 28,26 |

## 4.2 High flow

For the second five days, from 16/03/16 to 21/03/16 were chosen to analyse with the high flow method and a low temperature difference.

### 4.2.1 Mean temperature inside

The data obtained for the high flow balancing method in the cold period of March with a 60/45°C is shown in Figure 23. Both the outside temperature and the main temperature inside from 16/03/16 to 21/03/16 can be seen.

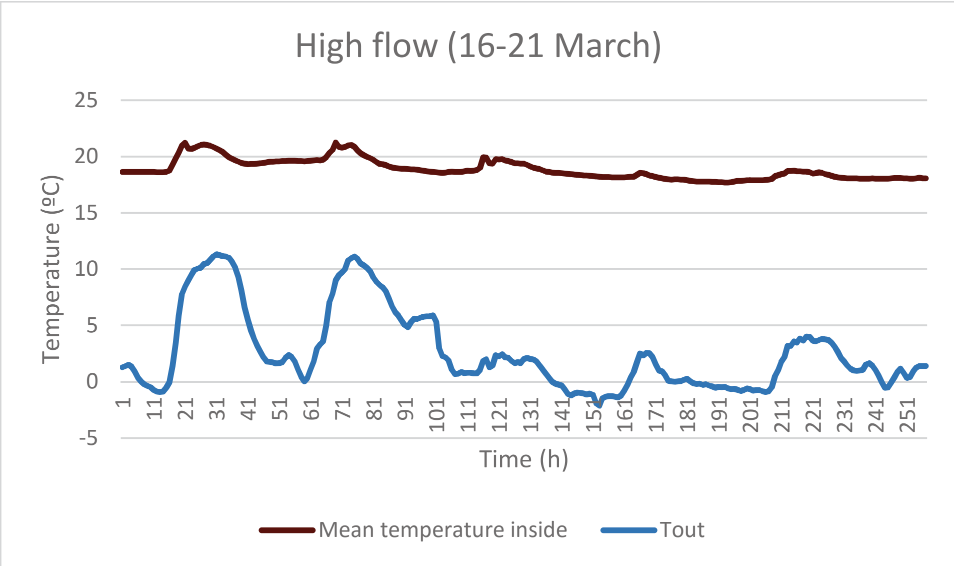


*Figure 23: results of high flow for 5 days.*

### 4.2.2 Effect of heating system

To calculate the effect in this case is also necessary to know the water mass flow and the pressure through the pipes, as for the previous case. These output data have obtained from TVAROR too. The difference with the high flow configuration is that more pressure is needed to drive the water mass flow because the flow is higher for this case. Thus, the power and the energy for this case have been calculated with the equation (9) (10).

$$\mathrm{P} = \frac{Q * p}{\eta} = \frac{0.51\frac{l}{s} * 12\ kPa}{0.7} = \frac{0.00051\frac{m3}{s} * 12000\ Pa}{0.7} = 8.74\ W$$

$$\mathrm{E} = P * t = 8.74\ W * 7740\ \mathrm{h} = 67647.6\ \mathrm{Wh}$$

### 4.2.3 Real supply and return temperature curves

In this case, it is going to show the real supply and return temperature curves for high flow. It also has been used three outside temperatures to draw a tendency curve, which are -1°C, 2°C and 5°C. Figure 24 shows the real supply and return temperature curves for low flow.

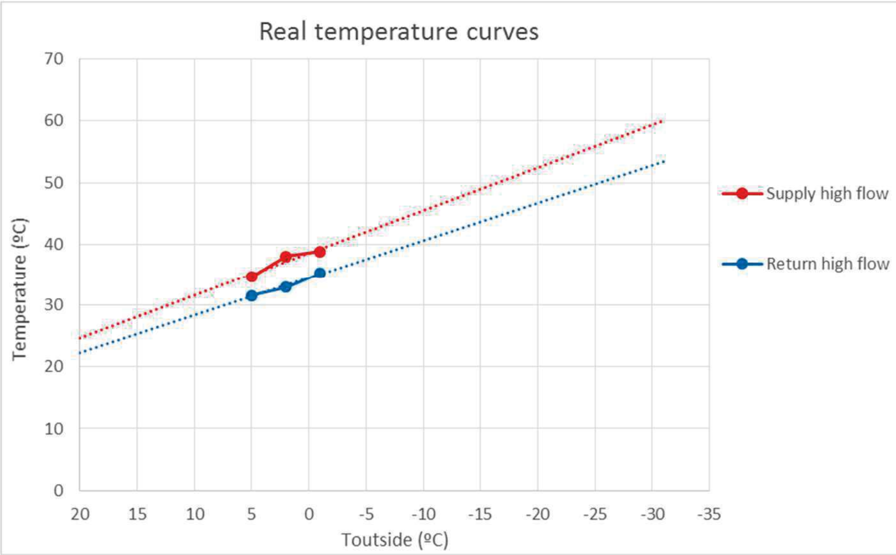


*Figure 24: real supply and return temperature curves for high flow.*

Finally, in Table 2 shows the output data of both supply and return temperatures for the outside temperatures selected. In this figure it is also possible to see the temperature difference for each outside temperature with a low flow balancing.

*Table 2: points of temperature with different outside temperatures for the high flow.*

| HIGH FLOW | Supply (°C) | Return (°C) |
|---|---|---|
| Tout (-1°C) | 38,79 | 35,24 |
| Tout (2°C) | 38,02 | 32,90 |
| Tout (5°C) | 34,63 | 31,56 |

# 5 Discussion

In this section, the obtained results are going to be discussed and commented on a clear way. For that, the two balancing methods (low and high flow) used in the thesis are going to be compared to each other. These balancing methods are going to be compared to each other to know which configuration is more profitable for the heating system used in this building. To discuss the results on a clear way, three different parts are going to be discussed separately:

- The mean inside temperature.
- The effect of heating system.
- The comparison between the real supply and return temperature curves.

## 5.1 Mean temperature inside

To compare both balancing cases it is interesting to know what the mean temperature inside is during the corresponding days of low and high flow. Low flow balancing configuration has been used from 08/03/2016 to 15/03/2016, while that high flow balancing method has been used from 16/03/2016 to 21/03/2016. Data from the devices has been measured every thirty minutes during all the day. Table 3 shows the average temperature inside for low flow and high flow.

*Table 3: average temperature inside.*

| | Average temperature inside (°C) |
|---|---|
| **Low flow** | 18.81 |
| **High flow** | 18.86 |

As it can be seen in Table 3, the average inside temperature during the first seven days with a low flow method was 18.81°C and for the next five days with a high flow method was 18.86°C.

Finally, it can conclude that the mean temperature inside was almost the same for both configurations. This indicates that the heating system works in a right way for two methods studied in this Master Thesis (low and high flow). The mean temperature inside is a little bit lower than the desired temperature for both configurations. The desired temperature in a building for offices could be around 21°C. However, this is the mean temperature for all the days, including, during the night when the sun is off and the temperature decreases. Thus, the temperature during the day, when the offices are going to be open, the inside temperature will be more comfortable and close to the desired temperature.

## 5.2 Effect of heating system

In this section, the energy consumed by the pump is going to be compared between the low and high flow. Table 4 shows the energy consumed by the pump.

*Table 4: energy consumed by the pump.*

| | E (Wh) |
|---|---|
| **Low flow** | 22987.8 |
| **High flow** | 67647.6 |

As it can be seen in the table above, the energy consumed by the pump is higher for the high flow. The energy consumed by the pump in the high flow is about three times more. Thus, it can be said that from the point of view of the energy consumed, the low flow method is better than the high flow method because the low flow method consumes less energy. However, the low flow method can have some problems. One of them is that if the water mass flow rate is very low, the pump may get dirty due to sediments. Besides, the pump generates more noise when there is a low flow configuration because of its necessary to strangulate more the valves. When the valves are more strangulated, the radiator valves also will have more dirt due to sediments.

## 5.3 Comparison between the real supply and return temperature curves.

In this part, the real supply and return temperature curves are going to be compared with the theoretical curves, which it can be seen in Figure 20. Low and high flow methods are going to be compared separately to evaluate which configuration is more similar to the theoretical curves. Figure 25 shows the real supply and return temperature curves for low and high flows.

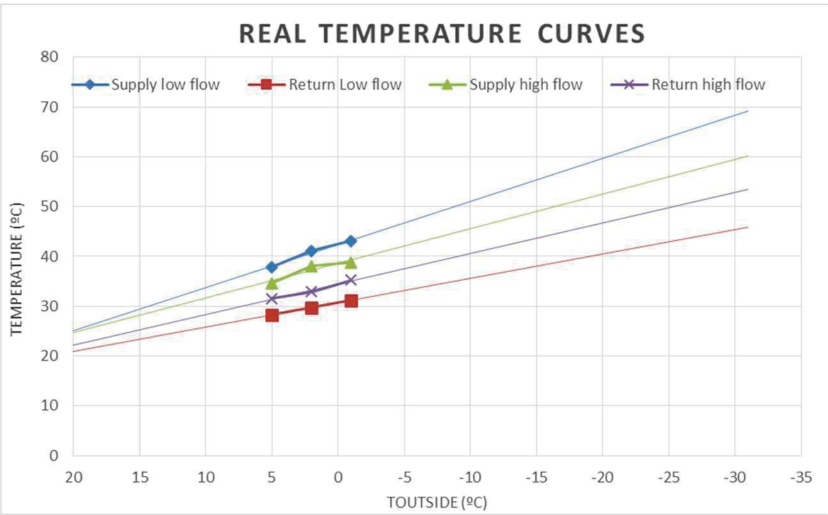


*Figure 25: real supply and return temperature curves.*

As it can be seen in the figure above, both low and high flow curves are similar to the theoretical curves.

The experimental low flow curves are practically the same as the theoretical curves. For an outdoor temperature of 20°C, the experimental low flow supply and return temperature are almost 20°C. Besides, as the outside temperature decreases, the supply and return temperatures will increase the temperature difference between each other. This can be seen numerically in the Table 5.

*Table 5: temperature difference between two points for the low flow method.*

| LOW FLOW | ΔT (°C) |
|---|---|
| Tout (-1°C) | 11,89 |
| Tout (2°C) | 11,36 |
| Tout (5°C) | 9,64 |

The experimental high flow curves are slightly different from a theoretical high flow curves. Although, for an outdoor temperature of 20°C, the experimental high flow supply and return temperature are almost 20°C. However, as the outdoor temperature decreases, the high flow temperature curves will not increase the temperature difference between each other. Thus, they are parallel curves to each other, which is wrong. This can be seen numerically in Table 6.

*Table 6: temperature difference between two points for the high flow method.*

| HIGH FLOW | ΔT (°C) |
|---|---|
| Tout (-1°C) | 3,56 |
| Tout (2°C) | 5,12 |
| Tout (5°C) | 3,07 |

Finally, it is shown that the experimental low flow curves are more similar to the theoretical curves than the high flow curves. Although, both of them start in a correct way, the low flow curves will increase the temperature difference between the supply and return, which is more similar than the theoretical curves.

# 6 Conclusion

According to the studies that have been carried out in this work, different results have been obtained for each type of method used.

Regarding to the study of the mean temperature inside, both the method of low as the high flow have a similar performance. This heating system achieved a similar indoor temperature for both configurations. The average temperature inside for low flow method was 18.81°C, while for high flow method the average temperature was 18.86°C. Indicating that this heating system works in a right way for both methods.

In regard to the effect of the heating system, the energy consumed by the pump to drive the water mass flow is higher for the high flow method than for the low flow method. The energy consumed by the pump with a high flow method for a year is 67.64 kWh, while for low flow method for a year is 22.98 kWh. Thus, from the point of view of energy consumed, the low flow method is better than the high flow method because the low flow consumes less energy. However, this energy is almost negligible for a company. So, it is not very relevant to choose which method is the best one.

On the other hand, comparing the experimental supply and return temperature curves against the theoretical curves, the experimental low flow curves are more similar to the theoretical ones. Although, both of them start in a correct way, the experimental low flow curves will increase the temperature difference between the supply and return, which is more similar than the theoretical temperature curves.

In conclusion it is more efficient to use the low flow balancing method for this particular building. Thanks to use the low flow method, it has been found that it is possible to achieve the same indoor temperature, using less energy and also obtain better characteristics of supply and return temperature. However, it must be taken into account that the low flow method can have some problems. One of them is that if the water mass flow rate is very low, the pump get dirty due to sediments. Besides the pump generates more noise because of it is necessary to strangulate more the valves. When the valves are more strangulated, the radiator valves also will have more dirt due to sediments.

## 6.1 Future work

In this work it was found that the low flow balancing technology starts to become profitable for heating systems. It will be able to develop heating systems more profitable thanks to this technology.

I would advice to test a new flow method with lower water mass flow than the low flow balancing used in this work for this building. Thus, it could be possible to increase the efficiency of the system. However, it must be taken into account the troubles explained before with the low flow methods. Besides, this problems enlarges as the flow decreases.

# 7 References

[1] M. Kuosa, K. Kontu, T. Mäkilä, M. Lampinen and R. Lahdelma, “Static study of traditional and ring networks and the use of mass flow,” *Applied Thermal Engineering,* vol. 54, pp. 450-459, 28 February 2013.

[2] H. Gad and S. Werner, “Achieving low return temperatures from district heating substations,” *Applied Energy,* vol. 136, pp. 59-67, 30 September 2014.

[3] T4T, “Textilles4Textiles,” WordPress, 04 04 2016. [Online]. Available: http://www.textiles4textiles.eu/advantages-disadvantages-district-heating/. [Accessed 02 05 2016].

[4] P. Launebutg and J. Wollerstrand, “Adaptative control of radiator systems for a lowest possible district heating return temperature,” *Energy and Buildings,* vol. 72, pp. 132-140, April 2014.

[5] X. Baoping, F. Lin and D. Hongfa, “Simulation on hydraulic heating system of building under a thermostat radiator valves,” Department of Buidling Science and Technology, Tsinghua University, Beijing, China, 2007.

[6] F. Tahersima, J. Stoustrup and H. Rasmussen, “An analytical solution for stability-performance dilemma of hydronic radiators,” *Energy and Building,* vol. 64, pp. 439-446, Septiembre 2013.

[7] A. Hesarakia, E. Bourdakisb, A. Ploski and S. Holmberg, “Experimental study of energy performance in low-temperaturehydronic heating systems,” *Enegy and Buildings,* vol. 109, pp. 108-114, 30 September 2015.

[8] Keppel, “Keppel DHCS,” Keppel Corporation, 2010. [Online]. Available: http://www.keppeldhcs.com.sg/our_product_overview.html. [Accessed 02 05 2016].

[9] A. Trüschel, “Hydronic heating systems, the effect of design on system sensivity,” Department of Building Services Engineering, Chalmers University of Technology, Göteborb, Sweden, 2002.

[10] W. P. L. Steg and C. Vlek, “Values, Environmental Concern and Environmental Behavior, a study into Household Energy use,” *Environment and Behavior,* vol. 36, no. 1, pp. 70-93, 2004.

[11] S. Karjalainen, “Gender differences in thermal comfort and use of thermostats in everyday thermal environments,” *Building and Environment,* vol. 42, no. 4, pp. 1594-1603, April 2007.

[12] A. Grace and P. Frawley, “Experimental parametric equation for the prediction of valve coefficient (Cv) for choke valve trims,” *Internation Journal of Pressure Vessels and Piping,* vol. 88, no. 2-3, pp. 109-118, February-March 20011.

[13] LPS Supplies, “LPS Plumbing and Heating,” Information technology, 2016. [Online]. Available: http://lpssupplies.com/15mm-ravenheat-angle-thermostatic-radiator-valve-p-1921.html. [Accessed 12 05 2016].

[14] C. Filippín, S. F. Larsen, A. Beascochea and G. Lesino, “Response of conventional and energy-saving buildings to design and human dependent factors,” *Solar Energy,* vol. 78, no. 3, pp. 455-470, March 2005.

[15] R. A. and H. P.E., “Selecting control and balancing valves in a variable flow system,” *ASHRAE JOURNAL,* pp. 53-62, June 1997.

[16] N. Lindvall, “Comparison of two different adjustment principles in a space heating system consists of hot water radiators,” Chalmers tejniska högskola, Göteborg, January 2006.

[17] IVT VÄRMEPUMPAR, “Handledning i montage, drifttagning och skötsel,” IVT 490, May 2004.

[18] Akademiska Hus, “Akademiska Hus,” Akademiska Hus 2014, 2014. [Online]. Available: http://www.akademiskahus.se. [Accessed 20 05 2016].

[19] A. Joelsson and L. Gustavsson, “District heating and energy efficiency in detached houses of differing size and construction,” *Applied Energy,* vol. 86, no. 2, pp. 126-134, February 2009.

[20] A. Hasan, J. Kurnitski and K. Jokiranta, “A combined low temperature water heating system consisting of radiators,” *Energy and Buildings,* vol. 41, pp. 470-479, 2009.