Cold tap water usage for a chilling system

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ABSTRACT

Both the increasing demand for comfort levels and growth in population are facts that assure that the energy demand in buildings will keep growing in the future. HVAC systems are the principal users of this total energy demand, where percentages over 50% have been reached. Air conditioning is essential to maintain the thermal comfort inside the buildings, and for this reason, innovative cooling systems should be analysed in order to reduce and improve energy usage of these systems.

The aim of this thesis is to explore the viability and limitations of a new chilling system that uses tap water as a cooling source. The project has been focused on a building owned by an insurance company in Gävle, where a cooling system has been designed to satisfy the cooling need for an extremely hot day in summer. Water is taken from the main pipe and, via a heat exchanger, it absorbs heat from the chilling circuit. The destination of the tap water, once has been used, has been discussed proposing 3 different options: deliver it to the waste, bring it back to the tap water network and reuse it for hot tap water. Later, based on the results, an overview of the system has been done pointing out the weak and strong parts.

When implementing this new system it has to be taken into account that cooling capacity is limited and extra requisites and limitations have to be accomplished since drinking water is used. The most energy efficient design is reusing the water for hot tap water use, since less heat will be needed to warm it up. However, if water is wanted to be reused it should not exceed 15°C in order to avoid an environment where legionella could grow and become a health human threat. A suitable situation for this system would be for building which needs cooling and has a high hot tap water demand.
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- Heat exchanger
- Water temperature sensor
- Water meter reader
- Valve
- Check valve
- Pressure reducing valve
- Regulating water (temperature signal)
- Pump
1 INTRODUCTION

1.1 Background

The speedily growth of energy use is one of the biggest concerns around world. This increase can be illustrated with the following numbers: in 1973 the world total energy use was 54400TWh whereas in 2011 it reached a value of 103700TWh. Besides, an estimation of the global energy use for 2035 has been settled on 120800TWh by International Energy Agency, meaning an increase of 16.5% by the end of the following couple of decades.¹ At the present, more than 80% of the world energy supply comes from oil, coal and gas, and only a 13% results from renewable sources [1]. Sweden is one of the pioneer countries to break these percentages; renewable energy accounts for more than 48% of the energy supply. In Sweden, the total final energy usage is 411TWh, which is distributed between three main sectors: transport, industry and residential and services [2].

Energy used in building, both residential and commercial, has increased its contribution towards the total energy usage, reaching these days values between 20% and 50% in developed countries (for Sweden, in 2010, it represented 40% of the total energy used[2]). Not only the growth in population but also the increasing demand for comfort levels combined with the rise in time spent inside the building assures that the energy usage in buildings will continue growing in the future [3].

Among the tools to ensure the suitable comfort in buildings, HVAC² systems are the most popular ones. Although they are the major energy consumers in buildings, they are usually the most cost-effective way to improve energy efficiency in conditioned air. Thus, design, operation and control of these systems could have significant impact on the energy saved [4].

As said before, air conditioning is essential for maintaining thermal comfort in indoor environments, particularly for hot and humid climates, where the duty to remove heat loads could be the main part where the energy is used [5].

Moreover, Instrumental observations, as well as, the reconstruction of global and hemispheric temperature evolution reveals a noticeable warming during the past 150 years [6]. Although climate in Sweden is rather moderate in summer, occurrence of heat waves and warm periods has been present. During the summer of 2006, several meteorological

¹ Final energy values once the losses (conversion and distribution) and the use for non-energy purposes are extracted from the total supply energy.

² HVAC. Heating, ventilation and air conditioning systems
stations in the south of Sweden recorded the highest summer and July mean temperature since measurements started in the middle of the nineteenth century [7]. Thus, increasing tendency of the temperature and occurrence of warmer summers are important factors that could increase energy demand for cooling. For this reason, innovative cooling systems should be designed that could reduce and improve energy usage for air conditioning.

Traditionally, the cooling demand was fulfilled by electrically driven technology, i.e. vapor compressor chillers, which resulted in an increase of electricity consumption. Furthermore, the main disadvantage of this chiller system is the amount of devices that have to be installed in every building or area.

Therefore, to improve the efficiency and reduce the operating and installation costs of the air conditioning system, a centralized way of cooling was developed: District cooling. The chilled water is produced in a central plant and distributed through an isolated pipe network to the building or consumers connected to the system. The chilled water is mainly used for air conditioning systems, and once the water passes these systems, it increases its temperature and it is returned to the central plant, where it is cooled and recirculated through the closed loop system.

For district cooling, different systems can be used to obtain the chilled water regarding the energy source. Freecooling is one of them, which, via heat exchangers, transfers the cold from the water of nearby lakes, oceans or waterways to the district network. Another system is using absorption chillers, where the primary energy source is the heat generated in district heating, heat waste from industries or garbage deports. The third system is using the high efficient chillers which use electricity as the source to obtain the chilled water. These three systems can also be combined with cold storage, which the most commonly is based on freezing of ice, but can also be based on another phase changing materials [8].

The cooling plant is frequently run by a company that also provides the local district heating. This is the most common way of producing district cooling in Sweden. The combination of district cooling based on absorption chillers and district heating especially advantageous during summer when the needs for heating is limited to basically domestic hot water [9].

In Gävle, Gävle Energi AB has finished the construction of the cooling plant for district cooling using heat waste from CHP (combined heat and power) plant. The cooling is produced in a central facility and then distributed to the property, where is transferred directly or via heat exchanger for air conditioning system.
Although district cooling grid is a potential new solution to satisfy the cooling demand in Gävle, other new friendly environmental ways could be investigated.

1.2 Aim and limitations

This thesis will explore the possibilities and limitations for a chilling system that uses cold tap water from the municipal network for a building in Gävle. The main idea is to explore a new way of cooling by using tap water as the cold source of the system. The thesis is going to be focused on a specific building in the municipality of Gävle; however, it is hoped that the conclusions of this work could be used as a guide when implementing the system in other buildings. The building, in which the study is focused, is currently being constructed so it has already a HVAC system designed and it is connected to the district heating and cooling. Hence, this thesis will only be focused on changing the cooling source, switching the connection from the cooling grid to the cold tap water, keeping the rest of the system as it was designed before.

In summary, a system for cooling with tap water will be designed for the existing building. Subsequently, the viability of this system will be questioned evaluating the strong and weak points of it.

Being the first time that this option is contemplated, some difficulties and limitations might appear during the development of the work.

1.3 Outline

The purpose of this section is to give a wide overview of the content of the thesis in order to facilitate the reader to go through it. The theoretical concepts and theories needed to develop the thesis and formulate the conclusions are explained in the 2nd chapter. Equations are listed numerically so as to make easier to spot them later.

In the 3rd chapter, brief information of the building willed to install the new system is given. It basically contains an analysis and description of the system that ensures the thermal comfort in the building since this information is needed to establish some parameters for the new installation.

In the 4th chapter, it is explained briefly the methodology and the steps followed in the calculations in order to give global view of the main expected results.
Later, in the 5th chapter, results are collected following the methodology defined in the previous chapter. In this chapter, it is also commented assumptions and simplifications that had to be done in order to keep forward with the calculations. Finally, the conclusion and discussion are presented in the 6th and 7th chapter, respectively.
2 THEORY

2.1 Introduction to HVAC systems

HVAC is acronym that stands for “heating, ventilation and air conditioning” and it includes a variety of active mechanical/electrical systems in order to provide thermal comfort in the buildings.

The heating system (H) is designed to add thermal energy to a space the keep some selected air temperature that would not otherwise be achieved due to the heat flows to the exterior environment. The ventilation system (V) introduces air to or removes air from the space. It moves the air without changing its temperature and it is used both to improve indoor air quality and improve thermal comfort. Air-conditioning (AC) is generally considered as the cooling system, which removes thermal energy to maintain a desired air temperature [10].

HVAC systems components can be grouped into three functional categories:

1. Source components.
   They provide or remove heat or moisture. Boilers, heat pumps, chillers and district heating/cooling are some examples.

2. Distribution components
   Central system produce heating/cooling effect in a single location, and then this effect must be transmitted to the various spaces in a building that require conditioning. Air, water and steam are the common media for transmission. The main components are:
   · Insulated pipes convey hot/cold water from the source to the final delivery components
   · Valves control the water flow as means of adjusting cooling or heating capacity to the demands of the building. They are also used to shut off water flow for maintenance.
   · Pumps are required to provide the energy input to overcome friction losses and circulate water through the system.
   · Ducts (ductwork) are used to convey air from the primary source to the finally delivery components.
   · Dampers are used to control air flow, either to balance flows throughout the system or to adjust air flow in response to changing building loads.
   · Splitters and turning vanes are used to reduce friction losses by reducing turbulence.
   · Fans provide energy motive force for air circulation.
   · Filters remove indoor pollutants
3. Delivery components

Serve as an interface between the distribution systems and occupied spaces. The most commonly delivery devices are the following ones:
- Diffuser introduces supply air into the space to provide good mixing with the room air.
- Radiator
- Radiant panels
- Chilled beams

2.2 First law of thermodynamics

[11] The First law of thermodynamics is referred to as the Conservation of energy Principle, meaning that energy can neither be created nor destroyed, but rather transform into various forms within the control volume is studied.

The balance equation within a control volume is

\[
\frac{dE}{dt} = Q - W \sum \dot{m}_i \cdot \left( h_i + \frac{V_i^2}{2} + g \cdot z_i \right) - \sum \dot{m}_o \cdot \left( h_o + \frac{V_o^2}{2} + g \cdot z_o \right) \quad (eq \ 2.1)
\]

The law of Conservation of mass implies that matter can neither be created nor destroyed, although it can be rearranged in a space or changed into a different form of matter.

When the principle is applied to fixed volumes, known as control volumes, following equation can be stated:

\[
\sum \dot{m}_{in} - \sum \dot{m}_{out} = \Delta m_{Control \ Volume} \quad (eq \ 2.2)
\]

For a steady state, properties of the control volume and its boundaries are not changing during the time while the fluid flows steadily through it, so equations (eq1) and (eq2) become:

\[
0 = Q - W \sum \dot{m}_{in} \cdot \left( h_i + \frac{V_i^2}{2} + g \cdot z_i \right) - \sum \dot{m}_{out} \cdot \left( h_o + \frac{V_o^2}{2} + g \cdot z_o \right) \quad (eq \ 2.3)
\]

\[
\sum \dot{m}_{in} - \sum \dot{m}_{out} = 0 \quad (eq \ 2.4)
\]
2.2.1 Heat exchangers and chilled beams

A simple way to calculate the heat transferred by a fluid that flows through a heat exchanger will be resulted after the following simplifications of equation (eq2.3)

Knowing that in those devices fluid velocity is kept constant, height does not change and \( W = 0 \), equation (eq2.3) becomes:

\[
\dot{Q} = \dot{m}(h_o - h_i) \quad \text{(eq 2.5)}
\]

Assuming that the process is done at a constant pressure, enthalpy can be expressed as

\[
\text{dh} = \text{Cp} \cdot \text{dT} \quad \text{(eq 2.6)}
\]

To calculate the enthalpy from the heat capacity at a constant pressure, it is needed to integrate the expression \( \text{Cp} \) in the range of temperatures.

\[
\Delta h = \int_{T_1}^{T_2} \text{Cp}(T)\text{d}T \quad \text{(eq 2.7)}
\]

To simplify the problem, it is assumed that the \( \text{Cp} \) does not vary with the temperature, so equation eq8 becomes

\[
\Delta h = \text{Cp} \cdot (T_2 - T_1) \quad \text{(eq 2.8)}
\]

Replacing (eq2.8) in (eq2.5):

\[
Q = \dot{m} \cdot \text{Cp} \cdot (T_{\text{in}} - T_{\text{out}}) \quad \text{(eq 2.9)}
\]

In terms of volumetric flow

\[
\dot{Q} = \dot{V} \cdot \rho \cdot \text{Cp} \cdot (T_{\text{in}} - T_{\text{out}}) \quad \text{(eq 2.10)}
\]

To simplify the problem, it has been supposed that fluid properties do not change with the temperature even if they do it in a small scale. For this reason, properties will be calculated at the medium temperature \( T_m \), defined as:

\[
T_m = \frac{T_{\text{in}} + T_{\text{out}}}{2} \quad \text{(eq 2.11)}
\]

Heat transferred by a fluid that flows through a heat exchanger can be defined as the following equation:

\[
\dot{Q} = \dot{V} \cdot \rho_m \cdot C_{\text{Pm}} \cdot (T_{\text{in}} - T_{\text{out}}) \quad \text{(eq 2.12)}
\]

Specific heat and density of water can be expressed in function of \( T \) [°C] as:
\[ \rho(T) = 1001.1 - 0.086 \cdot T - 0.0035 \cdot T^2 \quad (eq\ 2.13) \]

\[ Cp(T) = 4.214 - 0.002682T + 4.991 \cdot 10^{-5}T^2 - 4.519 \cdot 10^{-7}T^3 + 1.857 \cdot 10^{-9}T^4 \quad (eq\ 2.14) \]

### 2.2.2 Mixing chambers and pipe junctions

Energy balance in mixing chambers or pipe junctions can be simplified assuming that they are properly isolated \((\dot{Q} = 0)\), variation of kinetic and potential energy are negligible and no work is done in this device. Thus, equation (eq2.3) becomes:

\[ \sum \dot{m}_i \cdot h_i = \sum \dot{m}_o \cdot h_o \quad (eq\ 2.15) \]

### 2.3 Heat exchangers

The function of a heat exchanger is to transfer heat from one fluid to another. Heat transfer rate across the heat exchanger \((\dot{Q})\) is usually expressed as

\[ \dot{Q} = U \cdot A \cdot \Delta T_m \quad (eq\ 3.1) \]

\[ U \left[ \frac{W}{m^2\cdot{\degree}C} \right] \] is the overall heat transfer coefficient and it is function of the flow geometry, fluid properties and material composition of the heat exchanger.

\( \Delta T_m \) is the average temperature difference between the fluids is function of fluid properties and flow geometry as well.

\( A \ [m^2] \) is the heat transfer surface of the heat exchanger

Heat exchangers are typically classified according to the flow arrangement and type of construction. One of them is the double pipe counter flow and simplest schematic of this device is shown in Figure 1
If a counter flow heat exchanger fulfill the following conditions,

- Fluid specific heat does not vary with the temperature
- Convection heat transfer coefficient is constant throughout the heat exchanger

Then, $\Delta T_m$, in equation (eq3.1), can be defined as the Logarithmic Mean Temperature Difference (LMTD). See Figure 2

$$\text{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln \frac{\Delta T_1}{\Delta T_2}} \quad (eq3.2)$$

---

3 Heat transfer between a solid and a moving fluid is called convection. The equation for convection can be expressed as $q = h \cdot A \cdot dT$. Where $h$ is the convective heat transfer coefficient.
2.4 Fluids dynamics

2.4.1 Fluid flow in circular pipes

The fluid velocity in a pipe changes from zero at the surface to maximum because of the non-slip condition at the centre of the pipe. However, in fluid flow, it is convenient to work with an average velocity which remains constant in incompressible flow if cross section of the pipe is constant.

Flow through a cross-section circular pipe can be simplified as:

\[ \dot{v} = A \cdot c = \frac{\pi \cdot D^2}{4} \cdot c \quad (eq4.1) \]

A is the cross section

\( c \) is the velocity

D is the diameter of the pipe

2.4.2 Steady incompressible flow through simple pipes

A fluid moving through a pipeline is subjected to energy losses from various sources. A continuous resistance is exerted by the pipe walls due to the formation of a boundary layer which the velocity decreases from the centre of the pipe to zero at the boundary. In a steady flow in a uniform pipeline the boundary shear stress \( \tau \) is constant along the pipe, since the boundary layer is of constant thickness, and this resistance results in a uniform rate of total energy head degradation [12]

Bernoulli equation can be considered to be a statement of the conservation principle appropriate for flowing fluids.

Applying principle of energy conservation between section 1 and 2 of a circular pipe shown in Figure3, Bernoulli equation is obtained:

\[ Z_1 + \frac{P_1}{\rho \cdot g} + \frac{v_1^2}{2 \cdot g} = Z_2 + \frac{P_2}{\rho \cdot g} + \frac{v_2^2}{2 \cdot g} + h_f + h_L \quad (eq4.2) \]

Each term of the equation refers to a form of energy in the fluid per unit of weight sharing the same units: [m]

\( \frac{P}{\rho \cdot g} \) Pressure head

\( \frac{v^2}{2 \cdot g} \) Velocity head

Z Elevation head
Head lost due to friction $h_f$

Head losses due to singularities ($h_L$) include, among others, head losses at valves and pipe elbows.

### 2.5 Tap water quality in distribution systems

A drinking water distribution system provides a habitat for microorganisms, which are sustained by organic and inorganic nutrients presents on the pipe and in the water. Generally bacteria present in the water and on surfaces are harmless; however Legionella is one of the exceptions.

#### 2.5.1 Legionella

Legionella are small gram-negative rod-shaped bacteria. Over 40 individual species are known, however the majority of humans are infected by *Legionella pneumophila*. 

*Figure 3: Stretch of a pipe with pressure, elevation and velocity heads [13]*
Legionella are considered to be ubiquitous in small number in many natural water systems, but are particularly well suited to multiplication in warmer artificial aquatic environments in the built environment, such as cooling towers; water systems in hostels, homes, ships and factories, respiratory therapy equipment; fountains, etc. The most common mode of transmission occurs when inhalation of airborne droplets containing legionella.

In Sweden, at least 500 people are estimated to fall ill with this disease each year. Approximately one out of ten who fall ill dies from the disease. The most common reasons are lack of correct diagnostics and no reaction to the usual medical treatment. Control of Legionella can be done through chemical treatment or thermal methods. In most cases, the victims are people whose resistance is reduced by smoking, old age or ill health [14].

Control of Legionella growth can be done through thermal or chemical methods. In the following Table 1, how legionella reacts depending on the temperature of the aquatic system is shown.

<table>
<thead>
<tr>
<th>Temperature [°C]</th>
<th>Affects Legionella</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over 70</td>
<td>Disinfection range:</td>
</tr>
<tr>
<td>66</td>
<td>Legionella dies within 2 minutes</td>
</tr>
<tr>
<td>60</td>
<td>Legionella dies within 32 minutes</td>
</tr>
<tr>
<td>55</td>
<td>Legionella dies within 5-6 hours</td>
</tr>
<tr>
<td>20 to 45</td>
<td>Legionella multiply</td>
</tr>
<tr>
<td>Below 20</td>
<td>Legionella are dormant</td>
</tr>
</tbody>
</table>

Prevention of legionella in potable-water systems
Prevention of bacterial growth can be best achieved by keeping cool water below 15°C and flowing, or hot water over 55°C and flowing. The cold water supply should be kept cool, with temperatures at the outlets below 20°C. Pipework, storage tanks and other devices should be insulated against heat gains and never be placed in rooms where the temperature is high.

Pipework should be as short and easy to inspect as possible and should avoid stagnation zones, since microbiological quality of water deteriorates due to stagnation [15]. Water outlets should be should fit with mixer taps to reduce the risk of scalding.
Also, drinking water supplies can be kept free of significant levels of Legionella by chlorination. However, chlorine species used as a disinfectant in tap water have a deteriorating effect on many materials [16].

Eradication of Legionella (disinfection)
Legionella can be eradicated with the following techniques:

· Thermal disinfection.
· UV radiation
· Use of chlorine, chlorine dioxide, chloramine, ozone or iodine.
· Metal ionization (cooper and silver) [17]
3 DESCRIPTION OF THE BUILDING

3.1 Location

The Project has been carried out at the new building of an insurance agency which is being constructed close to the Gävle train station by SKANSKA. To be more precise, the building is located in one of the corners of the crossing between Drottninggatan and Norra Centralgatan, where before there was a car park. The location can be seen in the following Figure 4.

![Figure 4. Location of the building in the city centre of Gävle](image)

The building will have total of 6 floors with offices, bathrooms and a database room. A sketch of the facade once it will be finish can be seen in the following Figure 5.

![Figure 5. Sketch of the building with the programme IDA](image)
### 3.2 HVAC system description

SVECO AB\textsuperscript{4} has been the company responsible for the heating, cooling and ventilation system design and will be in charge of its maintenance. It is important to emphasize that since the building has been constructed while the project has been carried out, information needed to develop the thesis has been extracted from designs provided by SVECO AB.

In order to design the HVAC, heating and cooling systems, SVECO carried out simulations with the program IDA Indoor Climate and Energy\textsuperscript{5}.

SVECO designed the system in order that it could be capable to keep the thermal comfort inside the building for an extremely hot day in summer and cold day in winter, meaning that when more energy is used. Desired indoor temperature was fixed at 21°C.

The building has an air-based central HVAC system and the air handling unit is placed in the 6\textsuperscript{th} floor. The building is connected to district heating and cooling provided by Gävle Energi AB\textsuperscript{6}.

#### 3.2.1 Heating

The building is connected to the district heating which is provided by Johannes, the combined heat and power plant nearby Gävle. The hot water varies from 70 to 112°C and when it returns to the station, it has a temperature between 42 and 58°C.

District heating it is basically used as a heat source for:

- Ventilation.

Water in a closed circuit loop is heated via heat exchanger and circulated to the air handling unit in order to warm the air.

---

\textsuperscript{4} SVECO AB is a consulting company in the fields of construction, architecture and environmental engineering.

\textsuperscript{5} IDA ICE is a whole-building simulator allowing simultaneous performance assessments of all issues fundamental to a successful building design, mostly used in Scandinavia for designing HVAC systems.

\textsuperscript{6} Gävle energi AB is a complete regional energy company which provides electricity, district heating and district cooling.
· **Space heating.**
Ventilation is not enough to keep the thermal comfort, so heating is supported by radiators and ceiling panels distributed around the building. Via a heat exchanger, the water in a closed circuit that feeds those devices is warmed up to approximately 55°C.

· **Hot tap water.**
A third heat exchanger warms the cold tap water to provide hot water when needed.

To have a general understanding, a simple schema of the system is shown in Figure 6. For a detailed blueprint see Appendix 5.

![Figure 6. Simple schema for heating system in the building.](image)

3.2.2 **Cooling**

The building is connected to the district cooling and it is basically used as a cold source for: air conditioning, chilled beams and a chiller.
· Air conditioning.
Chilled water goes to the air handling unit to cool the air.

· Active Chilled beams.
The space conditioning in summer is supported by the active chilled beams (See Appendix 1) in those rooms that the indoor temperature might exceed the 21°C. The chilled beams can have 4 different sizes which vary in function of the cooling need in each room. The more cooling power needed the bigger size of the chilled beam. The chilled water that feeds the active chilled beams is at 14°C and the outgoing is 17°C. The manufacturer strongly recommends keeping those values in order to obtain the best performance of the devices. Besides, in order to adjust the cooling load to the demand of the building, the chilled water flow is regulated through valves in each chilled beam.

· Chiller
A data base room, in the first floor, has higher internal gains and can reach high temperatures in summer. Chilled beams could not provide enough cooling effect to decrease the temperature to acceptable levels; for this reason a vapor compressed chiller is needed.

Only one heat exchanger is responsible for absorbing the cold from the district cooling and delivering it to a water closed circuit.
As is shown in Figure, regarding the feeding temperature for the cooling devices, two circuits can be distinguishing: KS01 and KS02. KS02 is the circuit that brings, at 7 °C, a water fraction to the air handling unit and the rest to the chiller. KS01 is the circuit that feeds the chilled beams at 14°C. Since the chilled water is leaving the heat exchanger at 7°C, part of the returning water from the chilled beams at 17°C has to be mixed in order to reach the 14°C.

---

7 Fläktwods
3.3 Water tap connection

The tap water is provided by Gästriken Vatten AB. The local water source is from ground water, a postglacial sediment in Valbo-Åsen.

The main pipe supporting the surroundings has a diameter of 80 mm and the pressure varies between 3.5 and 4 bar.

The cold tap water temperature has small variation. The temperature basically depends on the outside and ground temperature where the building is placed. Water is around 8°C when pumped from the water plant.

In the following figure, a simple schema of the system is shown.

---

8 Gästrike Vatten AB manages the operation of the water works, sewage water treatments, water pipes, waste water and pumping stations for the municipalities of Gävle, Hofors, Ockelbo and Älvsborg
Water flow is measured when entering to the building by Gästrike Vatten AB in order to quantify the water usage and charge the company accordingly.

When hot water is needed, the water coming from the main pipe flows to the heat exchanger, where is warmed up to 60°C, and finally, it goes to the tap where is mixed with cold water to achieve the desired temperature. When hot water is not needed anymore, it is recirculated, keeping it above 55°C.

This measure is done basically to avoid that water decreases its temperature under a limit value where legionella could grow and survive [18]. Moreover, it makes the system capable to response quickly when hot water is needed again; so it only takes few seconds to bring back hot water when the hot tap opens again.

The whole building is provided with 4 shower placed in the first floor, small kitchen in the last floor and 22 toilets together with 22 washbasin.
The washbasin is, in average, the domestic device with more number of uses per capita in a day (4.0 uses per day) and responsible for a total use around 34%. It is followed by the kitchen sink (3.7 uses a day) and accounts a 32% of the total consumption [19].

Gastrike Vatten charges in Gävle are for residential buildings are:

- Fixed annual fee 1337.5 K/year
- Apartment fee (if it is over $25 \text{m}^2$) 668.75 K/year
- Variable water and sewage charge 16.25 K/$\text{m}^3$

---

9 Prices available at Gastrike Vatten official web page: http://www.gastrikevatten.se/brukningsavgift-gavle
4 METHOD

In order to obtain the results a structure has been followed. The thesis has been divided in different parts.

Before starting numbering the different parts, notice that the new cooling system has been designed for extremely hot summer day in Gävle, where the cooling demand of the building is going to be the highest.

Firstly, in order to see if the tap water has enough capacity for the specific application, the cooling demand for the whole building has been calculated. Secondly heat exchanger has been chosen to satisfy the cooling effect calculated in the previous section. Next, the tap water flow needed to provide the cooling effect has been calculated. Finally, regarding what to do with the used tap water, three options have been contemplated.
5 PROCESS AND RESULTS

5.1 Cooling demand

As explained in section 3.2.2, the chilled water can be divided in two different circuits regarding the temperatures: KS01, KS02. The characteristics of the two flows are shown in Table 2. Density and the heat capacity have been calculated for the mean temperature of each circuit with the equations (eq2.13) and (eq2.14), respectively.

Table 2. Flow characteristics of KS01 and KS02

<table>
<thead>
<tr>
<th></th>
<th>Ti [°C]</th>
<th>To [°C]</th>
<th>Tm [°C]</th>
<th>ρ [kg/m³]</th>
<th>Cp [kJ/kg·K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>KS01</td>
<td>14</td>
<td>17</td>
<td>15.5</td>
<td>998.92</td>
<td>4.183</td>
</tr>
<tr>
<td>KS02</td>
<td>7</td>
<td>12</td>
<td>9.5</td>
<td>999.96</td>
<td>4.193</td>
</tr>
</tbody>
</table>

Hence, two cooling effects have been calculated KS01.

Having the flow as well as the inlet and outlet temperature for each chilled beam, the cooling delivery power for each device has been calculated using the equation (eq2.12)\(^{10}\)

Complete results are shown in Appendix 2 for each chilled beam. Summing the values, it has been obtained the cooling need together with the flow for each floor of the building. Results are shown in Table 3.

Table 3. Cooling demand and total flow through the chilled beams for each floor

<table>
<thead>
<tr>
<th>Floor</th>
<th>n° chilled beams</th>
<th>Flow [l/s]</th>
<th>Q [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>0.49</td>
<td>6.18</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>0.34</td>
<td>4.21</td>
</tr>
<tr>
<td>4</td>
<td>19</td>
<td>0.96</td>
<td>12.02</td>
</tr>
<tr>
<td>5</td>
<td>16</td>
<td>0.86</td>
<td>10.79</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>0.32</td>
<td>3.96</td>
</tr>
<tr>
<td>TOTAL</td>
<td>57</td>
<td>2.97</td>
<td>37.17</td>
</tr>
</tbody>
</table>

\(^{10}\) Assuming that heat delivered to the room = heat absorbed form the chilled water
In the first floor there is no chilled beam installed. The total maximum cooling that the chilled beams will have to provide to the building is 37.17 kW by circulating 2.97 l/s spread in the different devices

**KS02**

Having the flow as well as the inlet and outlet temperature for the chiller and the air handling unit, the cooling need for each device has been calculated using the same equations as before (eq2.12).

In the following Table 4 the results are shown.

<table>
<thead>
<tr>
<th>Floor</th>
<th>Purpose</th>
<th>Flow (l/s)</th>
<th>Q (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>chiller</td>
<td>0.95</td>
<td>19.9</td>
</tr>
<tr>
<td>6</td>
<td>HVAC</td>
<td>2.21</td>
<td>46.3</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>3.16</strong></td>
<td><strong>66.2</strong></td>
</tr>
</tbody>
</table>

The total cold power that the chilled water has to delivery is 103.4kW

However, the fact that KS02 feeds the air handling unit and the chiller with water at 7°C, makes impossible to switch the cooling source from district cooling to tap water, since the last one comes into the building at 10°C.

For this reason, the total cooling demand taken into account is the one that the chilled beams provide to the building, 37.2kW (36% of the total need); it does not contemplate neither the given by the chiller nor the needed for air conditioning.

Hence, to tap water will only be used to cool the chilled water that flows through the chilled beams to 14°C, as it shows Figure 9.

*Figure 9. Schema of the system for cooling the chilled water with cold tap water*
5.2 Heat exchanger design

As it shows the previous figure, a heat exchanger has to be selected in order to transmit the cooling effect from the cold tap water to the water that circulates through the chilled beams.

There are different types of heat exchanger: plate heat exchanger, tube heat exchanger, spiral heat exchanger, etc. However, the best economical and thermal solution for the described application is the plate heat exchangers because of its compactness, easy maintenance, good heat transfer characteristics and flexibility to increase the heat transfer area [20]. See [Appendix 3] for more information.

5.2.1 Type election

In order to choose the suitable plate heat exchanger, it has been followed the steps indicated in the Alfa Laval\textsuperscript{11} brochure\textsuperscript{12}

See Appendix 3 to see the detailed steps and formulas detailed in Alfa Laval brochure.

Previous parameters:
Characteristics of hot stream, chilled beams side, are shown in Table5.

Table 5. Hot stream (chilled beams) characteristics

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot stream</td>
<td></td>
</tr>
<tr>
<td>$T_1$ [°C]</td>
<td>17</td>
</tr>
<tr>
<td>$T_2$ [°C]</td>
<td>14</td>
</tr>
<tr>
<td>Flow [kg/s]</td>
<td>2.96</td>
</tr>
</tbody>
</table>

Temperatures of cold stream, tap water side, are shown in Table6.

It is difficult to measure the temperature of the water that comes inside the building, so estimations have been done. Temperature of the cold tap water has been set at 10°C since we are contemplating an extreme case.\textsuperscript{13}

\textsuperscript{11} Alfa Laval AB is a Swedish company founded in 1883 which started in the separation of solutions, now deals in the production of specialized products and solutions for heavy industry

\textsuperscript{12} Alfa Laval Brochure provided by a technical teacher in HIG

\textsuperscript{13} Water is leaving plant at 8°C
Since the returning tap water temperature is unknown, an approximation of this value has been done too. A plate heat exchanger has counter-flow streams; for this reason, as is shown in Figure 2, the temperature $T_4$ cannot be higher than $T_1$, though, it can be a close value due to heat transfer effectiveness. However, has it is explained in section 2.4.1, is recommended that cold water should not exceed 15°C; then $T_4$ has been set at this temperature.

Table 6. Temperatures of cold stream

<table>
<thead>
<tr>
<th>Cold stream</th>
<th>$T_3$ (°C)</th>
<th>$T_4$ (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tap cold water</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Returning tap water</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

The cold that the chilled water has to absorb from the cold tap water via the heat exchanger has been supposed to be the same effect that the chilled beams deliver to the rooms, since these two devices have insignificant heat losses. Effect ($\dot{Q}$) is 37.2 kW

Calculation of the parameters:
The following parameters have been calculated using the formulas in the Appendix 3

$$\Delta T_1 = 2°C$$
$$\Delta T_2 = 4°C$$
$$\delta t = 3°C$$
$$LMTD = 2.89$$
$$\Theta = 1.04$$
$$\phi = 12.88$$

Using Figure A3.1, with a maximum flow of 2.96 kg/s and $\Theta = 1.040$, it is obtain that the suitable flat heat exchanger is CB26

Once checked in Figure A3.2 that the value $\phi$ is lower than $\phi_{max}$, it can be confirmed that the best heat exchanger for this application is CB26

Once the type of heat exchanger has been chosen, the heat transfer area of the device has been calculated using the equation (eq3.1) and (eq3.2)

$U$ value has been fixed to $6\frac{\text{kW}}{\text{m}^2\cdot\text{°C}}$

The total area of the heat exchanger is $A = 2.15 \text{ m}^2$

$^{14}$ Medium value of the ones provided in the CB26 brochure. See Appendix 4
5.3 Cold tap water flow

In this section, it has been determined the cold tap water flow needed to cool the water from 17 to 14°C. Assuming that there are not heat loses in the heat exchanger, the power delivered by the cold tap water is the same to decrease the temperature of the chilled water 3 degrees.

Isolating the flow in the equation (eq2.12) and replacing the values from the Table 7

<table>
<thead>
<tr>
<th>Cold water</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>T3 [°C]</td>
<td>10</td>
</tr>
<tr>
<td>T4 [°C]</td>
<td>15</td>
</tr>
<tr>
<td>Tm [°C]</td>
<td>12.5</td>
</tr>
<tr>
<td>ρ [kg/m³]</td>
<td>999.47</td>
</tr>
<tr>
<td>Cp [kJ/kg·K]</td>
<td>4.187</td>
</tr>
</tbody>
</table>

The total tap water flow needed is 1.78 l/s

5.4 New installation

Once calculated the cold water flow to satisfy the cooling need, other issues should be analysed.
Gasstrike Vatten AB informed that under any circumstances water can be sent out from their water pipe system to a building, if the water is not purchased first. For this reason, the cold tap water used for cooling has to flow through the water meter reader and be paid as tap water.
As Figure 10 shows, a regulation valve, equipped with temperature sensor, is placed before the heat exchanger in order to regulate the flow to satisfy the cooling demand of the building at any time.
Different options have been contemplated regarding the destination of the warmed water in the heat exchanger: deliver it to waste, bring it back to the tap water network system and reuse it as a tap water.

Before starting analysing each option, characteristics of the main pipe water are shown in Table 8. Pressure in the pipes has been set as 3.5 bar and water velocity at 2.5 m/s\(^{15}\).

The flow has been calculated using equation (eq4.1)

Table 8. Main pipe water characteristics

<table>
<thead>
<tr>
<th>MAIN PIPE CHARACTERISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter [m]</td>
</tr>
<tr>
<td>Pressure [bar]</td>
</tr>
<tr>
<td>Flow [kg/s]</td>
</tr>
<tr>
<td>Temperature [°C]</td>
</tr>
</tbody>
</table>

\(^{15}\) tap water velocity varies between 1.5 and 3 m/s
5.4.1 Option 1: deliver water to waste

As Figure 11 shows, once tap water has been used, it is delivered to the waste. Since water in the main pipe is at 3.5 bar and it is delivered to atmospheric pressure, there is a big pressure difference in a short pipe length. For this reason, pressure reducing valves\(^\text{16}\) are needed in order to control the water that flows through the heat exchanger.

\(^{16}\) They automatically reduce the high incoming water pressure from the city mains to provide a lower, more functional pressure for distribution at home.
5.4.2 Option 2: back to main tap water system

![Diagram of the system](image)

*Figure 12. Schema of the system if the water is brought back to the water network*

The idea of this option is that, once the water has been warmed in the heat exchanger is delivered back to the main water pipe close to the building. The warmed water will be mixed with the cold tap water that flows through the main pipe, raising its temperature.

Pressure reducing valves are not needed due to the water is returned to the main pipe at the same pressure. However, as it is shown in *Figure 12*, a pump has to be installed in order to overtake head loses due to friction. Furthermore, a check valve\(^{17}\) should be placed in the returning pipe (after the heat exchanger) to avoid the flow going upwards.

---

\(^{17}\) Check valve allows the fluid to flow through it only in one direction.
5.4.2.1 Thermal effect in the main pipe

![Figure 13 Schema of the pipe junction](image)

The pressure for the three streams (Figure 13) is the same and has a value of 3.5bar. In order to quantify the temperature increment, values in Table 9 have been replaced in equation (eq2.15) for pipe junctions.

<table>
<thead>
<tr>
<th></th>
<th>From heat exchanger (1)</th>
<th>Main pipe beginning (2)</th>
<th>Main pipe end (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T [^{\circ}C]</td>
<td>15</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>(\dot{m}) [kg/s]</td>
<td>1.78</td>
<td>10.79</td>
<td>12.57</td>
</tr>
<tr>
<td>(h) [kJ/kg](^{18})</td>
<td>63.32</td>
<td>42.36</td>
<td>-</td>
</tr>
</tbody>
</table>

Specific enthalpy is 45.3kJ/kg and temperature \(T_3\) is 10.7\(^{\circ}\)C, meaning an increase of main pipe temperature of 0.7 degrees after the water is returned back.

5.4.3 Option 3: Water reuse

In this section, the possibility to reuse the flow that leaves the heat exchanger after absorbing heat from the chilled beam circuit, is contemplated.

\(^{18}\) Specific enthalpy for stream 1 and 2 has obtained using Application online available at: [http://thermodynamik.hs-zigr.de/fpc/index.php](http://thermodynamik.hs-zigr.de/fpc/index.php) Introducing 2 water properties, application provides the desired one
Figure 14. Schema of the system when hot water is needed

As Figure 14 shows, when hot water is needed and chilled beams are active, a fraction of water used for cooling purpose heads to the heat exchanger (fed by district heating) instead of returning back to the main pipe. This water fraction will be heated up to 60°C for hot tap water usage. With this measure, a reduction of energy can be done, since the water is preheated at 15°C by the chilled beams water.

5.4.3.1 Energy saving example

In order to quantify how much energy can be saved, peak tap water demand has been estimated together with its temperature.

Building requirements: warmed water peak demand and water temperature

As said before, the building is going to be used as offices for an insurance company, for this reason the 4 showers, placed in the first floor, rarely are going to be used. Toilet flushes only use cold water; consequently, they are not going to be taken into account for the water demand.

The water peak demand is going to happen during lunch time, when kitchen’s sink might be used as well as some washbasin. It has been set that, at the most, 8 washbasins will be in use at the same time, delivering water at 0.2 l/s at 36 °C19 each one.

---

19 Value provided by a technical professor in HIG
In Table 10 characteristics of the tap water flow are shown.

**Table 10** Characteristics of water flow when demand is high.

<table>
<thead>
<tr>
<th>Desired tap water temperature</th>
<th>( T_{\text{tap}} ) [°C]</th>
<th>36</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volumetric flow</td>
<td>[l/s]</td>
<td>1.6</td>
</tr>
<tr>
<td>Density</td>
<td>( \rho ) [kg/l]</td>
<td>0.993</td>
</tr>
<tr>
<td>Flow</td>
<td>( \dot{m} ) [kg/s]</td>
<td>1.59</td>
</tr>
<tr>
<td>Specific enthalpy</td>
<td>( h_{\text{tap}} ) [kJ/kg]</td>
<td>151.1</td>
</tr>
</tbody>
</table>

A total flow of 1.59 kg/s is needed to satisfy the water demand\(^{20}\).

**Hot/cold water flow to satisfy the demand**

As it is shown in Figure 15, hot and cold water flow have been calculated to satisfy the peak demand at the desired temperature. The two flows will be mixed in the tap outlet delivering the desired temperature in each sink.

![Figure 15 Mixing flow schema in the taps outlets](image)

**Table 11**. Cold and hot flow tap water properties

<table>
<thead>
<tr>
<th></th>
<th>Hot stream</th>
<th>Cold stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature [°C]</td>
<td>60</td>
<td>10</td>
</tr>
<tr>
<td>Specific enthalpy [kJ/kg]</td>
<td>251.4</td>
<td>42.4</td>
</tr>
</tbody>
</table>

Replacing the values of Table 10 and Table 11 in equations (eq2.4) and (eq2.15), it has been obtained that \( \dot{m}_{\text{hot}}=0.83\) kg/s and \( \dot{m}_{\text{cold}}=0.76\) kg/s.

**Heating power from the district heating**

In this part, the heating power to warm up 0.83 kg/s up to 60°C has been calculated for both systems, the actual and the proposed one.

---

\(^{20}\) It only contemplates the washbasin and kitchen sink. Water used in toilet flushes is not included.
Actual system

Water coming at 10°C from the water tap network has to be heated in the heat exchanger, See Figure 16.

Figure 16. Actual system to obtain tap water at a desired temperature.

Knowing that \( \dot{m}_{\text{cold2}} = \dot{m}_{\text{hot}} \), and using equation (eq2.1), heat power delivered by the district heating is 172.8 kW.

Proposed system

In the new proposed system showed in Figure 17, it will be prioritized the usage of the chilled water instead of the cold one. If available flow is lower that the hot water demand, cold water coming from the network will be used as well.

The available flow at 15°C is the same as the one calculated in section 5.3, which is 1.61 kg/s. Since \( \dot{m}_{\text{chbeam,available}} < \dot{m}_{\text{hot}} \), then \( \dot{m}_{\text{chbeam}} = \dot{m}_{\text{hot}} \) and no extra cold water is needed.

Using equations (eq2.12), the heating power needed for this new system is 155.5 kW
A heat flow rate of 17.3 kW , using the new system, can saved.
6 DISCUSSION

A dynamic study could have been better in order to analyze and discuss the new system viability; nevertheless, not being in possession of the appropriate tools, it has been impossible to go further with the calculation and make, for instance, an economic analysis. Discussion is based on the obtained results for unfavorable situation in summer, when the cooling demand reaches the highest levels.

Using tap water as a cooling source makes the system unable to satisfy the cooling demand of the whole building, since tap water is not cold enough. Therefore, only a 36% of the cooling need, delivered through the chilled beams, could be provided with the new system; while the district cooling connection is kept to satisfy the rest.

Besides, Gastrike Vatten does not allow, under any circumstances, to use water, if it is not paid first; consequently, it was thought that the flow could be minimized by increasing ,as much as possible, the returning temperature (T4). However, this temperature is recommended not to exceed 15°C, in order to prevent legionella growth.

Three options have been studied regarding what to do after tap water has been used.

Delivering water into waste has an extra charge, then, not only will the company have to pay for water consumption but also for delivering it to the waste. However, with this system, the tap water flow can be minimized by increasing the returning temperature. This can be done because this water does not represent a health threat because since it is going to be treated and disinfected in the plant.

A worrying point of bringing back the water to the main pipe is the thermal effect that the warmed water could transfer to the drinking water system. In the studied case, main pipe water temperature only increased 0.7°C after water was delivered. However, if the proposed system was applied in big scale, the thermal effect could be much more significant; reaching an alarming point where a suitable environment for legionella could be generated. By increasing the flow through the heat exchanger, temperature in the outlet can be reduced and, consequently, the thermal effect in the main pipe does it too, increasing the operational cost.

The third option is the more energetic efficiency one since water is reused for hot tap water. Hot tap water demand for offices is low and with this new system a 17,2kW of
heat delivered by the district heating could be reduced. However, this number is an estimation when hot water demand is the highest, so it rarely occurs. Furthermore, a tendency towards template or cool water rather than hot water when using the washbasins is rising in summer.

Another important issue is the stagnation of the water when hot water is not needed anymore. Increase of water temperature as well as stagnation is a risk for human health, since both have been proved to deteriorate drinking water quality and promote legionella growth. Then, even water coming from the cooling circuit will be warmed up to 60°C, legionella dies within 32 minutes, so a risk of using the water before legionella is killed exists.
7 CONCLUSION

When implementing a system using tap water as a cooling source, it has to be taken into account that cooling capacity is limited and extra requisites and limitations have to be accomplished since drinking water is used.

Delivering the used water to the waste is much more expensive than keeping the system connected to the district cooling. Using drinkable water implies previous processes to keep its quality; thus, that makes it an expensive source with less cooling capacity. Bringing back the warmed water to the system is not energy efficiency since cold and warm water are mixed, and it also represents a heath human threat.

Reusing the water for hot water seems to be the best option, although what to do with the water when hot water is not needed is still an incognita. This option could be suitable for buildings with a much higher demand of hot tap water such as gyms, where cooling might be needed in the room where clients exercise and hot tap water for the showers.

Besides, it is really important not to deteriorate the quality of the tap water when using it as a cooling source. Tap water cannot exceed 20°C and stagnation should be avoided. A solution for this problem could be draining the system when a long period without water consumption has occurred.

Despite this system is limited and have some health requirements, more research could be done and go further to find better solutions.
REFERENCES


APPENDIX 1: Chilled beams

Water offers a more energy efficient way of distributing energy in the form of heating and cooling around a building than ‘all air’ systems because of its high specific heat capacity and thermal conductivity. One of those water-base systems are the chilled beams. The basic thermal transfer component for chilled beams is a fin and tube heat exchanger (often referred to as coils). Rows of interconnected copper pipes are usually bonded to aluminum thermal conduct fins. This arrangement is then mounted in a sheet metal casing, which can be:

· Freely suspended from a soffit
· Installed above a perforated ceiling
· Integrated flush into a suspended ceiling system

Chilled beams require a relatively modest cooling water temperature (14-17 °C) and they work using convection rather that radiation. They are arranged at a regular intervals along the ceiling plane to provide uniform cooling to the occupied space below.

There are two main types of chilled beams:

Passive chilled beams
Passive chilled beams work using natural convection. Warm air rising up in the space passes over the top and into the passive chilled beams. As the air between the aluminum thermal conducting fins is cooled, it becomes denser and returns due to the negative bouyancy, as it is shown in FigureA1.1

![FigureA1.1 Passive chilled beam operation](image)

Active chilled beams
Chilled beams incorporate primary air supply to enhance and control the induction of air through the coil. There is normally some form of primary air duct or plenum running
along the length of the beam. This allows the primary air to be discharged into the beam, usually through nozzles, enhancing the induction of room air through the coil. As it shows Figure A1.2, the primary air is mixed with the cooled air before being discharged into the space through integral slots. A picture of an active chilled beam can be seen in Figure A1.3.

APPENDIX 2: Cooling demand calculation for chilled beams

The chilled beams can have 4 different sizes which vary in function of the cooling need in each room. The four different sizes have been denominated with the letter S, M, L and XL. S represents the smallest one while the XL is the biggest.

To calculate the cooling effect that the chilled beams provide to each room the following equation has been used:

\[ Q = \dot{v} \cdot \rho_m \cdot C_p_m \cdot (T_{in} - T_{out}) \]

In the following tables, it is shown the size, the flow and the cooling effect for each chilled beam for every floor of the building.

<table>
<thead>
<tr>
<th>Table A2 1. Characteristics of chilled beams on floor 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2nd FLOOR</strong></td>
</tr>
<tr>
<td>Size</td>
</tr>
<tr>
<td>L</td>
</tr>
<tr>
<td>S</td>
</tr>
<tr>
<td>XL</td>
</tr>
<tr>
<td>XL</td>
</tr>
<tr>
<td>M</td>
</tr>
<tr>
<td>M</td>
</tr>
<tr>
<td>TOTAL</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table A2 2. Characteristics of chilled beams on floor 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3rd FLOOR</strong></td>
</tr>
<tr>
<td>Size</td>
</tr>
<tr>
<td>XL</td>
</tr>
<tr>
<td>M</td>
</tr>
<tr>
<td>L</td>
</tr>
<tr>
<td>L</td>
</tr>
<tr>
<td>M</td>
</tr>
<tr>
<td>L</td>
</tr>
<tr>
<td>M</td>
</tr>
<tr>
<td>TOTAL</td>
</tr>
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### Table A2.3 Characteristics of chilled beams on floor 4

<table>
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<tr>
<th>4th FLOOR</th>
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<tbody>
<tr>
<td>Size</td>
<td>n° chilled beams</td>
<td>Flow (l/s)</td>
<td>Q (W)</td>
</tr>
<tr>
<td>M</td>
<td>1</td>
<td>0.030</td>
<td>376.0</td>
</tr>
<tr>
<td>L</td>
<td>2</td>
<td>0.130</td>
<td>1629.5</td>
</tr>
<tr>
<td>M</td>
<td>1</td>
<td>0.030</td>
<td>376.0</td>
</tr>
<tr>
<td>L</td>
<td>2</td>
<td>0.130</td>
<td>1629.5</td>
</tr>
<tr>
<td>M</td>
<td>1</td>
<td>0.032</td>
<td>401.1</td>
</tr>
<tr>
<td>XL</td>
<td>2</td>
<td>0.095</td>
<td>1190.8</td>
</tr>
<tr>
<td>M</td>
<td>1</td>
<td>0.040</td>
<td>501.4</td>
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<tr>
<td>L</td>
<td>2</td>
<td>0.140</td>
<td>1754.9</td>
</tr>
<tr>
<td>M</td>
<td>1</td>
<td>0.048</td>
<td>601.7</td>
</tr>
<tr>
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<td>902.5</td>
</tr>
<tr>
<td>M</td>
<td>2</td>
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<td><strong>TOTAL</strong></td>
<td><strong>19</strong></td>
<td><strong>0.959</strong></td>
<td><strong>12021.0</strong></td>
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### Table A2.4 Characteristics of chilled beams on floor 5

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<th>5th FLOOR</th>
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<td>Size</td>
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<td>Flow (l/s)</td>
<td>Q (W)</td>
</tr>
<tr>
<td>M</td>
<td>1</td>
<td>0.033</td>
<td>413.7</td>
</tr>
<tr>
<td>L</td>
<td>2</td>
<td>0.095</td>
<td>1190.8</td>
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<tr>
<td>M</td>
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<td>0.033</td>
<td>413.7</td>
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<tr>
<td>L</td>
<td>2</td>
<td>0.095</td>
<td>1190.8</td>
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<tr>
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<tr>
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<tr>
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<td>0.041</td>
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<td><strong>TOTAL</strong></td>
<td><strong>16</strong></td>
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### Table A2.5 Characteristics of chilled beams on floor 6

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<td>Q (W)</td>
</tr>
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<td>L</td>
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<td><strong>TOTAL</strong></td>
<td><strong>4</strong></td>
<td><strong>0.316</strong></td>
<td><strong>3961.0</strong></td>
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</tbody>
</table>
APPENDIX 3: Plate Heat exchanger. Alfa Laval brochure

The advantageous characteristics of plate heat exchanger are:

- Thin material for heat transfer surfaces. This provides high heat transfer because the heat penetrates less material and the material cost is lower.

- High turbulence in the flow. This provides high convection resulting in a higher heat exchange rate between the flows. Higher heat transfer per unit area means that it is possible to have smaller global surfaces for a given situation, which contributes to a more economical system. The high turbulence also causes a high self-cleaning effect. The fouling factor has significantly less effect in a plate heat exchanger than on a conventional-shell one, getting a significantly longer operating times between the cleaning sessions.\(^\text{21}\)

- Flexibility. Plate heat exchanger design, with a number of heat transfer plates for the suspension in a stand, means that it is easy to build when the load increases. It is also easy to open for cleaning if required

Steps to choose the appropriate plate heat exchanger (water/water)

In order to solve thermal problem, certain parameters must be known and others can be calculated from those. The main parameters are:

Previous parameters

1. Effect [kW].

2. In and outgoing temperature of the primary and secondary side [°C]
   - \(T_1\) = Initial temperature on the warm side
   - \(T_2\) = Output temperature on the warm side
   - \(T_3\) = Initial temperature on the cold side
   - \(T_4\) = Output temperature on the cold side

---

\(^{21}\) After a period of operation the heat transfer surfaces for a heat exchanger may became coated with various deposits present in the flow system, or the surfaces may become corroded as a result of the interaction between the fluids and the material used for construction of the heat exchanger. In either event, this coating represents an additional resistance to the heat flow, and thus results in decreased performance. The overall effect is usually represented by a fouling factor
3. Flow of the warm side [kg/m³]

Parameter that need to be calculated

1. Using the current temperature program rate \( \Delta T_1, \Delta T_2 \) and \( \delta t \):
   \[
   \Delta T_1 = T_1 - T_4 \quad [\text{K}]
   \]
   \[
   \Delta T_2 = T_2 - T_3 \quad [\text{K}]
   \]
   \[
   \delta t = T_1 - T_2 \quad [\text{K}]
   \]

2. LMTD. Logarithmic mean temperature difference
   \[
   LMTD = \frac{\Delta T_1 - \Delta T_2}{\ln \frac{\Delta T_1}{\Delta T_2}}
   \]

3. Thermal length \( \Theta \)
   \[
   \Theta = \frac{\delta t}{LMTD}
   \]

4. Calculate \( \phi \) (control factor)
   \[
   \phi = \frac{P}{LMTD}
   \]

Using the following diagram (Figure A3.1), entering the thermal length and the maximum flow rate, the type of heat exchanger can be determined
Check if the device is approved by the table below (minimum size of device type). If this is not correct, choose the type that is closest to the right of the table.

**FigureA3 1** Diagram to choose the suitable heat exchanger

**FigureA3 2** Heat exchanger in function of the parameter $\Phi_{\text{max}}$
Användning
Värme- och kyluppgifter, värmeåtervinning.
Media: vätska/vätska, ånga/vätska, gas/vätska.
Exempel: vatten/vatten, vatten/olja etc.
ånga/vatten, ånga/olja etc.
freon/vatten, luft/vatten etc.

Utförande

Standardvärmeväxlar
Alfa Lavals lödda plattvärmeväxlar levereras som standard i storlekar enligt tabell. Alla standardapparater är utförda som 2-stråksväxlar med 4 st anslutningar i ena gaveln och 2 st anslutningar i den andra gaveln.

Teknisk data (PED godkända)
Min. arbetstemperatur: -160 °C
Max. arbetstemperatur: +175 °C
Max. arbetstryck: 32 bar
Provttryck: 48 bar
Värmeöverföringstal: 5000-7000 W/m °C
Material: syrafast stål (kopparlod)

Tillbehör
Isolering: 30 mm freonfri formgjuten polyuretanskum täckt med oöm ABS-plast.
Kopplningar för svets eller lödanslutning.
Stålsanslutning passar mot stålör DN25 (utvändig diameter 33,7 mm).
Mässingsanslutningen passar till kopparrörl 22x1,5 mm som träds in i mässingsanslutningen och löds med silverlod.
CB26 - 2 stråk

Mått och vikt

<table>
<thead>
<tr>
<th>Storlek</th>
<th>A längd</th>
<th>Vikt tom</th>
<th>Vikt fylld</th>
<th>Anslutning</th>
</tr>
</thead>
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<tr>
<td></td>
<td>mm</td>
<td></td>
<td></td>
<td>DN</td>
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<td>25</td>
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<td>* CB26-120H:2</td>
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<td>16,8</td>
<td>19,8</td>
<td>25</td>
</tr>
</tbody>
</table>

* = lagervara

Förslag på inkoppling

- T1  Kallvatten
- S1  Varmvatten
- S2  VVC
- S3  Ev. retur från RAD
- S4  Fjärrvärme in
- T4  Fjärrvärme ut

Rätten till ändringar förbehålls