REDUCTION OF THE COSTS IN A HOUSE IN VALBO THAT USES ELECTRICITY AS ENERGY SOURCE

*Study of the installation of a heat pump or connection to the district heating*

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LIST OF SYMBOLS

\( Q_{\text{trans}} \) = transmission losses (W)
\( Q_{\text{mec v}} \) = ventilation losses due to mechanical ventilation (W)
\( Q_{\text{nat v}} \) = ventilation losses due to natural ventilation (W)
\( Q_{\text{hot tap water}} \) = heat used for the hot tap water (W)
\( Q_{\text{radiation}} \) = heat supplied by the solar radiation (W)
\( Q_{\text{internal heat gen}} \) = Internal heat generation (W)
\( Q_{\text{supply heat}} \) = heat needed in the heating system of the house (W)
\( A_j \) = the area of the different surfaces (m\(^2\))
\( U_j \) = U- value (W/m\(^2\).K)
\( K_{tr} \) = conductance due to transmission (W/K)
\( T_{\text{room}} \) = room temperature (ºC)
\( T_{\text{out}} \) = Outdoor temperature (ºC)
\( \Delta T_{\text{air}} \) = air temperature difference (K)
\( \Delta T_{\text{w}} \) = water temperature difference (K)
" \( \rho \) " = density (kg/m\(^3\))
\( C_p \) = specific heat capacity (J/kg.K)
\( V \) = Volume (m\(^3\))
\( \eta_t \) = temperature efficiency (-)
\( K_v \) = Conductance due to mechanical ventilation (W/K)
\( K_{\text{nat v}} \) = conductance due to natural ventilation (W/K)
\( m_{\text{hot water}} \) = mass flow of water (kg)
\( K_{\text{rad}} \) = solar radiation factor (-)
\( Q_{\text{degree}} \) = is the degree-hours (ºC h / year)
\( E_{\text{trans}} \) = Need of energy due to transmission (W.h/year)
\( E_{\text{mec v}} \) = Need of energy due to mechanical ventilation (W.h/year)
\( E_{\text{nat v}} \) = need of energy due to natural ventilation (W.h/year)
\( E_{\text{hot tap water}} \) = need of energy for the hot tap water (W.h/year)
\( E_{\text{radiation}} \) = energy due to solar radiation (W.h/year)
\( E_{\text{internal gen}} \) = internal energy generation (W.h/year)
\( E_{\text{supply heat}} \) = energy needed for the heating system of the house (W.h/year)
SUMMARY

The analyzed building in this project is located in Valbo, 9016 Stiftelsev 6. This house is a property of Gavlegårdarna, and it is being used as a house for disabled people. The building consists of five apartments, with one patient in each apartment. Some social workers help those patients in everything they need, making their living in the house as easy as possible.

The aim of this project is to find out the best option of reducing the energy consumption in this house. There are some alternatives to reduce the energy or the energy costs as; efficiency measures, load management and energy conversion.

This project is focused on the energy conversion for reducing the energy consumption. As it is the best option for obtaining a considerable reduction in the annual costs.

First of all the energy balance of the house is analyzed. By studying the energy balance it is possible to find out how the energy consumption of the house is divided. On one hand there is the heat supplied and on the other hand the heat losses.

The heat supplied is divided in; the internal heat generation, solar radiation and current heating system. Their values are; 7.5 MW, 5 MW, 52 MW respectively.

The heat lost is divided in; transmission losses, hot tap water, mechanical ventilation and natural ventilation. Their values are; 35.5 MW, 9 MW, 13 MW and 6.4 MW respectively.

The biggest losses are the transmission losses that stands for 54% of the total heat losses. It is possible to think on measures to decrease this value, however in a house that is already built this is not always a good method to really decrease the energy consumption.

As it was said before this project is focused in the reduction of the energy consumption by means of converting to another energy supplying method. Two alternatives have been studied: the installation of a heat pump and the connection to the district heating of Gävle.
Different kinds of heat pumps are studied and it has been concluded that the best option is a ground heat pump. The other alternatives were ruled out because they are not compatible with the situation of the house or the specified aspects.

Ground heat pumps have a coefficient of performance of 3, which means that to obtain 3 KW of heat, 1 KW of electricity is used in the compressor. Therefore the electricity consumption decreases by a 70% by the use of a ground heat pump.

The investment cost differs depending on the type of installation used. Vertical or horizontal installations were studied. The investment cost is 230000 Kr for the vertical installation and 175000 Kr for the horizontal installation.

As it is mentioned before vertical installations are more expensive but they provide cooling in summer, that otherwise can’t be done by a horizontal system. Moreover, the pay back time is 6.3 years for a vertical installation and 4.8 years for a horizontal installation.

It must be considered that in 15 years the compressor of the heat pump must be changed.

Concerning to the alternative of connecting to the district heating of Gävle, a reduction of 41.8% was obtained in the energy annual cost. It must be said that after talking with Stewe Jönsson it was obtained that the investment of the installation was of 525000 Kr. That investment cost, results in a pay back time of 24.1 years.

Finally, after comparing the three alternatives, choosing a horizontal heat pump seems to be the best option for reducing the annual energy cost and its pay back time is the lowest. However, another option can be studied.

The investment cost of connecting to the district heating is really high, but after studying the drawing of the district heating network around the house another alternative was obtained.

As there is a big neighbourhood around the house, if some of them decide to connect to the district heating net they could make an agreement to pay the installation cost together. Therefore, the pay back value would decrease considerably.
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1. INTRODUCTION

The world resources of crude oil and natural gas are located primarily in West Asia and in the former Sowjet Union, the latter having an almost equal supply of natural gas as the former. The exploitable deposits of coal are located primarily in North America (USA and Canada) and in Asia/Oceania (China and Australia). Europe only owns a very small of the world energy resources; the largest contribution comes from coal deposits (Poland, Germany, United Kingdom in the order of the resources magnitude).

Even when the world economies grow at only moderate rates, the energy demand to allow for the growths will lead to an acute shortage of crude oil and natural gas after the year 2030, and when the coal resources are included, all resources of fossil biologic energies will have vanished before the end of the 21st century. Therefore, the use of new sources as renewable energies must be imminent if we want to have a sustainable development, without energy shortages.

In the figure 1.1 the evolution of the global demand is shown.

![Figure 1.1: Global Energy Demand]

Renewable energies have the disadvantage of an extremely small energy density. Nevertheless, their contribution has to rise considerably within the next 50 years if a severe energy shortage should be avoided.

Apart from avoiding a possible energy shortage, it must be considered that during the last decade of the 20th century, the effect of greenhouse gases emissions on the global climate was recognized as one of the most urgent environmental problem.

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1 World Energy Outlook 2006
Global carbon-dioxide (CO2) emissions will reach 40 Gt in 2030, a 55% increase over today’s level\(^2\). China will overtake the United States as the world’s biggest emitter of CO\(^2\) before 2010. These trends would accentuate consuming countries’ vulnerability to a severe supply disruption and resulting price shock. They would also amplify the magnitude of global climate change.

![Figure 1.2 Distribution of the energy demand](image)

It must be noticed that building energy consumption occupies one of the largest share in the total energy consumption, as it is shown in the figure 1.2.

Therefore, reducing energy demand and improving energy efficiency in buildings is nowadays essential to achieve a sustainable built environment. At the same time, it is important not to harm people’s health, well being and comfort in buildings. Thus, designing buildings which are both healthy and sustainable is one of the most challenging tasks of today’s civil engineering\(^3\).

Clean alternatives as district heating can be used, instead of electricity for the heating system of the buildings. By this way, it is possible to reduce the CO\(_2\) emission level and other pollutants. This alternative is really interesting as it has the ability of absorbing low grade heat sources such as; garbage burning and industrial waste heat.

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\(^1\) World Energy Outlook 2006  
The aim of this project is to study the energy balance of a residential building that is located in Valbo and if it is possible replace the existing heating system by a more efficient one and/or lower annual cost.

Figure 1.3 Situation of the house in Valbo

This building is being used as a residential place for disabled people. There are five different apartments where they can have their own privacy and some social workers are always available for helping them in everything they need.

Figure 1.4 Drawing of the house

Nowadays the heating system works in this way; there is a boiler that is heated up by electricity and this hot water is then divided into the radiators, hot tap water and reheat of the supply air of the house until the temperature they ask for.
The energy balance is made to distinguish the different parts that are taking part in the heat that goes to the building and the heat losses by the building.

On one hand, there is the heat losses by the building that consists on, the heat transmission through the walls, the heat that is released due to the mechanical ventilation, the losses due to natural ventilation when the habitants open a window and finally the heat used for heating the hot tap water of the house.

On the other hand, there is the heat supplied into the building. This heat comes from the heating system of the house, the natural solar radiation and the internal heat generation, that is produced by the people living inside the building and the activity that this people is doing for instance: watching television and cooking.

After the study of the energy balance of the house, two different alternatives must be studied. The study is about replacing the actual heating system by a heat pump or by connecting to the district heating system of Gävle Energy. When choosing the best alternative, the most efficient system must be chosen. Because more efficient system means more economic system as well, that is what we care of.

When talking about the alternative of the district heating some aspects must be considered. The district heating grid doesn’t arrive to everywhere, as a consequence Gävle Energy is the one that decides if this option is profitable or not. They will give an investment cost and then the district heating tariffs will be applied. If there is not a district heating pipeline near the house, the investment cost would be really high due to the huge work that would be needed.

When talking about the alternative of installing a heat pump, it must be decided which kind of heat pump to install. Some aspects will be considered, for instance; the noise that the heat pump produces, the available area for installing the collector, if there is a water protected area under the house and of course the effect for supplying the heating system.

After studying each possibility, the best option is going to be chosen considering the annual energy savings and the obtained pay-back time.
2. THEORY

2.1 ENERGY BALANCE

There are two main factors that must be considered when talking about residential buildings. On one hand, the need of space heating must be minimized by a building envelope that minimises the heat losses. On the other hand the health and comfort of the habitants must be studied. The building must be done by materials that release no harmful gases, vapours and smells. As a consequence the need of high ventilation rates are avoided.

In residential buildings with cold climate there is not usually a technical device for the removal of the heat surplus. That is due to a not very usual situation of a heat surplus in the building, when this occurs windows are opened producing a natural removal of the heat surplus.

Moreover, the more the heat deficit decreases the lower need of heat for space heating. So if less space heating is needed, less electricity is needed and as a consequence the economical aspect becomes better. The way of decreasing the heat deficit is by improving the envelope of the building, considering the internal heat generation and by lowering the ventilation rate.

As it is shown in the Figure 2.1.1, for residential buildings the heat surplus that has to be removed is so small that there is no need of space cooling. Therefore, the heat surplus is released opening windows by natural ventilation. As it is only space heating needed, as much we improve the building envelope, the less the space heating is needed.
The energy balance is totally different depending on the season. In the following pictures, Figure 2.1.2 these differences are shown for winter and summer seasons.

(a) \hspace{1cm} (b)

Figure 2.1.2 Different energy balances for winter and summer season.

The aim of this project is to study the heating system of a building and think on the best alternative concerning to the energy savings. As a consequence the cold season must be studied and the energy balance must be made following the direction of the first picture.

The figure 2.1.2(a) shows the different directions of the heat flows during winter.

When making an energy balance there are two main parts, the supply of heat and the heat losses through the building.

In the balance, the heat losses = heat supply

\[ Q_{\text{hot tap water}} + Q_{\text{nat v}} + Q_{\text{mec v}} + Q_{\text{trans}} = Q_{\text{radiation}} + Q_{\text{internal heat gen}} + Q_{\text{supply heat}} \]
The aim in this first part of the project is to calculate the percentage of the amount of energy that corresponds to each colour as it is shown in the Figure 2.1.3.

**Heat losses by transmission** \((Q_{\text{trans}})\)

The heat losses by transmission are due to a difference of temperature between the indoor and outdoor air temperature. Specifically when outdoor temperature is lower that the room temperatures, as in cold seasons. Whenever this happens the building losses heat to the surroundings by the walls, doors, windows, roof and ground.

As it is shown in the formula below, the heat losses by transmission depend on the area of the transmission surface and the heat transmission coefficient of itself.

\[
Q = \sum A_j U_j \cdot (T_{\text{room}} - T_{\text{out}}) = K_{\text{tr}} \cdot (T_{\text{room}} - T_{\text{out}})
\]

Usually the heat losses through the walls are smaller comparing with the losses through the windows. Even if the area of the wall is huge comparing with the windows, the U value is really high for the windows.

As it is shown in the Table 2.1.1, the U value for the wall is 0.17 [W/m² °C] and the U value of the widows is of about 2 [W/m² °C].
### Table 2.1.1 Uvalues

<table>
<thead>
<tr>
<th></th>
<th>U [W/m² °C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>WALL</td>
<td>0.17</td>
</tr>
<tr>
<td>WINDOWS</td>
<td>2.00</td>
</tr>
<tr>
<td>DOORS</td>
<td>1.00</td>
</tr>
<tr>
<td>CEILING</td>
<td>0.12</td>
</tr>
<tr>
<td>FLOOR-OUT</td>
<td>0.30</td>
</tr>
<tr>
<td>FLOOR-GROUND</td>
<td>0.30</td>
</tr>
</tbody>
</table>

The U value is not always the same for each surface. For instance, the U value of the wall depends on the date it was built, and in the case of the building that is being studied it was built 15 years ago. When talking about windows the U value varies if it is single, double or triple glazed window. In this case the windows are triple glazed.

**Heat losses due to natural ventilation** \( (Q_{nat \ \text{vent}}) \)

The heat losses due to natural ventilation are the heat losses by air infiltration. This loss is produced by the pressure difference of the outdoor and indoor air. As it is shown in the formula below it depends on the \( \rho \) density, \( C_p \) the specific heat capacity of the air, \( V \) infiltration air flow and indoor and outdoor temperature.

\[
Q_{\text{nat \ vent}} = V_{\text{infiltr}} \cdot \rho \cdot C_p \cdot (T_r - T_{\text{out}}) = K_{\text{nat \ vent}} \cdot (T_r - T_{\text{out}})
\]

This value tends to be about the 15% of the transmission losses and depends absolutely on how the building has been build (this value is obtained from Roland Forsberg that is an expert of ventilation systems). Therefore, if the windows are not well fitted in the walls the risk of huge air infiltrations is really high.
Heat losses due to mechanical ventilation \( (Q_{\text{mec vent}}) \)

When talking about the mechanical ventilation, there are two different flows, supply and exhaust flow.

The supply flow is the one that goes in to the room and the exhaust air is the one that is released from the room. In the building studied, the ventilation system is the same in each apartment. There is a supply coil and two exhaust coils, one in the toilet and the other one in the kitchen. The coils are shown in the Figure 2.1.4.

![Figure 2.1.4 the supply and exhaust coils of each apartment](image-url)
The air handling system of the building is located in the control room as it is shown in the Figure 2.1.5. It has a heat exchanger that exchanges the heat of the exhaust air to heat the supply air. By this way, energy of the exhaust air is being used, which would otherwise leave the house. The efficiency of the heat exchanger is not really high; its efficiency is of 50-55%, which is why a re-heater is used to farther increase the supply air until the required temperature. This re-heater works with hot water that comes from the boiler.
In the Figure 2.1.6, it is more schematically explained how the heat exchanger works and which way is followed by the supply and exhaust flow. In some cases a bypass is made. As it is shown, the air handling system includes more devices than the air-air heat exchanger, like filters and fans.

These are the typical symbols that appear in schematic pictures of heat exchangers. Figure 2.1.7.

In the case of the air handling unit that is being studied, there is no air cooling coil because this ventilation system is only used for space heating.

That is why there is only an air heating coil, which works with hot water that has been called as a re-heater before.

As it is shown in the formula below the formula used for mechanical ventilation is quite similar to the one used for natural ventilation. It depends on the \( \rho \) density, \( C_p \) the specific heat capacity of the air, \( V \) ventilation air flow and indoor and outdoor temperature. However, in this case the formula is multiplied by an efficiency factor \( (1-\eta_t) \), this factor shows the efficiency of the heat exchanger.

\[
Q_{\text{mech vent}} = V_{\text{vent}} \cdot \rho \cdot C_p \cdot (1 - \eta_t) \cdot (T_r - T_{\text{out}}) = K_v \cdot (T_r - T_{\text{out}})
\]
Heat used for hot tap water \( (Q_{\text{hot tap water}})\)

The heat used for heating the tap water is calculated by the following formula:

\[
Q = m_{\text{hot water}} \cdot C_p \cdot \Delta T
\]

Where \( m_{\text{hot water}} \): is the mass flow of water that is measured in (kg).

\( C_p \): is the specific heat of the water that is 4.18 and is measured in (KJ/ kg.K).

\( \Delta T \): is the temperature difference between the supplied water by the water grid and the necessary temperature for the hot tap water.

The hot tap water is heated until 60ºC. This is due to need of preventing the Legionella disease.

Figure 2.1.8 Water is heated up to 60ºC in the boiler.
**Heat supplied by solar radiation** (\(Q_{\text{RADIATION}}\))

The solar radiation is a very important factor to consider due to the high quantity of heat surplus generated in the building. As it is said at the beginning as much energy we get by other means, less space heating is needed.

For calculating the heat supplied by the solar energy through each window, three aspects must be considered.

Firstly the orientation of the house shown in the Figure 2.1.9, each window has a different orientation and that differs a lot when making the calculations. For instance, the windows that are orientated to the North and West get less solar radiation comparing to the ones that are orientated to the South and East.

![Figure 2.1.9 Orientation of the building.](image)

Secondly, there are two ways of building a window as it is shown in Figure 2.1.10. Depending if the glass of the window is closer to the outer side or not the heat produced by the solar radiation differs.

![Figure 2.1.10 Outer and inner window](image)
The heat produced is higher when the glass is closer to the outer side as in the figure 2.1.10(a). For the house that is being studied, the windows are built following the case (b); the glass is farther from the outer side.

Thirdly, the shading of the windows must be studied. The shading efficiency is defined by the solar radiation factor $K_{rad}$. The definition of this factor is the relation between the solar energy radiated into the room and the solar energy radiated from outside towards outer pane. As it is shown in the Figure 2.1.11, there are different ways of shading a window differing on the $K_{rad}$.

![Figure 2.1.11 Different ways of shading a window and $K_{rad}$ coefficient](image)

For the house that is being studied Figure 2.1.12, the windows are protected by Venetian blinds that decrease considerably the solar emission, with a solar radiation factor of 0.28.

![Figure 2.1.12 Venetian blinds](image)

**Internal heat generation** ($Q_{\text{internal heat generation}}$)

The internal heat generation is an important value to consider when talking about the decrease of the heat supply in the building. The internal heat generation is divided in the heat released by the people living in the building and the heat released due to the activities that they are practising. This activities are cooking, having a shower, watching the television…. 
It is also important to consider the heat that is produced by the lightning system.

For the case of the heat released by the people; Metabolism is measured in Met as it is shown in Figure 2.1.13 (1 Met=58.15 W/m² body surface).
Body surface for normal adult is 1.7 m².
A sitting person in thermal comfort will have a heat loss of 100 W.
Considering that the people living in the building that is being studied are disabled people, 100 W is a good approximation of the heat that they release.

**Figure 2.1.13 Metabolism**

The heat released depending on the activity that this people practice, is the typical activity that can be practice in a household. These activities are divided in cooking, watching television…

It must be also considered the heat released by the lightning equipment. This heat is not a high value because they use some low consumption bulbs, some bulbs of 60 W and 40 W and a lot of lamps of 15 W that are located in every window.

**Heat supplied by the heating system**  \( (Q_{\text{supply heat}}) \)

This supply heat is the electricity used to heat the water that is used for the heating system of the house.
For calculating the corresponding energy consumption, a different term is going to be used, “E” need of energy. The unit of this new term is (KW.h/year).

\[
E_{\text{hot tap water}} + E_{\text{nat v}} + E_{\text{mec v}} + E_{\text{trans}} = E_{\text{radiation}} + E_{\text{internal heat gen}} + E_{\text{supply heat}}
\]

Where;

\[
E_{\text{trans}} = K_{tr} \cdot q_{\text{degree}}
\]

- \(K_{tr}\) : is the conductance due to transmission (W/K)
- \(q_{\text{degree}}\) : is the degree-hours (°C h / year)

\[
E_{\text{mec v}} = K_{v} \cdot q_{\text{degree}}
\]

- \(K_{v}\) : is the conductance due to ventilation (W/K)
- \(q_{\text{degree}}\) : degree-hours (°C h)

\[
E_{\text{hot tap water}} (KW.h) = m_{\text{hot water}} (kg) \cdot C_{p_{\text{water}}} (KJ/kg.k) \cdot \Delta T (k) / 3600 (s/h)
\]

- \(m_{\text{hot water}}\) : is the mass flow of water that is measured in (kg).
- \(C_{p_{\text{water}}}\) : is the specific heat of the water that is 4.18 and is measured in (KJ/ kg.K).
- \(\Delta T\) : is the temperature difference between the supplied water by the water grid and the necessary temperature for the hot tap water.

The hot tap water is heated until 60°C. This is due to need of preventing the Legionella disease.
2.2 HEAT PUMP

2.2.1 What is a heat pump and how does it work?

A heat pump is used to transfer heat from one place to another and this technology has been used in Sweden for decades. It can be used as a refrigerator or as a heating system. In this case, the heat pump is going to be introduced as a heating system. For both cases, the working fluid follows the same cycle. Nevertheless, the heat pump cycle is fully reversible, due to the use of a reversing valve in the cycle.

Heat pumps can provide year-round climate control for home - heating in winter and cooling and dehumidifying in summer.

As it is shown in the Figure 2.2.1.1, the refrigerant follows a cycle were it evaporates and condensates.

The cycle is divided in to different components:

**Refrigerant:** Is the working fluid on the cycle, which absorbs, transports and releases heat alternately through the heat pump.

**Reversing valve:** Is the device that controls the direction of the refrigerant in the heat pump. This valve is used when the heat pump is used for both activities; as a refrigerator in summer and as a heating system in winter.
The **Coil**: Is a loop, or loops, of pipes where heat transfer takes place. The piping must be provided of fins to increase the heat exchanged by increasing the surface.

The **evaporator**: Is a coil or heat exchanger in which the refrigerant absorbs heat from its surroundings and boils becoming a low-temperature vapour.

The **compressor**: Is a device that works electrically and pumps the working fluid between the evaporator and condenser. It increases considerably the temperature of the refrigerant.

The **condenser**: Is a coil or heat exchanger in which the refrigerant releases heat to its surroundings and becomes a liquid.

The **expansion valve**: Is the device that decreases the pressure created by the compressor. As a consequence the temperature drops considerably and the refrigerant becomes a low-temperature vapour/liquid mixture.

![Figure 2.2.1.2 Heat pump Cycle shown in T-s diagram](image)

In the graphic above Figure 2.2.1.2, it is shown the cycle that the working fluid follows.

The ideal cycle, is called Carnot cycle, it consists on two isentropic and two isothermal lines (1, 2C, 3, 4C). In the real cycle, the working fluid goes through the evaporator (heat exchanger) were the energy is transferred from the cold medium to the refrigerant (4R-1). The refrigerant will then evaporate. The refrigerant is transported in the circuit by the compressor to increase the pressure and temperature of the refrigerant (1-2C). In the condenser (heat exchanger) the refrigerant releases the heat absorbed in the evaporator (2R-3). The released energy is then transferred from the refrigerant to the heating system of the house, hot water system in this case. The expansion valve regulates
the mass flow of the refrigerant to maintain the pressure difference between the high pressure and the low pressure side (3-4R).

![Figure 2.2.1.3 Different working fluid](image)

Depending on the refrigerant chosen as a working fluid, the T-s diagram changes, as it is shown in the Figure 2.2.1.3.

### 2.2.2 Type of heat pumps

Heat pumps use the low temperature geothermal energy and they get the energy from the sun energy absorbed by the earth during the year.

![Figure 2.2.2.1 Earth absorbs 51% of the solar energy](image)

As it is shown in the Figure 2.2.2.1, the earth absorbs the 51% of the solar energy incoming.

There are different types of heat pumps that are being used in residential buildings. These heat pumps use different means to get the energy needed for the heating system of the house.
Moreover, there is a huge difference on the efficiency obtained with each heat pump and also in the economical aspect. The more efficient the heat pump is, the more investment it supposes.

These are the heat pumps that are going to be studied:

- Ground proves heat pumps.
- Surface collector heat pumps.
- Ground water heat pumps.
- Air water heat pumps.
- Exhaust air heat pumps.

The positive and the negative aspects of each one are studied. As well as the investment cost they suppose.

**GROUND PROVE**

![Figure 2.2.2.2 Ground installation Heat Pump (Source: NIBE Company)](image)

In the lower subsoil of the so-called “near-surface geothermal layer” lies a heat source that can be used all year long, which has an almost constant temperature. It can be used for every possible building type, large or small, public or private. Depending on the region it is also referred to as, “vertical absorption, ground spit or ground lance”. It requires little space and the ground probe can be drilled on the smallest of plots. Therefore it is ideal for refurbishment or adaptation from a heating system fuelled by fossil fuels to the use of geothermal energy.
The working fluid is a mixture of water-glycol that circulates in a closed circuit (similar to the cooling system of a car). Depending on the necessary size of the heat pump unit a specialized company ascertains the depth and amount of bore holes in which the u-shaped plastic tubing is installed and pressed, in order to achieve good heat transfer.

**Positive aspect**

- Excellent source.
- Stable temperatures.
- High efficiency.
- Reduction of the electricity use by a 70%.

**Negative aspects**

- High costs.
- Big civil work or construction needed.

As it was said before, the earth absorbs the solar energy during the year and depending on the deepness the temperature of the ground is higher and keeps more constant.

*Figure 2.2.2.3 Temperature of the ground depending on the deepness*

In the Figure 2.2.2.3, it is shown that at 30m the ground energy keeps constant during the whole year. This deepness is really high and it supposes a really high cost.
SURFACE COLLECTOR

During the summer, solar heat is stored in the soil. This is either directly absorbed as insulation or as heat from rain and the air from the near-surface layer of the soil. The highest efficiency can be obtained from soil with high water content. The heat is extracted from the soil by means of buried plastic piping system.

The working fluid is an environmentally-friendly, non-freezing emulsion of water- and glycol that circulates through the piping line.

The soil above the earth collector may not be sealed off under any circumstances, i.e. by buildings, asphalt or concrete. That is why as it was explained before, this system uses the solar energy absorbed and stored in the earth, so if the soil is trapped under a building it is impossible to absorb the solar energy and make use of it.

Earth collectors do not require a permit. Installation depth is approx. 20 cm-1m below the local frost line.

*Figure 2.2.2.4 Vertical installation Heat Pump (Source: NIBE Company)*

**Positive aspects**
- The most installed system.
- Not so expensive.
- High efficiency obtained.

**Negative aspects**
- A big area is needed for installing the heat exchanger.
- Big civil work needed.
If ground water is available and easily accessible, it can be used as a heat source due to the fact that it has a temperature of between 7 and 12°C all-year around.

It is advisable not to pump water for single and two-family houses from a depth greater than approximately 15 m. This would lead to expenditures being too high.

A distance of approximately 10 to 15 m should be kept between the withdrawal point (supply well) and the reinsertion point (deep-well). Furthermore the flow direction should be considerate in order to avoid a “flow short-circuit”.

These installations require a permit and must meet statutory requirements. A separator exchanger system is needed to provide the optimal protection.

Positive aspects
- Excellent source.
- Stable temperatures (7-12 °C all year around)
- Best efficiency.

Negative aspects
- Not available everywhere (water availability).
- Expensive.
- Legislation.
- Need of a separator exchanger system.
Air/water heat pumps make use of the heat energy of the outside air.

The heat pumps are designed for outside placement as it is shown in figure 2.2.2.6 and transform an existing radiator system into an excellent, complete heating system.

**Positive aspects**

- Cheap system.
- Easy to install.

**Negative aspects**

- Lowest efficiency.
- Very noisy.
EXHAUST AIR HEAT PUMPS

Exhaust air heat pumps offer a range of benefits. The basic principle behind these pumps is to use the heat in the air, which would otherwise leave a house, to heat the house and provide hot water.

There have been developed systems that provide efficient ventilation, maximum cost savings and a warm, comfortable environment.

How it works:

1. A fan in the heat pump collects the heated ventilation air from the house.

2. The ventilation air heats the refrigerant which vaporises.

3. In the compressor the temperature of the refrigerant is increased significantly.

4. The heat is transferred to the heating and hot water system in the house by a condenser.

5. The pressure of the refrigerant falls in an expansion valve and it returns to its liquid form. The liquid refrigerant returns to the evaporator.

Positive aspects
- Use of the exhaust air.
- Easy to install.
- Savings on the costs.

Negative aspects
- Maximum capacity provided 6 kW.
- Less efficient.
2.3 DISTRICT HEATING

What is district heating?

District heating uses water that is centrally heated and distributed through a pipe-system to individual users in areas of high concentration of activities and housing. In large cities 10 000s of users can be connected to a system serving millions of people.

It utilizes resources that otherwise would have been lost, and offers the customer simple, safe and comfortable heating. When electricity is produced in a plant fired with biofuel it becomes green power and makes possible selling green certificates.

Some of the reasons why District Heating is used are the following ones:

- Flexibility for heat production.
- Enables combined heat and power production.
- Larger system results in better efficiency.
- Larger system results in lower specific costs.
- Ability for absorbing low grade heat sources such as from garbage burning, industrial waste heat, heat pumps.
- Low level of emission of CO2 and other pollutants.
- Low level of local pollution.
- Suitable thermal comfort.

The central authorities strongly support the development of district heating through a wide range of measures, including:

- National least-cost energy planning.
- Monitoring of the least-cost urban heat planning.
- Monitoring of strict zoning of district heating and other sources for heating.
- Encouragement of local authorities and utilities to implement least cost projects.
- Implementation of legal measures that enforce building owners to connect and remain connected to district heating.
- Ban on electric heating in new buildings.
- High taxation of fossil fuels for heating.
- Investment subsidies to utilities which rehabilitate and complete networks.
- Investment subsidies to consumers who install central heating and connect to district heating.

There are three main parts in the district heating:

- Production
- Distribution
- Customer or end user

**Production**

The production of hot water takes place in CHP plants (combined heat and power generation).

**CHP plants** allows to use the fuel at the most efficient way by producing as much electrical power as possible and using the remaining heat efficiently. This results in lowest possible exergy losses. CHP plant allows the application of low quality fuels such as biomass and municipal wastes. This is why it is so important the use of district heating.

In order to produce hot water they use green sources, making use of municipal wastes that supposes no cost and that have a useful energy inside.

![Monthly load profile for a typical district heating plant - 200 MW](image)

**Figure 2.3.1 Monthly load profile for a typical district heating**

In the graphic above, the load profile for a CHP plan is explained. They combine the use of different sources each month to reach their goal that is to achieve high temperature differences $T_{\text{app}} - T_{\text{return}}$.

Heat pump is a base load, which operates almost all the year. Wood chips boiler, operate all year excepting the summer time. Pellets are more expensive and therefore they
are chosen for covering the high loads in the winter time. In the top load region, an oil boiler is used for the highest loads in the coldest winter days.

**Figure 2.3.2 Duration diagram for the CHP plant.**

**CHP plant of Gävle**

The CHP plant that supplies the heat to the district heating of Gävle is Johannes plant. This plant produces electricity and heat for the municipality of Gävle and the main fuels used by the plant are woody biofuels as; bark, forest residues and wood waste.

When the energy produced in Johannes plant is not enough for supplying the demand of Gävle, other two plants supply this energy deficit. These plants are called Ersbo and Carlsborg and they use oil as main fuel.

**Figure 2.3.3 The Johannes plant and its main components.**
After mixing the biofuel it is transported by a conveyor belt to the boiler where it will be burned in the bubble fluidised bed boiler.

A high pressure steam is produced in the boiler and it is then sent to a turbine where it will expand and produce electricity. The exhaust steam is used in the district heating net. It is condensed in two condensers transferring the heat to the hot water that will supply the district heating network of Gävle.

The exhaust gases of the boiler are cleaned in an electrostatic precipitator. After that they are sent to the condensation system where they transmit their heat to be used in the district heating network.

So the heat used in the district heating is obtained by the heat transmitted by the exhaust gases of the boiler and the exhaust steam.

**Distribution**

The district heating grid distributes hot water to all customers in the main pipe and it distributes it to the individual customers by the service pipes. All the customers have a district heating substation were the heat is shared to the heating system of the house (radiator) and the hot tap water.

In the Figure 2.3.4 it is shown all the district heating process, from the production to the end user. The heat is produced in the CHP plant and is distributed by the district heating grid to the district heating substation of each customer.

There are two pipe lines, one for the supply hot water and the other for the return cold water. The return cold water goes back to the CHP plant where it will be heated up again.
As it was said before, all the customers have a district heating substation where the hot water is shared between the heating system of the house and the hot tap water.

The district heating supply temperature depends on the expected load, which is a function of the outdoor temperature, as it is shown in figure 2.3.5.
There is some heat losses through the district heating grid from the heat produced in the CHP plant to the customer. This is why the heat produced in the CHP plant is not the same heat amount that arrives to the customer.

Figure 2.3.6 Energy balance in a district heating system

The different losses in a district heating system:

- Production losses: 8 - 12%
- Distribution heat losses: 10 - 20%
- Customer losses: 5 - 10%
3. PROCES AND RESULTS

In this third part of the project how the results were obtained is explained as well as the method used for calculating every energy consumption and the final results.

As in the second part of the report, each part will be explained separately. First of all all the energy balance will be explained, secondly the heat pumps system and thirdly the connection to the district heating grid.

3.1 ENERGY BALANCE

Firstly it must be said that, for making the final energy balance a proper unit must be used. This unit is the KW.h per year, and from now on, when talking about energy consumption “E” will be used.

As it was said before in an energy balance, the heat losses are equal to the heat supply.

\[ E_{\text{hot tap water}} + E_{\text{nat v}} + E_{\text{mec v}} + E_{\text{trans}} = E_{\text{radiation}} + E_{\text{internal heat gen}} + E_{\text{supply heat}} \]

**Need of energy due to transmission (E_{\text{trans}})**

It was mentioned in the previous part of the project that the heat losses through the envelope of a building are calculated in the following way.

\[ Q = \sum A_j U_j \cdot (T_{\text{room}} - T_{\text{out}}) = K_{tr} \cdot (T_{\text{room}} - T_{\text{out}}) \text{ (KW)} \]

For the calculation of the \( K_{tr} \), the entire conductance must be added up. For this aim, first of all, the surface and \( U \) values of each surface must be defined.

<table>
<thead>
<tr>
<th>WALL</th>
<th>WINDOWS</th>
<th>DOORS</th>
<th>CEILING</th>
<th>FLOOR-OUTDOOR</th>
<th>FLOOR-GROUND</th>
</tr>
</thead>
<tbody>
<tr>
<td>AREA (m²)</td>
<td>185.35</td>
<td>32.05</td>
<td>14.48</td>
<td>344.60</td>
<td>89.60</td>
</tr>
<tr>
<td>( U ) (W/m².K)</td>
<td>0.17</td>
<td>2.00</td>
<td>1.00</td>
<td>0.12</td>
<td>0.30</td>
</tr>
<tr>
<td>( K_{tr} ) (W/K)</td>
<td>31.51</td>
<td>64.10</td>
<td>14.48</td>
<td>41.35</td>
<td>26.88</td>
</tr>
</tbody>
</table>

*Table 3.1.1 Area, U value and \( K_{tr} \) of each surface*
As it is shown in the Table 3.1.1, there are two $Ktr$ values for the ground conductance. The reason is that the heat transmitted is not the same in the entire ground surface. From one meter of the outer wall the heat transmitted to the ground goes through the ground to the outside. And from one meter to the centre the heat goes directly to the ground.

![Figure 3.1.1 Heat is transmitted through the ground](image)

It is considered that the temperature of Gävle changes for each month as it is shown in the Table 3.1.2, and the mean value for the year is about $5^\circ C$. The hottest months are May, June, July, August and September. That is why the heating system is not needed during this period. For the inside temperature $23^\circ C$ are supposed.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>-5.1</td>
</tr>
<tr>
<td>February</td>
<td>-4.9</td>
</tr>
<tr>
<td>March</td>
<td>-2.2</td>
</tr>
<tr>
<td>April</td>
<td>3.3</td>
</tr>
<tr>
<td>May</td>
<td>8.7</td>
</tr>
<tr>
<td>June</td>
<td>13.8</td>
</tr>
<tr>
<td>July</td>
<td>16.6</td>
</tr>
<tr>
<td>August</td>
<td>15.3</td>
</tr>
<tr>
<td>September</td>
<td>10.7</td>
</tr>
<tr>
<td>October</td>
<td>5.3</td>
</tr>
<tr>
<td>November</td>
<td>0.9</td>
</tr>
<tr>
<td>December</td>
<td>-2.1</td>
</tr>
<tr>
<td><strong>MEAN Temp</strong></td>
<td><strong>5.025</strong></td>
</tr>
</tbody>
</table>

*Table 3.1.2 Temperature in Gävle during the year*
With all the information needed, it is possible to calculate the Q value (KW) for each month. All the calculations are summarized in an excel table in the appendix (Appendix 1: transmission losses, Q transmission) but the total result is given in the table below.

<table>
<thead>
<tr>
<th>Month</th>
<th>Q (W)</th>
<th>Q (KW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>6387.7</td>
<td>6.4</td>
</tr>
<tr>
<td>February</td>
<td>6352</td>
<td>6.3</td>
</tr>
<tr>
<td>March</td>
<td>5870.6</td>
<td>5.9</td>
</tr>
<tr>
<td>April</td>
<td>4889.8</td>
<td>4.9</td>
</tr>
<tr>
<td>May</td>
<td>3926.9</td>
<td>3.9</td>
</tr>
<tr>
<td>June</td>
<td>3017.5</td>
<td>3</td>
</tr>
<tr>
<td>July</td>
<td>2518.2</td>
<td>2.5</td>
</tr>
<tr>
<td>August</td>
<td>2750</td>
<td>2.8</td>
</tr>
<tr>
<td>September</td>
<td>3570.3</td>
<td>3.6</td>
</tr>
<tr>
<td>October</td>
<td>4533.2</td>
<td>4.5</td>
</tr>
<tr>
<td>November</td>
<td>5317.8</td>
<td>5.3</td>
</tr>
<tr>
<td>December</td>
<td>5852.7</td>
<td>5.9</td>
</tr>
<tr>
<td>TOT</td>
<td>54986.8</td>
<td>55</td>
</tr>
</tbody>
</table>

Table 3.1.3 Transmission losses during the year (KW)

For calculating the corresponding energy consumption E (KWh/year) a new formula must be applied;

\[ E = K_{tr} \cdot q_{\text{degree}} \]

Where;

- \( K_{tr} \) : is the conductance due to transmission (W/K)
- \( q_{\text{degree}} \) : is the degree-hours (°C h / year)

The \( q_{\text{degree}} \) value is obtained by the Table 3.1.4. For using this table the mean temperature and the room temperature are needed. In this case, mean temperature is 5°C and room temperature is 23°C.

Therefore, the \( q_{\text{degree}} = 139500 \) (°C.h/ year).
Table 3.1.4 Q degree table

With all the information needed, it is possible to calculate the $E_n$ value (KWh/year). All the calculations are summarized in an excel table in the appendix (Appendix1: Transmission losses, $E$ transmission) but the total result is given in the table below.

<table>
<thead>
<tr>
<th>Ktrans (w/k)</th>
<th>q degree (h.k/year)</th>
<th>$E$ (w.h)</th>
<th>$E$ (KW.h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>254.82</td>
<td>139500</td>
<td>35546855.4</td>
<td>35546.8</td>
</tr>
</tbody>
</table>

Need of energy due to mechanical ventilation ($E_{mec\, v}$)

The formula used for calculating the energy consumption $E_{mec\, v}$ (KWh/year) of the mechanical ventilation is quite similar to the one used for calculating the $Q_{mec\, v}$ value (KW).

For the $Q$ value we had that;

$$Q_{\text{mech vent}} = V_{\text{vent}} \cdot \rho \cdot C_p \cdot (1 - \eta_t) \cdot (T_r - T_{\text{out}}) = K_v \cdot (T_r - T_{\text{out}})$$
For calculating the $E_{mec\ v}$, the formula that must be used is;

$$E_{mec\ v} = K_v \cdot q_{\text{degree}}$$

Where $K_v$: is the conductance due to ventilation (W/K)

$q_{\text{degree}}$: degree-hours ($^\circ$C h)

The value of $q_{\text{degree}}$ is easy to obtain, at it was explained before for a room temperature of 23°C and a mean temperature of 5°C, it is obtained a $q_{\text{degree}}$ value of 139500 (h.k/year).

For obtaining the value of $K_v$, more calculations have to be done.

$$K_v = V_{\text{vent}} \cdot \rho \cdot Cp \cdot (1 - \eta_t)$$

For obtaining the value of $V_{\text{vent}}$, a lot of measurements have been done in the building. There were different flows written in the drawings of the house but for getting a more accurate result the measurements were made. For the measurements different types of devices can be used.

For instance, if you want to calculate the total supply and exhaust flow the (Velocci Calc Plus TSI) measurement tool must be used. This thermo anemometer is a multi parameter ventilation analyzer. This tool or device is used in the control room of the building where the ventilation system is located. By simple measurements; temperature, air flow and relative humidity can be obtained.

*Figure 3.1.1 measuring the ventilation with the Velocci Calc Plus TSI*
These are the values obtained by the use of this device:

For the Supply flow:
- $V = 3.5 \text{ m/s} \rightarrow 171.8 \text{ l/s}$
- $T_1 = 23^\circ \text{C}$
- $RH = 28\%$
- $Tvhp = 2.8^\circ \text{C}$

For the Exhaust flow:
- $V = 2.6 \text{ m/s}$
- $T_1e = 23^\circ \text{C}$
- $HR = 29.6\%$
- $Tvhp = 4^\circ \text{C}$

The difference between the air flows is something that must be considered. In this case the supply air flow is higher than the exhaust air flow. This is not a good result, because if it is so, there will be moisture problems in the house envelope. After comparing the results, by the use of both methods it is conclude that all the exhaust air is not released by the exhaust pipe. There must be an additional exhaust pipe that releases the exhaust air flow that is missing.

The other measuring technique consists on measuring the air flows, room by room and a different device is used, the anemometer Swema Flow 230. This technique is more complex because it supposes a harder work as more measures have to be done. After making all the measures, all the supply flows are added and the same for the exhaust flows.

**Figure 3.1.2 measuring the Supply flow with the Swema Flow 230**

For measuring supply flow, an external nozzle must be added to the measuring machine as it is shown in the figure 3.1.2. This nozzle is used because the supply flow is usually higher than the exhaust. By the use of this device a more accurate measure of the supply is obtained.
For measuring the exhaust flow it is not necessary to add the nozzle, as it is shown in the Figure 3.1.3.

Figure 3.1.3 measuring the Exhaust flow

Figure 3.1.4 Swema Flow 230

These are the values obtained:

For each apartment: (5 apartments)

Supply = 21 l/s
Exhaust WC = 8 l/s
Exhaust Kitchen = 11 l/s

Total values:

For the big living room:

Supply = 28 l/s
Exhaust Kitchen = 40 l/s

SUPPLY = 167 l/s

For the house keeper’s room:

Supply = 15 l/s
Supply = 19 l/s
Exhaust WC = 8 l/s

EXHAUST = 203 l/s

For the corridor:

2 exhaust = 30 l/s
For calculating the thermal efficiency of the heat exchanger, four temperatures have to be defined \((T_{1\text{supply}}, T_{2\text{supply}}, T_{1\text{exhaust}} \text{ and } T_{2\text{exhaust}})\).

As it shown in the graphic above, the heat exchanger has a counter flow;

For a counter flow the thermal efficiency of the heat exchanger is:

\[
\eta = \frac{(T_{1\text{supply}} - T_{2\text{supply}})}{(T_{1\text{supply}} - T_{1\text{exhaust}})}
\]

Where:

- \(T_{1\text{supply}} = 8 \degree C\)
- \(T_{2\text{supply}} = 16 \degree C\)
- \(T_{1\text{exhaust}} = 23 \degree C\)
- \(\eta = 0.53\)

\(\eta = 0.53\)

\[K_v = V_{vent} \cdot \rho \cdot C_p \cdot (1 - \eta) = (171.8/1000) \cdot 1.2 \cdot 1000. (1 - 0.53) = 96.89 \text{W/K}\]

\[E_v = K_v \cdot q_{\text{degree}} = 13516.8 \text{KW.h}\]

**Need of energy for the hot tap water** \((E_{\text{hot tap water}})\)

To calculate the energy needed for the hot tap water we use the formula below.

\[E_{\text{hot tap water}} \text{(KW.h)} = m_{\text{hot water}} \text{(kg)} \cdot C_p_{\text{water}} \cdot (KJ/kg.k) \cdot \Delta T \text{ (k)} / 3600 \text{ (s/h)}\]
The data given by Gävlegardarna (appendix 2), are the water flows per each month, therefore the energy needed to heat the tap water is calculated per each month. For calculating the need of energy for the whole year, the sum of the need of each month is made.

It has been supposed a temperature of 5°C for the supply temperature of the water that arrives to the boiler. The supply water is heated until it reaches a temperature of 60°C to avoid the risk of catching the Legionella disease.

![Figure 3.1.6 The boiler is from the NIBE Company](image)

With all the information needed, it is possible to calculate the $E_{\text{hot tap water}}$ value (KWh/year). All the calculations are summarized in an excel table in the appendix (Appendix2: E hot tap water)) but the total result is given in the table below.

<table>
<thead>
<tr>
<th>Year</th>
<th>TOT (Kg)</th>
<th>HOT (Kg)</th>
<th>$\Delta T$ (K)</th>
<th>$E_{\text{hot tap water}}$ (Kw.h/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007 TOT</td>
<td>344049.80</td>
<td>137619.92</td>
<td>55</td>
<td>8788.56</td>
</tr>
<tr>
<td>2006 TOT</td>
<td>375763.80</td>
<td>150305.52</td>
<td>55</td>
<td>9598.68</td>
</tr>
<tr>
<td>2005 TOT</td>
<td>363266.60</td>
<td>145306.64</td>
<td>55</td>
<td>9279.44</td>
</tr>
<tr>
<td>AVERAGE $E_{\text{hot tap water}}$ (Kw.h)</td>
<td></td>
<td></td>
<td></td>
<td>9222.23</td>
</tr>
</tbody>
</table>

*Table 3.1.5 $E_{\text{hot tap water}}$ results*
Energy supplied by the solar radiation \( (E_{\text{radiation}}) \)

As it was said before for making the calculation of the energy supplied by the solar radiation, three aspects have to be studied: the orientation of the windows, if the windows are closer to the inner or the outer side of the house and the shading of the windows.

For obtaining the orientation of the house the (Appendix 5: Incidence angle of the solar radiation) in the appendix was used.

<table>
<thead>
<tr>
<th>AREAS (m2)</th>
<th>ORIENTATION (º)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NORTH</td>
<td>0.53</td>
</tr>
<tr>
<td>SOUTH</td>
<td>5.52</td>
</tr>
<tr>
<td>EAST</td>
<td>15.87</td>
</tr>
<tr>
<td>WEST</td>
<td>10.12</td>
</tr>
</tbody>
</table>

Table 3.1.6 Orientation of the house

Considering that Valbo is located in the Latitude 60°N and the windows are closer to the inner side of the house, the following data are obtained per each month and orientation. These data were obtained by the use of (Appendix 4: solar radiation per Wh/m².day) in the appendix.

<table>
<thead>
<tr>
<th>Latitude 60°N</th>
<th>N (-120°)</th>
<th>E (-30°)</th>
<th>S (60°)</th>
<th>W (150°)</th>
<th>SOLAR ENERGY(W.h/m².day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JANUARY</td>
<td>70</td>
<td>180</td>
<td>140</td>
<td>70</td>
<td>460</td>
</tr>
<tr>
<td>FEBRUARY</td>
<td>400</td>
<td>3530</td>
<td>2240</td>
<td>340</td>
<td>6510</td>
</tr>
<tr>
<td>MARS</td>
<td>1290</td>
<td>5290</td>
<td>3920</td>
<td>730</td>
<td>11230</td>
</tr>
<tr>
<td>APRIL</td>
<td>2810</td>
<td>6160</td>
<td>5420</td>
<td>1640</td>
<td>16030</td>
</tr>
<tr>
<td>MAY</td>
<td>3910</td>
<td>5920</td>
<td>5840</td>
<td>2570</td>
<td>18240</td>
</tr>
<tr>
<td>JUN</td>
<td>4570</td>
<td>5790</td>
<td>6070</td>
<td>3180</td>
<td>19610</td>
</tr>
<tr>
<td>JULAY</td>
<td>4410</td>
<td>5870</td>
<td>6050</td>
<td>3020</td>
<td>19350</td>
</tr>
<tr>
<td>AUGUST</td>
<td>3240</td>
<td>5950</td>
<td>5520</td>
<td>2020</td>
<td>16730</td>
</tr>
<tr>
<td>SEPTEMBER</td>
<td>1930</td>
<td>5580</td>
<td>4530</td>
<td>1070</td>
<td>13110</td>
</tr>
<tr>
<td>OCTOBER</td>
<td>650</td>
<td>4290</td>
<td>2850</td>
<td>480</td>
<td>8270</td>
</tr>
<tr>
<td>NOVEMBER</td>
<td>160</td>
<td>1590</td>
<td>990</td>
<td>160</td>
<td>2900</td>
</tr>
<tr>
<td>DECEMBER</td>
<td>50</td>
<td>120</td>
<td>90</td>
<td>40</td>
<td>300</td>
</tr>
</tbody>
</table>

Table 3.1.7 solar radiation for each month
Multiplying these values by the area of the windows and the days of the month, the following value is obtained:

<table>
<thead>
<tr>
<th>NORTH (Wh)</th>
<th>EAST (Wh)</th>
<th>SOUTH (Wh)</th>
<th>WEST (Wh)</th>
<th>E radiation (KW.h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>380497.6</td>
<td>24315855.3</td>
<td>7352474.4</td>
<td>4738082.8</td>
<td>36786.9</td>
</tr>
</tbody>
</table>

But it must be considered that there is no heat from the middle of May to the middle of September. Therefore the radiation value that must be used in the energy valance is:

| E rad heating season (Kw.h) | 18212.8 |

The data obtained from the Table 4 of the annex are the values of the heating due to the direct solar radiation, but it must be considered the shading of the windows.

The shading is a very important aspect that must be considered, because as it is shown in the graphic below, it decreases the heat supplied by the sun.

![Figure 3.1.7 solar radiation with and without shading](image)

The shading coefficient for the Venetian blinds is \( K_{rad}=0.28 \).
Applying the shading coefficient, the value that will be used in the energy
valance is obtained;

<table>
<thead>
<tr>
<th>E rad heating season (Kw.h)</th>
<th>18212.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>E' rad heating season (Kw.h)</td>
<td>5099.6</td>
</tr>
</tbody>
</table>

All the calculations are summarized in an excel table (Appendix 3: Eradiation)
of the appendix.

**Internal generation of energy** \((E_{\text{internal generation}})\)

The internal heat generation is divided in 3 parts; the heat released by the
people living there, the heat released by the lighting equipment and the heat realised
due to atypical activities that go on in a residential building.

HEAT RELEASED BY PEOPLE

As it was mentioned in the section before, the heat released by the people
depends on the metabolism and the surface of this people.

Considering that the people living in the house are disabled people, their
activity implies a value of 1Met.

- 1 Met=58.15 W/m2
- The surface of a normal adult =1.7 m²
- It must be considered only the cold season for making the
calculations.

\[
58.15 \, \text{W/m}^2 \times 1.7 \, \text{m}^2 \times 5112 \, \text{h/year} = 505346.7 \, \text{Wh/year} = 505.3 \, \text{KWh/year}
\]

The value above represents the heat released by a sitting person in thermal
comfort, but there are 5 people living there. So the value must be multiplied by 5. The
total heat released by the people is about **2526.7 KWh/year**.
HEAT RELEASED BY THE LIGHTING EQUIPMENT

This is the lighting equipment that we have all around the house.

Each apartment: (5 apartments)
2 fluorescent lamps (20W)
2 bulbs of 60 W
4 bulbs of 15 W

Living room:
2 bulbs of 40W
3 bulbs of 15W
2 fluorescent lamps (20W)

Total lightning consumption: 2012W

Corridor:
10 bulbs of 60W
2 low consume bulbs of 26W

Office:
2 bulbs of 40W
1 bulb of 15W

The heating season is only considered for the energy balance, 243 days.

How many ours per day are the lights on? 8h is the average considering that not all the lamps are switched on in a day.

The heating released by the lightning system is the 90% of the electricity consumption.

\[ 2012W \times 243 \text{ day/year} \times 8h \times 0.9 = 3520.2 \text{ kW.h} \]

HEAT RELEASED BY DOMESTIC ACTIVITY

The electricity released by the domestic activity is about 6000kW.h per year, which is obtained from the cooking, television and computer. Considering that the heat released is the 25% of the electricity consumption, a value of 1500kW.h is obtained.
Finally the total internal heat generation is obtained:

\[ E_{\text{internal generation}} = E_{\text{people}} + E_{\text{lightning}} + E_{\text{domestic activity}} \]

\[ E_{\text{internal generation}} = 7547 \text{ kW.h/year} \]

**ENERGY BALANCE**

The amount of heat released by natural ventilation is obtained from the energy balance. As it is known the heat lost and the heat supplied must be the same, so a value of 6484 kW.h is obtained for the natural ventilation. This represents the 18% of the total heat released by the transmission through the building envelope.

<table>
<thead>
<tr>
<th>Q(−)</th>
<th>E (KW.h)</th>
<th>Q (+)</th>
<th>E (KW.h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANSMISSION</td>
<td>35546.8</td>
<td>HEATING</td>
<td>52124</td>
</tr>
<tr>
<td>HOT TAP WATER</td>
<td>9222.2</td>
<td>RADIATION</td>
<td>5099</td>
</tr>
<tr>
<td>MEC VENTILATION</td>
<td>13517</td>
<td>INTERNAL GENERATION</td>
<td>7547</td>
</tr>
<tr>
<td>NATURAL VENTILATION</td>
<td>6484</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 3.1.8 the energy balance*

*Figure 3.1.8 the energy balance*
3.2 INSTALLATION OF HEAT PUMP

Sweden is the European country that has more heat pumps installed as a heating system. As it is shown in the Figure 2.3.1, USA is the country with the highest installed capacity. This is due to the huge use of heat pumps for cooling and air conditioning. The use of heat pumps has followed an exponential growth in countries as Sweden, Germany, Austria and Switzerland.

Moreover, heat pumps are environmentally friendly systems because they produce no CO\textsubscript{2} emissions. Economic savings are being obtained with their use because they are more economic than conventional systems. They make use of the energy stored in the ground and they can be used as a heating system in cold seasons and cooling systems in warmer seasons.

Furthermore, in the middle of September of 2007 a green label was introduced for the use of heat pumps and financial subventions are being made.

![Figure 3.2.1 Installed Heat pumps in different countries](image)

The peak load for heating the house is around 20KW. This value is obtained by a factor that is used by Gävle Energy technical department. This factor considers the worst situation possible and it is going to be used in this project to obtain the capacity needed in
the heat pump. The worst situation possible for a house made of wood is an outside temperature of about -22°C. This value is obtained from the (appendix 7: The worst temperature of a house made of wood) in the appendix.

**Peak load = Heat (KW.h) / 2500 h**

\[
\text{Peak load} = \frac{52124 \text{ (KW.h)}}{2500 \text{ h}} \approx 20 \text{ (KW)}
\]

After a meeting with Jim Freding, a specialist of heat pumps working in the technical department of IVT, a capacity of **17 KW** is going to be asked for the heat pump. This value has been chosen because for a peak load of 20 KW a heat pump with a capacity of 17KW is often selected.

These systems are not designed to cover the 100% of the energy needed. They are designed to cover the 50%-60% of the peak load, 20KW in this case. By this way they cover the 90% of the annual heating demand.

If a heat pump of 17 KW is chosen it supposes an 85% of the peak load, so almost all the annual heat demand would be covered.

![Figure 3.2.2 the duration diagram shows that the heat pump chosen supplies almost the annual heat demand](image-url)
For covering the whole peak load, a heat pump with the double of capacity would be needed. In this case a heat pump of 40 KW. However, it supposes an expensive investment and the heat pump will switch off during many operating hours, reducing considerably its life.

Choosing a type of heat pump:

Air-water heat pumps:

To maximise the efficiency of a heat pump when providing heating it is important to have as high a source temperature as possible. Overall efficiencies for GSHPs (ground source heat pumps) are higher than for air source heat pumps because ground temperatures are higher than the mean air temperature in winter and lower than the mean air temperature in summer. The ground temperature also remains relatively stable allowing the heat pump to operate close to its optimal design point whereas air temperatures vary both throughout the day and seasonally and are lowest at times of peak heating demand. Moreover, for heat pumps using ambient air as the source, the evaporator coil needs also a defrosting at low temperatures and they are very noisy when they are working, so a special licence is necessary when installing this kind of heat pumps.

As the house being studied is an individual house were disabled people is living, a very noisy system is not profitable. That is why the study of the installation of an air-water heat pump has been ruled out.

Ground water heat pumps:

Even if ground water heat pumps are very effective, their installation is not very common, because it is not easy to find a water source. These water storages are located in specific places and in this case there is no water source around the house. This is why the study of the installation of a water-water heat pump has been ruled out.

Exhaust air heat exchangers:

As it was explained in the theoretical part of the heat pumps, exhaust air heat pumps make use of the exhaust air that in other case will be released out. In the house that is being studied, this is not like that.
The exhaust air is used in a heat exchanger to heat the air supplied into the house. After using it, the air is expelled from the house. This is a fact to consider, because at the beginning the exhaust air has 23°C but after the heat exchanger its temperature decreases to 12°C. Therefore, the efficiency of an exhaust air heat exchanger is not as high as when it was 23°C. Moreover, after searching the WebPages of some heat pump companies as IVT, NIBE, Euronom and Viessman it is concluded that the capacity of these heat pumps has a maximum capacity of 6 KW.

Ground source heat pumps:

- Horizontal
- Ground prove

First of all the COP (coefficient of performance) of this kind of Heat Pumps must be mentioned. The COP relates the supplied work and the obtained heat.

\[
\text{COP} = \frac{Q}{W}
\]

Where Q, is the heat obtained from the condenser of the heat pump and W is the work made to run the compressor.

The COP value for these kinds of heat pump used to be between 3 and 4. In the figure 3.2.2 it is shown the graphic of a ground heat pump, that for a ground temperature of 5°C heats up the water to 55°C.

For this situation the COP value is 3. Therefore, to obtain 3 KW of heat, 1KW of electricity is used in the compressor.
A standard liquid/water heat pump can be installed for both possibilities, with a horizontal or vertical collector. The annual energy saving will be in the same range for both installations.

The horizontal collector installation cost is lower than a vertical one. However the area needed is much higher and there is no possibility to run free cooling in summer time, which can be done with a vertical collector.

Recommended by the IVT Company of heat pumps, these are the ground source heat pumps that can be installed to provide the energy demanded.

- IVT GREENLINE E, 14-26

- IVT GREENLINE HT PLUS

The cost of the heat pumps is 50,000 kr and for both heat pumps a vertical or horizontal installation can be used. The difference on the costs is going to be studied in the following section.

**Horizontal**

For a horizontal installation these are the characteristics that the heat exchanger must have:

- There are 900m of piping.
- There must be 1m between each pipe.
- The deepness of the installation is 90cm.
The compressor of the heat pump rises the temperature of the working fluid by the use of electricity. This electricity is the 30% of the electricity used in the current heating system.

<table>
<thead>
<tr>
<th><strong>HORIZONTAL HP</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment cost (kr)</td>
<td>175000</td>
</tr>
<tr>
<td>Compresor el cost (kr)</td>
<td>15637.2</td>
</tr>
<tr>
<td>Savings (kr/year)</td>
<td>36486.8</td>
</tr>
<tr>
<td>Savings (%)</td>
<td>70</td>
</tr>
<tr>
<td>Pay back (year)</td>
<td>4.8</td>
</tr>
</tbody>
</table>

Table 3.2.1 the obtained data for a horizontal heat pump

On the table above, all the costs have been summarized. On one hand the investment cost and on the other hand the new electricity costs.

The savings have been obtained by comparing the current situation and the one with the heat pump.

The pay back is obtained by using the formula below and its values are 4.8 years. Therefore in 4.8 years it is possible to start getting profits or savings. This value is quite good because the typical pay back of heat pumps is between 3 and 8 years.

The pay back of the system = Investment cost (kr) / Savings (kr/year)
**Vertical**

For a horizontal installation these are the characteristics that the heat exchanger must have:

- 2 Holes
- The deepness of the holes must be of 140 m

![Figure 3.2.4 Heat pump with vertical collector](image)

The compressor of the heat pump rises the temperature of the working fluid by the use of electricity. This electricity is the 30% of the electricity used in the current heating system.

<table>
<thead>
<tr>
<th>VERTICAL HP</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment cost (kr)</td>
<td>230000.0</td>
</tr>
<tr>
<td>Compresor el cost (kr)</td>
<td>15637.2</td>
</tr>
<tr>
<td>Savings (kr)</td>
<td>36486.8</td>
</tr>
<tr>
<td>Savings (%)</td>
<td>70</td>
</tr>
<tr>
<td>Pay back (year)</td>
<td>6.3</td>
</tr>
</tbody>
</table>

*Table 3.2.1 the obtained data for a vertical heat pump*

The payback of this installation is 6.3 years and comparing with the one with vertical collector, they will start getting profits later.
The problem of this kind of installation is that even if it is possible to obtain free cooling on summer, the deepness of the holes is really high. Therefore in some cases there are protected areas in which it is impossible to work in. Moreover, the installation cost is much higher than in the horizontal.

Anyway, a pay back of 6.3 years is a good value, considering that after that time, the savings would be of 70%.

### 3.3 CONEXION TO THE DISTRICT HEATING SYSTEM OF GÄVLE

After having a meeting with Stewe Jönsson the person in charge of the District heating system of Gävle, important information was obtained about all the costs when connecting to the district heating system of Gävle.

![Figure 3.3.1 The District heating network of Gävle (Source: Gävle Energy)](image)

In the picture above, all the district heating grid of Gävle is shown. The centre of the town is the most crowded place; therefore the district heating system is really developed in that place.
The house of Valbo has two possibilities for connecting to the district heating grid, because there are two main pipes near it. In the picture below both situations are shown:

Figure 3.3.2 one of the possible connections
The investment cost is the same for both connections because there is the same distance to both pipelines. The investment cost is 525000 kr.

This value is really high and expensive, however if the houses around agree to connect to the district heating grid it would be possible for them to pay the investment cost together.

This alternative is available when there are a lot of buildings around a district heating pipeline as in this situation.

In this case the investment value per house would be smaller; each house would pay the cost of installing the substation and the cost of a piece of the pipeline. By this way the pay back time would decrease considerably.

*Figure 3.3.3 the other possible connection*
Concerning to the energy price of the district heating, the total cost is divided in different parts:

- Annual fixed fee.
- Annual effect fee.
- Energy cost.
- Taxes.

**Annual fixed fee**

This fee is paid every year and it depends on the effect needed. In this case the effect is 20 KW, this value was calculated before with the help of Gävle Energy. They divide the annual need of energy by a factor. **Peak load = Heat (KW.h) / 2500 h**

Considering the effect needed, a value of 674 kr is obtained from (the Appendix 9: district heating costs) in the appendix.

**Annual effect fee**

This fee depends also on the effect needed and its value is obtained by the following calculation; **395,3 kr . Effect (KW)**.

**Energy cost**

The energy consumption has always a similar evolution during the year. As it is shown in the graphic below, the energy demand is higher during the coldest season.

![Figure 3.3.4 Energy consumption during the year](image-url)
Gävle Energy divides the costs in two seasons, the cold and the warm season.

- The cold season: from November to March costs 317.6 kr/MW.h.
- The warm season: from April to October costs 268 kr/MW.h.

These values are obtained from (the Appendix 8: district heating costs) in the appendix.

In the table below, these tariffs are used for obtaining the annual energy cost:

<table>
<thead>
<tr>
<th>MONTH</th>
<th>Energy consumption (%)</th>
<th>Energy consumption (KW.h)</th>
<th>Energy price (kr/MW.h)</th>
<th>Energy Cost (kr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>July</td>
<td>2.5</td>
<td>1303.1</td>
<td>268</td>
<td>349.2</td>
</tr>
<tr>
<td>August</td>
<td>2.5</td>
<td>1303.1</td>
<td>268</td>
<td>349.2</td>
</tr>
<tr>
<td>September</td>
<td>4.5</td>
<td>2345.6</td>
<td>268</td>
<td>628.6</td>
</tr>
<tr>
<td>October</td>
<td>8.5</td>
<td>4430.5</td>
<td>268</td>
<td>1187.4</td>
</tr>
<tr>
<td>November</td>
<td>11.5</td>
<td>5994.3</td>
<td>317.6</td>
<td>1903.8</td>
</tr>
<tr>
<td>December</td>
<td>14</td>
<td>7297.4</td>
<td>317.6</td>
<td>2317.6</td>
</tr>
<tr>
<td>January</td>
<td>15</td>
<td>7818.6</td>
<td>317.6</td>
<td>2483.2</td>
</tr>
<tr>
<td>February</td>
<td>13</td>
<td>6776.1</td>
<td>317.6</td>
<td>2152.1</td>
</tr>
<tr>
<td>Mars</td>
<td>13</td>
<td>6776.1</td>
<td>317.6</td>
<td>2152.1</td>
</tr>
<tr>
<td>April</td>
<td>9</td>
<td>4691.2</td>
<td>268</td>
<td>1257.2</td>
</tr>
<tr>
<td>May</td>
<td>4</td>
<td>2085.0</td>
<td>268</td>
<td>558.8</td>
</tr>
<tr>
<td>June</td>
<td>2.5</td>
<td>1303.1</td>
<td>268</td>
<td>349.2</td>
</tr>
<tr>
<td>100</td>
<td>52124.0</td>
<td></td>
<td></td>
<td>15688.5</td>
</tr>
</tbody>
</table>

*Table 3.3.1 Energy cost during the year*

After making the calculations, a value of 15688.5 kr is obtained for the annual cost. It must be considered that this value is the energy cost without the annual fees and taxes.

**Taxes**

The taxes are applied to the sum of the total annual cost of energy: energy cost + fees.

It implies the 25% of the total annual cost.

On the table below, all the costs obtained before are summarized. After adding all the values, a total annual cost of 30335.6 kr is obtained for the district heating.
The cost decreases by a 41.8% by connecting to the District Heating grid of Gävle instead of continuing with the current situation.

Considering the total annual cost and the investment cost of 525000 kr the pay back time obtained is 24.1 years. This value is so huge due to the high investment cost that connecting to the district heating network supposes.

<table>
<thead>
<tr>
<th>DISTRICT HEATING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment cost (kr) 525000</td>
</tr>
<tr>
<td>Energy cost (kr/year) 30335.6</td>
</tr>
<tr>
<td>Savings(kr/year) 21788.4</td>
</tr>
<tr>
<td>Savings(%) 41.8</td>
</tr>
<tr>
<td>Pay back (year) 24.1</td>
</tr>
</tbody>
</table>

*Table 3.3.3 the obtained data for the district heating*
4. DISCUSSION

The aim of this project is to find the best option to decrease the energy cost of a building by replace the existing heating system. At the moment this house is using electricity for heating the water of a boiler until 60ºC. This water is then distributed to the heating system of the house and to the hot tap water. As it is known electricity is the most expensive source nowadays, so a better option must be used for supplying the energy needed in the house.

There are three ways of affecting the energy cost:

- Efficiency measures.
- Load management.
- Conversion to another kind of supplying energy.

After making the energy balance of the house, the conversion to other two alternatives was studied; installation of a heat pump and connection to the district heating system.

Concerning to the heat pumps, ground energy heat pumps were chosen. An annual saving of 70% was obtained for both installations, horizontal and vertical heat pump.

However, the pay back time is different; it is 4.8 years for the horizontal installation and 6.3 for the vertical installation.

Concerning to the connection to the district heating of Gävle, an annual saving of 18.5% was obtained after applying all the connection and annual fee. Gavle Energy thought that there were two possibilities of connecting the house to the district heating grid.

Comparing the three alternatives:

<table>
<thead>
<tr>
<th>Energy Price Depending on the Alternative</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ENERGY PRICE(kr)</strong></td>
</tr>
<tr>
<td>Current situation</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>10000</td>
</tr>
<tr>
<td>20000</td>
</tr>
<tr>
<td>30000</td>
</tr>
</tbody>
</table>

*Figure 4.1 Energy prices depending on the chosen alternative*
As it is shown in the picture above, the best results are obtained with the introduction of a heat pump. The only electricity they use is the electricity needed for running the compressor.

The reduction in the energy use is directly related to the cost savings. Therefore, the highest savings are obtained for the heat pumps installation. These savings are of the order of 70% as it is shown in the figure below.

![Figure 4.2 Savings of each alternative](image)

The pay back time is a really important issue to consider when talking about making an investment. Depending on the pay back, the moment when profits or savings are going to be obtained is really different.

In the graphic below the pay back of the different alternatives is shown, being the vertical heat pump the one with lowest pay back and the connexion of the district heating the one with highest pay back.

![Figure 4.3 Pay back time for each alternative](image)
Even if with the use of the heat pumps the need of electricity is reduced by 70%, this is not the best alternative when talking about environmental issues. It is really important to use different sources apart from electricity to obtain the heat needed in the house. Hence, the use of district heating would be the most environmentally friendly in this case.

Greenhouse effect is one of the biggest problems of our society, even if there are some agreements for reducing the CO₂ emissions as the Kyoto protocol, they are not enough for protecting the environment and maintaining a sustainable development.

This is why alternatives as district heating are really helpful for environment, by they use it is possible to reduce the CO₂ emission level and other pollutants.

More over, district heating provides a suitable thermal comfort with a low level of local pollutants, as it has the ability of absorbing low grade heat sources such as; garbage burning and industrial waste heat.

It is known by everybody, that the costs of the heat pumps are really small comparing with the ones for connecting to the district heating. However, if every single habitant of a country chooses the most expensive alternative (district heating) instead of the cheap one, it is possible to change the environmental situation of the country to a better one.

Therefore, Sweden is one of the countries that takes care more about the environment in the world. Even if the use of heat pumps is really spread all over the country, the use of district heating is increasing a lot.

Thus, Sweden is a country that must be used as an example to follow when talking about environmental way of living.
If the energy balance is studied, it can be noticed that the transmission losses suppose a huge value concerning to the heat losses.

These transmission losses are divided in the way shown in the Figure 4.4:

![Figure 4.4 Transmission losses through different surfaces (\%)](image-url)

<table>
<thead>
<tr>
<th>E trans (%)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>WALL</td>
<td>12.4</td>
</tr>
<tr>
<td>WINDOWS</td>
<td>25.2</td>
</tr>
<tr>
<td>DOORS</td>
<td>5.7</td>
</tr>
<tr>
<td>CELING</td>
<td>16.2</td>
</tr>
<tr>
<td>FLOOR-OUT</td>
<td>10.5</td>
</tr>
<tr>
<td>FLOOR-GROUND</td>
<td>30.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100.0</td>
</tr>
</tbody>
</table>

**Figure 4.4** Transmission losses through different surfaces (%)

It can be observed that the highest losses of heat are due to transmission through the floor and windows.

Therefore, if the U value of windows and floor are decreased better values for transmission losses will be obtained. As a consequence, less energy will be need for space heating.
5. CONCLUSIONS

Considering the aim of this project, decreasing the energy cost of a building in Valbo by means of converting to a different energy source, two different alternatives have been studied. These alternatives are; the installation of a heat pump and the connection to the district heating network.

For both alternatives, there is a reduction in the energy cost; however this reduction is much higher in the heat pumps. Heat pumps reduce their energy use by a 70 %, because they only make use of the electricity to run the compressor which increases the temperature of the working fluid in the heat pump.

In the table below the data obtained for each alternative are summarized; annual energy cost, investment, annual savings and the pay back time.

<table>
<thead>
<tr>
<th></th>
<th>Current situation</th>
<th>Vertical HP</th>
<th>Horizontal HP</th>
<th>District Heating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy price (kr)</td>
<td>52124</td>
<td>15637.2</td>
<td>15637.2</td>
<td>30335.6</td>
</tr>
<tr>
<td>Investment</td>
<td>-</td>
<td>230000.0</td>
<td>175000.0</td>
<td>525000</td>
</tr>
<tr>
<td>Total cost</td>
<td>-</td>
<td>245637.2</td>
<td>190637.2</td>
<td>555335.6</td>
</tr>
<tr>
<td>Savings (%)</td>
<td>-</td>
<td>70</td>
<td>70</td>
<td>41.8</td>
</tr>
<tr>
<td>Pay back (year)</td>
<td>-</td>
<td>6.3</td>
<td>4.8</td>
<td>24.1</td>
</tr>
</tbody>
</table>

*Table 5.1 Summary of the possible situation*

Considering these values it is concluded that the best option is the installation of a heat pump. However it is not easy to say which of the installations, vertical or horizontal is better. More over, it must be considered that the electricity price is expected to rise considerably on the following years; therefore this conclusion might be changed.

The cost of the horizontal collector installation is lower than a vertical one. Nevertheless the area needed is much higher and there is no possibility to run free cooling in summer time, which can be done with a vertical collector.

It must be considered also, that the compressor of the heat pump must be replaced in 15 years.
Concerning to connecting to the district heating network, it must be considered a possible agreement of the neighbourhood to share the payment of the district heating pipeline. By this way, the pay back time will be reduced, for instance to 16 years.

In the pictures above, the difference between the two options is shown. In the first picture, Figure 5.1, the house of the project is only connected to the district heating grid. In the Figure 5.2, six houses of the neighbourhood are connected.

Investing in connecting to the district heating has more sense, when some houses of the neighbourhood agree to connect also and they share the investment costs. Connecting to the district heating decreases the annual energy cost and is an environmentally friendly option.
REFERENCES

ENERGY BALANCE
- Slides from the subject, Building energy systems.

HEAT PUMP
- http://www.nibe.com/heating/
- http://www.viessmann.de/en
- www.euronom.se
- http://en.ivt.se/
- http://www.thermia.se/
- http://www.ctc-giersch.ch/de/firma/
- http://geoheat.oit.edu/bulletin/bull21-1/art4.pdf (information and tables about the heat pumps in several countries)
- http://www.greenspec.co.uk/html/energy/GSHP.html (general information, heat pump types, environmental impact)
- http://www.greenspec.co.uk/documents/energy/GSHP1.pdf (8domestic ground heat pumps)
- http://oee.nrcan.gc.ca/publications/infosource/pub/home/Heating_and_Cooling_with_a_Heat_Pump_Section1.cfm (Figure 2.2.1.1 Heat pump componentes)
- www.earthsourcegeothermal.com/technical.html (Figure 2.2.1)
- http://www.annex28.net/pdf/Annex28_N28.pdf (Figure 3.2.2 COP for ground source heat pumps)

DISTRICT HEATING
- Slides from the subject, energy systems
- Gävle Energy
- http://www.kristianstad.se/upload/Spnak/dokument/2%20District%20heating,%20brochure%202006.pdf (the district heating of kristianstad)
- http://www.dbdh.dk/artikel.asp?id=462&mid=24 (measures for the development of the district heating)
APPENDIX

Appendix 1: TRANSMISION LOSSES

Q_TRANSMISSION

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### FLOOR-GROUND

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### E_TRANSMISSION

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### Appendix 2: E **HOT TAP WATER**

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**2007 TOT** | **344.00** | **137.60** | **8787.29**

![Q HOT TAP WATER](image)

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Vattenrapport
9016 Stiftelsev 6
Driftsansvarig: U Bengt / Bengt
Stiftelsev 6 gruppoende

Vatten 9016 Stiftelsev 6

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<tr>
<td>Apr</td>
<td>28,1</td>
<td>28,1</td>
<td>28,1</td>
<td>28,1</td>
<td>28,1</td>
</tr>
<tr>
<td>Maj</td>
<td>24,9</td>
<td>24,9</td>
<td>24,9</td>
<td>24,9</td>
<td>24,9</td>
</tr>
<tr>
<td>Jun</td>
<td>29,0</td>
<td>29,0</td>
<td>29,0</td>
<td>29,0</td>
<td>29,0</td>
</tr>
<tr>
<td>Jul</td>
<td>21,0</td>
<td>21,0</td>
<td>21,0</td>
<td>21,0</td>
<td>21,0</td>
</tr>
<tr>
<td>Aug</td>
<td>29,4</td>
<td>29,4</td>
<td>29,4</td>
<td>29,4</td>
<td>29,4</td>
</tr>
<tr>
<td>Sep</td>
<td>28,6</td>
<td>28,6</td>
<td>28,6</td>
<td>28,6</td>
<td>28,6</td>
</tr>
<tr>
<td>Okt</td>
<td>28,0</td>
<td>28,0</td>
<td>28,0</td>
<td>28,0</td>
<td>28,0</td>
</tr>
<tr>
<td>Nov</td>
<td>30,0</td>
<td>30,0</td>
<td>30,0</td>
<td>30,0</td>
<td>30,0</td>
</tr>
<tr>
<td>Dec</td>
<td>31,8</td>
<td>31,8</td>
<td>31,8</td>
<td>31,8</td>
<td>31,8</td>
</tr>
</tbody>
</table>

2007 (prof) | 344,0 | 344,0 | 344,0 | 344,0 | 344,0 | 344,0 | 344,0 | 344,0 | 344,0 | 0 | -8.4 |
2006 | 372,0 | 372,0 | 372,0 | 372,0 | 372,0 | 372,0 | 372,0 | 372,0 | 372,0 | 0 | 3.4 |
2005 | 383,3 | 383,3 | 383,3 | 383,3 | 383,3 | 383,3 | 383,3 | 383,3 | 383,3 | 0 | 0 |
## Appendix 3: E Radiation

### LATITUD 60ºN

<table>
<thead>
<tr>
<th>day</th>
<th>NORTH (Wh)</th>
<th>EAST (Wh)</th>
<th>SOUTH (Wh)</th>
<th>WEST (Wh)</th>
<th>E radiation (W.h)</th>
<th>E radiation (KW.h)</th>
<th>K rad</th>
<th>E' radiation (KWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 31</td>
<td>1150.1</td>
<td>88554.6</td>
<td>23956.8</td>
<td>21960.4</td>
<td>135621.9</td>
<td>135.6219</td>
<td>0.28</td>
<td>37.974132</td>
</tr>
<tr>
<td>February 29</td>
<td>6148</td>
<td>1624612</td>
<td>358579.2</td>
<td>99783.2</td>
<td>2089122.3</td>
<td>2089.1223</td>
<td>0.28</td>
<td>584.954244</td>
</tr>
<tr>
<td>March 31</td>
<td>21194.7</td>
<td>2602521</td>
<td>670790.4</td>
<td>229015.6</td>
<td>3523522</td>
<td>3523.522</td>
<td>0.28</td>
<td>986.58616</td>
</tr>
<tr>
<td>April 30</td>
<td>44679</td>
<td>2932776</td>
<td>897552</td>
<td>497904</td>
<td>4372911</td>
<td>4372.911</td>
<td>0.28</td>
<td>1224.41508</td>
</tr>
<tr>
<td>May 31</td>
<td>64241.3</td>
<td>2912462</td>
<td>999340.8</td>
<td>4782304.9</td>
<td>4943030.6</td>
<td>4943.0306</td>
<td>0.28</td>
<td>1384.048568</td>
</tr>
<tr>
<td>June 30</td>
<td>72663</td>
<td>2756619</td>
<td>1005192</td>
<td>4799922</td>
<td>4799.922</td>
<td>4799.922</td>
<td>0.28</td>
<td>1343.97816</td>
</tr>
<tr>
<td>July 31</td>
<td>72456.3</td>
<td>2887864</td>
<td>1035276</td>
<td>494343.4</td>
<td>4943.0306</td>
<td>4943.0306</td>
<td>0.28</td>
<td>1384.048568</td>
</tr>
<tr>
<td>August 31</td>
<td>53233.2</td>
<td>2927222</td>
<td>944582.4</td>
<td>4558751.5</td>
<td>4558.7515</td>
<td>4558.7515</td>
<td>0.28</td>
<td>1276.45042</td>
</tr>
<tr>
<td>September 30</td>
<td>30687</td>
<td>2656638</td>
<td>750168</td>
<td>324852</td>
<td>3762345</td>
<td>3762.345</td>
<td>0.28</td>
<td>1053.4566</td>
</tr>
<tr>
<td>October 31</td>
<td>10679.5</td>
<td>2110551</td>
<td>487692</td>
<td>150585.6</td>
<td>2759508.4</td>
<td>2759.5084</td>
<td>0.28</td>
<td>772.662352</td>
</tr>
<tr>
<td>November 30</td>
<td>2544</td>
<td>756999</td>
<td>163944</td>
<td>48576</td>
<td>972063</td>
<td>972.063</td>
<td>0.28</td>
<td>272.17764</td>
</tr>
<tr>
<td>December 31</td>
<td>821.5</td>
<td>59036.4</td>
<td>15400.8</td>
<td>12548.8</td>
<td>87807.5</td>
<td>87.8075</td>
<td>0.28</td>
<td>24.5861</td>
</tr>
<tr>
<td><strong>TOT</strong></td>
<td><strong>380497.6</strong></td>
<td><strong>24315855</strong></td>
<td><strong>7352474.4</strong></td>
<td><strong>4738082.8</strong></td>
<td><strong>36786910.1</strong></td>
<td><strong>36786.9101</strong></td>
<td>10300.33483</td>
<td></td>
</tr>
</tbody>
</table>

**SOLAR RADIATION**

![Solar Radiation Chart](chart)
For the heating season: Were $E$ is the solar energy without the venetian blinds and $E'$ is the solar energy with the effect of the Venetian blinds. $E'_{\text{rad}} = E_{\text{rad}} \times 0.28$

<table>
<thead>
<tr>
<th>$E_{\text{rad}}$ heating season (Kw.h)</th>
<th>$E'_{\text{rad}}$ heating season (Kw.h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18212.88105</td>
<td>5099.606694</td>
</tr>
</tbody>
</table>

For the heating season: Were $E$ is the solar energy without the venetian blinds and $E'$ is the solar energy with the effect of the Venetian blinds. $E'_{\text{rad}} = E_{\text{rad}} \times 0.28$
Appendix 5: INCIDENCE ANGLES OF SOLAR RADIATION
## Appendix 6: Mean Temperature for Each Month in Gavle

### Meteorologi och klimatologi

#### Temperatur och relativ fuktighet

<table>
<thead>
<tr>
<th>Station</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>Maj</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Okt</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marinbryggan</td>
<td>0.2</td>
<td>-0.4</td>
<td>-0.3</td>
<td>-0.1</td>
<td>0.9</td>
<td>1.0</td>
<td>1.2</td>
<td>1.6</td>
<td>1.5</td>
<td>1.5</td>
<td>1.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Karesund</td>
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<td>-1.8</td>
<td>-1.8</td>
<td>-1.8</td>
<td>-2.0</td>
<td>-2.0</td>
<td>-1.9</td>
<td>-1.9</td>
<td>-1.8</td>
<td>-1.8</td>
<td>-1.6</td>
<td>-1.3</td>
</tr>
<tr>
<td>Kinna</td>
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<td>-1.2</td>
<td>-1.2</td>
<td>-1.2</td>
<td>-1.2</td>
<td>-1.2</td>
<td>-1.2</td>
<td>-1.2</td>
<td>-1.2</td>
<td>-1.2</td>
<td>-1.2</td>
<td>-1.2</td>
</tr>
<tr>
<td>Petses</td>
<td>-0.2</td>
<td>-0.2</td>
<td>-0.2</td>
<td>-0.2</td>
<td>-0.2</td>
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<td>-0.2</td>
<td>-0.2</td>
<td>-0.2</td>
<td>-0.2</td>
<td>-0.2</td>
<td>-0.2</td>
</tr>
<tr>
<td>Stenholme</td>
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<td>-2.2</td>
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<td>-4.6</td>
<td>-5.6</td>
<td>-6.6</td>
<td>-7.6</td>
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<tr>
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<td>-2.0</td>
<td>-3.0</td>
<td>-4.0</td>
<td>-5.0</td>
<td>-6.0</td>
<td>-7.0</td>
<td>-8.0</td>
<td>-9.0</td>
<td>-10.0</td>
<td>-11.0</td>
</tr>
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<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Nordnäs</td>
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<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Örjan</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
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<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
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<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
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<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
</tr>
</tbody>
</table>

### Normaltemperatur i °C för månaderna och året, 1931–1960

Källa: Klimatet för Sverige, Statens meteorologiska centralbyrå.
Appendix 7: THE WORST TEMPERATURE FOR A HOUSE MADE OF WOOD.
## Appendix 8: DISTRICT HEATING COSTS

### FJÄRRVÄRMEPRISER
Samtliga avgifter och priser exkl. moms
Gällande från och med 2003-09-01

#### FASTA AVGIFTER

<table>
<thead>
<tr>
<th>TAxA</th>
<th>E</th>
<th>FAST AVGIFT/ÅR</th>
<th>EFFEKTAVGIFT/kW, år</th>
<th>ANM.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td></td>
<td>3 152 kr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1B</td>
<td></td>
<td>4 240 kr</td>
<td></td>
<td>Småhus</td>
</tr>
<tr>
<td>1C</td>
<td></td>
<td>5 120 kr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1D</td>
<td></td>
<td>5 680 kr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0 - 20</td>
<td>674 kr</td>
<td>882 kr x E</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>21 - 100</td>
<td>4 350 kr</td>
<td>704,8 kr x E</td>
<td>Övriga</td>
</tr>
<tr>
<td>4</td>
<td>101 - 500</td>
<td>25 900 kr</td>
<td>497,6 kr x E</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>501 -</td>
<td>51 800 kr</td>
<td>448,8 kr x E</td>
<td></td>
</tr>
</tbody>
</table>

*"E" är normalårskorrigerat medelvärde av uppdräts medeleffekt i kW för perioden november - mars de två senaste säsongerna före debiteringsårets början.*

### ENERGIPRISER

<table>
<thead>
<tr>
<th>Taxa 1A-D</th>
<th>Småhus</th>
<th>28,00 öre/kWh</th>
<th>Året runt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Med småhus menas ann och hushållshus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taxa 2 - 5</td>
<td>Övriga</td>
<td>317,60 kr/MWh</td>
<td>November - Mars</td>
</tr>
<tr>
<td></td>
<td>Vinterpris</td>
<td>317,60 kr/MWh</td>
<td>April - Oktober</td>
</tr>
<tr>
<td></td>
<td>Sommarpris</td>
<td>258,00 kr/MWh</td>
<td></td>
</tr>
</tbody>
</table>

Energialgiften debiteras efter uppdräts energiförbrukning.