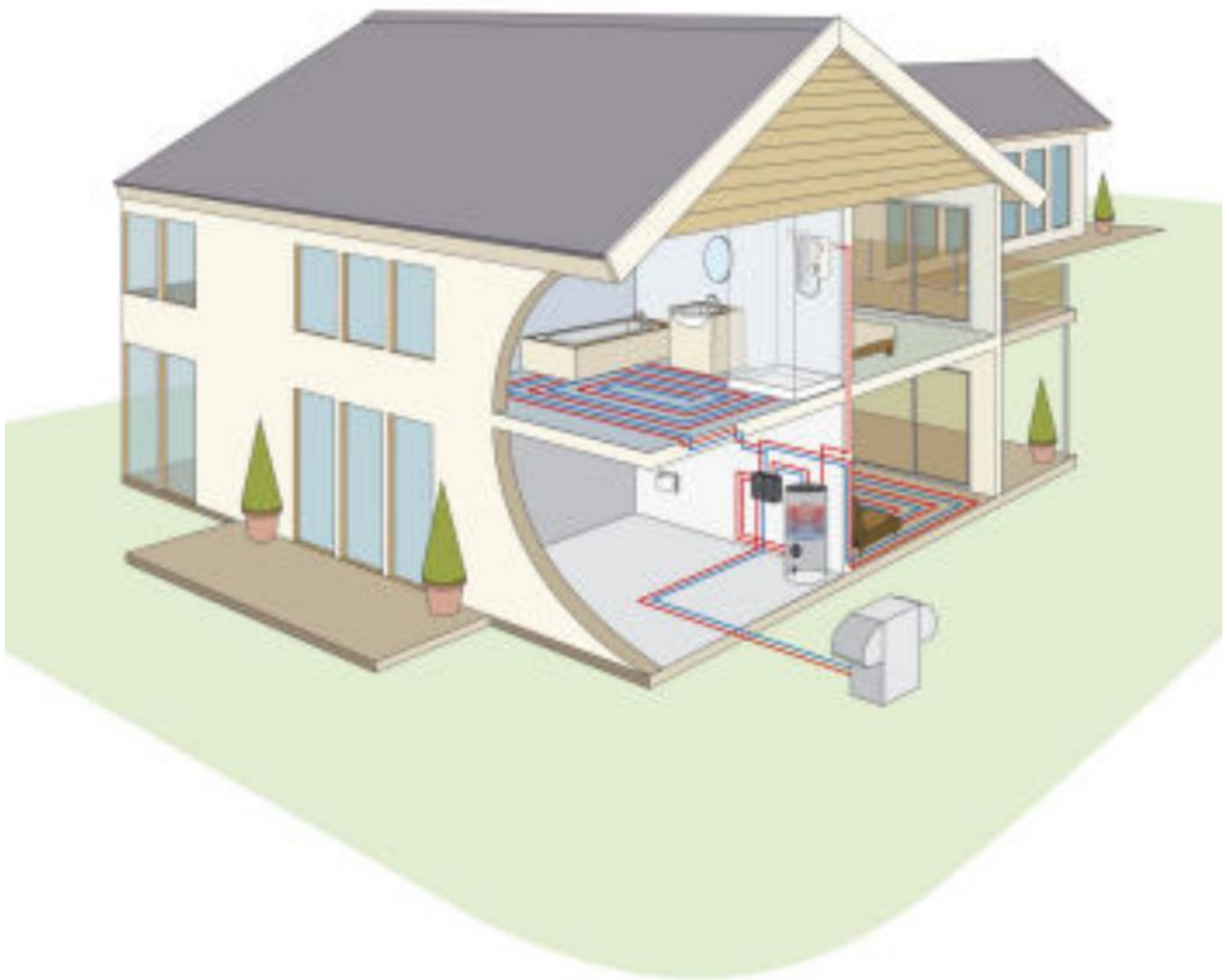


Intelligent Heat Pumps



Master Program in Sustainable Energy Planning and Management
Group SEPM3_2010-2, January 2011

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<http://www.plan.aau.dk>**Title:**

"Intelligent Heat Pumps"

Theme:

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Abstract:

Two and a half million Danish domestic heating installations were found in 2009, in which 14% are oil based. To reduce the CO₂ emissions and fossil fuel dependency, several electrical Heat Pumps solutions are considered as alternative to the existing gasoil installation which is taken as reference. Analyzes are done considering the Heat Pump operation as part of the future smart grid for a typical household having a annual heat demand of 18 MWh. A 4.5 kW Heat Pump with an additional 6 kW Electric Boiler is modelled in COMPOSE without storage and with three different storage capacities (250 L, 500 L, 1000 L). The optimal solution in terms of cost, wind integration and environmental impact turned out to be the Heat Pump with Electric Boiler coupled with a 500 L hot water storage tank. Furthermore, the replacement with an 18 kW Heat Pump only appears to be an improved solution for 1000L storage tank, allowing higher wind power integration.

**Total number of pages including
annexes: 48**

Preface

The semester report entitled “Intelligent Heat Pumps” was written by group SEPM3_2010-2, which is formed by a 9th semester master student at Sustainable Energy Planning and Management, Department of Development and Planning at Aalborg University, Denmark.

The project was conducted during the period of 1st of September 2010 to 5th January 2011.

Literature references are marked with the author name and the date of publication in brackets according to Chicago style. The appendices containing supplementary materials are assigned with capital letters and referenced in the document. Tables and figures are numbered in format x.y, where x is the chapter number and y is the number of the item.

The student express special thanks to its supervisor, Morten Boje Blarke for its support and ideas provided during the project work.

Special thanks are also given to the external support, Jakob Worm from PlanEnergi Nordjylland and Lotte Holmberg Rasmussen from Nordjysk Elhandel.

The report is conducted by:

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Ancuta Gabriela Dragomir

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List of abbreviations

DH	District heating
DUC	Dansk Undergrounds Consortium
DONG	DONG Energy
CHP	Combined Heat and Power Plant
HP	Heat Pump
PV	Photovoltaic
COMPOSE	Compare Options for Sustainable Energy
DEA	Danish Energy Agency
OM	Operation and Maintenance
CO ₂	Carbon Dioxide
COP	Coefficient of Performance
EB	Electric Boiler
Exist.Gasoil	Existing Gasoil
HP-EB	Heat Pump and Electric Boiler without storage
HP-EB 250 L	Heat Pump and Electric Boiler with 250 liters tank water storage
HP-EB 500 L	Heat Pump and Electric Boiler with 500 liters tank water storage
HP-EB 1000 L	Heat Pump and Electric Boiler with 1000 liters tank water storage
kW	Kilowatt
kWh	Kilowatt hour
MWh	Megawatt hour
TJ	Terajoule
kJ	Kilojoule
GWh	Gigawatt hour
PLC	Power Line Carrier
GSM	Global System for Mobile Communications
TSO	Transmission system operator
DKK	Danish currency
Kg	Kilogram
m ²	Square meters
m ³	Cubic meters
L	Liter
AM	Ante meridiem
PM	Post meridiem

1 Introduction

1.1 Problem formulation

In 2009 more than two and a half million domestic heating installations were registered in Denmark of which 14% are oil based. More precisely, the detached houses with a heating system based on gasoil are the project main focus. Unfortunately the exact number of this type of houses from the total of 14% is unknown. What is known is that in such areas the district heating and the natural gas pipes are not available and therefore a more appropriate option is the electrical Heat Pump.

Two major case studies (the Existing Gasoil and the New Heat Pump) are modelled in COMPOSE, a techno-economic software. In both cases a model family with an annual net heating demand of 18 MWh who lives in a detached house of 130 square meters was chosen for discussions. Having a typical example, the final results of both projects can be compared in terms of cost and environment impact.

The HP selected for analysis is an air to water Sanyo 4.5 kW. In order to meet the house peak demands, it will operate together with an additional electric boiler of 6 kW. After replacing the conventional Gasoil boiler with HP the heat consumption will be reflected on the electricity bill and therefore the project attention goes to electricity production.

According to CEPOS report, in the last years the electricity production from wind reached an average of 19%. In 2006, only 5% was used for national consumption, while the remaining 14% was exported to the neighbouring countries. Based on this affirmation the next key question comes up: **How can Denmark make value of its wind?** The answer is through the use of smart grids.

Using a smart meter the family will have access to electricity prices and therefore the storage can be used to optimize the cost. The HP is analyzed without and with water tank storage of three different capacities: 250 L, 500 L and 1000 L.

All the above considerations lead to the following research question:

How can the fossil fuel consumption be reduced and use more wind electricity for national consumption through the use of smart grids, while considering the following socio-economic consequences:

- The financial cost (including the fiscal and economical cost);
- Reduction of primary energy consumption; and in direct way
- Reduction of carbon dioxide (CO₂) emissions.

1.2 Methodology

The project use quantitative research methods, such as historical data and forecasts having the purpose of achieving a broad understanding of Denmark's current energy system.

The software model COMPOSE is used to create the Existing Gasoil case study named the 'reference' project as well as the New Heat Pump called 'alternative' project.

In order to illustrate the cost and the environmental impact evolution, the fuel (gasoil and electricity) price projections were retrieved from DEA likewise the electricity production and CO₂ costs. All these projections are imported to COMPOSE in form of annual profiles. The Financial Cost is presented as the sum of Economic Cost and Fiscal Cost. The Fiscal Cost results are outlined with negative values which are considered benefits. In order to present the final results, the COMPOSE data was exported to Excel files.

Regarding the distribution over the next 20 years of marginal electricity producers in Denmark, the Western case is taken as example. For Eastern Denmark it is assumed to be the same. From the below figure can be noticed that wind represents the base load while natural gas the marginal. Each annual production was determinate based on the marginal production cost and wind turned out to be the lowest. Therefore, in COMPOSE analysis the wind power will be select as the lower threshold (Blarke, 2010).

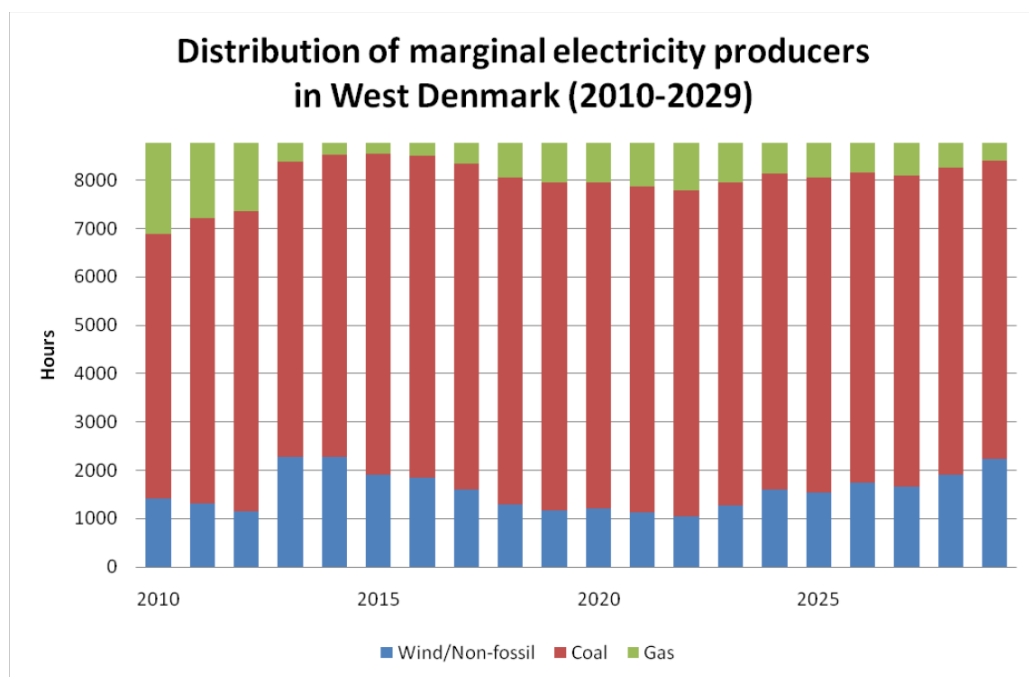


Figure 1.1 Distribution of marginal electricity producers over the next 20 years (Blarke, 2010)

2 Energy System in Denmark

2.1 The Heating System in Denmark

In the last three decades, the heating system in Denmark underwent significant changes in terms of power supply of domestic consumers. According to Statistics Bank of Denmark, the main heating sources for private houses may be summarised as following:

- District Heating (DH);
- Central heating with oil;
- Central heating with natural gas;
- Central heating without oil or natural gas;
- Stoves, electricity;
- Stoves, other; and
- Unknown.

As was expected, for a small number of households the heat installation is unknown.

The following figure outlines the evolution in time for each source concerning only the occupied dwellings. The data was retrieved from Statistics Bank of Denmark and the time framework chosen for discussion is 1981 – 2009. As can be notice, in 2009 more than two and a half million domestic heating installation were registered in Denmark (black line) with the majority coming from DH supply (blue line).

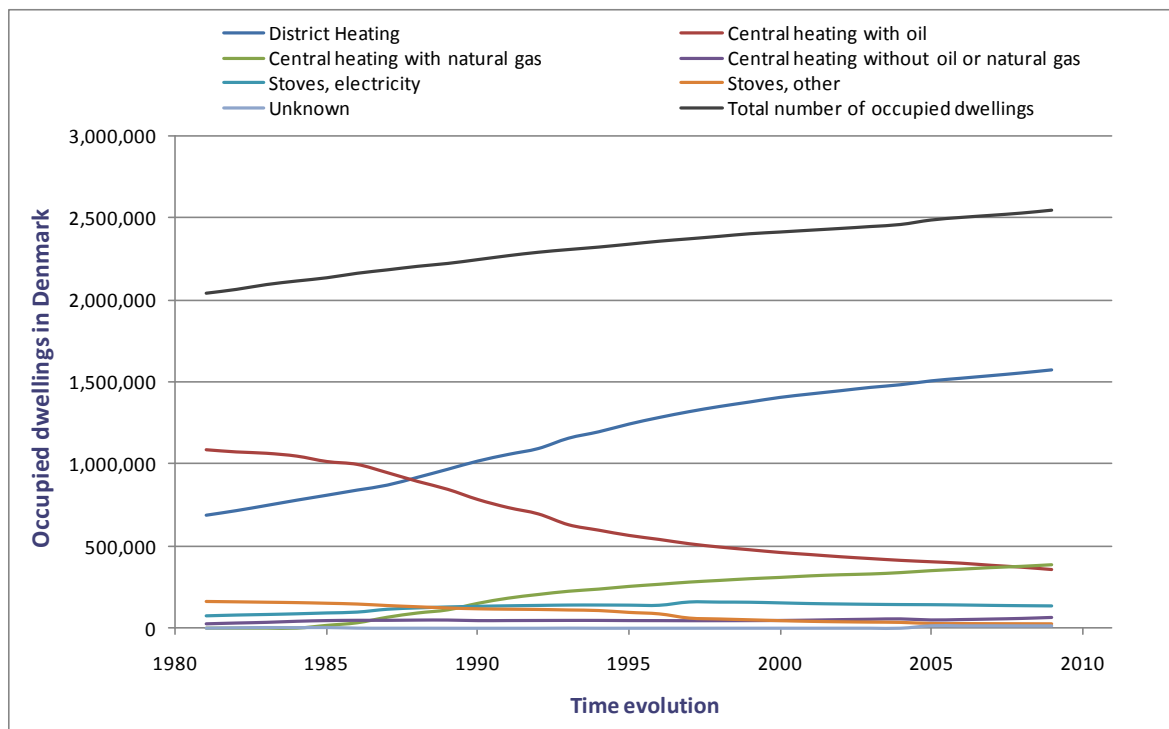


Figure 2.1 Time evolution of the main heating sources (StatBank Denmark)

For a more detailed comparison, the extremities years, 1981 and 2009 were presented in a table form as below.

Table 2.1 Data comparison (StatBank Denmark)

	1981		2009	
District Heating	689,685	33.81%	1,570,262	61.62%
Central heating/with oil	1,085,376	53.21%	360,330	14.14%
Central heating/with natural gas	0	0.00%	388,617	15.25%
Central heating/without oil or natural gas	26,419	1.30%	62,176	2.44%
Stoves, electricity	71,316	3.50%	130,769	5.13%
Stoves, other	165,340	8.11%	20,575	0.81%
Unknown	1,571	0.08%	15,511	0.61%
Total number of dwellings in Denmark	2,039,707		2,548,240	

The DH supply has gained field among domestic consumers; in the eighties, around 34% of Denmark's dwellings were connected to it, compared with 2009 when the share doubled. The central heating based on oil experienced a dramatic decline. If in 1981 more than half of houses were dependent on oil, in 2009 only 14% of them still use it, meaning that most of the oil consumers changed to DH or natural gas.

Looking into the Danish natural gas history, in 1979, after three years of investigation, Dansk Undergrounds Consortium (DUC) on behalf of A.P. Møller – the finder of Tyra, the most important Danish gas field in the North Sea, enters into the first natural gas contract with DONG. After one year, in 1980, the construction of the first transmission system started which represented the backbone of the Danish market. After four years, on 1st of October 1984, the DUT started to supply the first Danish natural gas from Tyra and connected the private consumers to the grid (Energinet.dk). Due to all this, the data regarding the central heating with natural gas was available since 1985. It's visible that over time, the natural gas won a strong position in terms of domestic heating; in 2009 exceeding the number of oil based heating systems.

Furthermore, a slight increase was also registered concerning the central heating without oil or natural gas and electrical stoves. It is very likely that in areas without DH or natural gas, the households use biofuel such as wood chips, pellets or electricity.

The stoves based on other type of fuel, such as coke or coal, have recorded a significant drop. In 2009 less than 1% of the total dwellings are still using this type of installation.

2.1.1 The Danish District Heating

Simply, "District heating is a technical system for heating a town or a part of a city" (SWEP.net). The following figure presents in an understandable manner how the district heating system works.

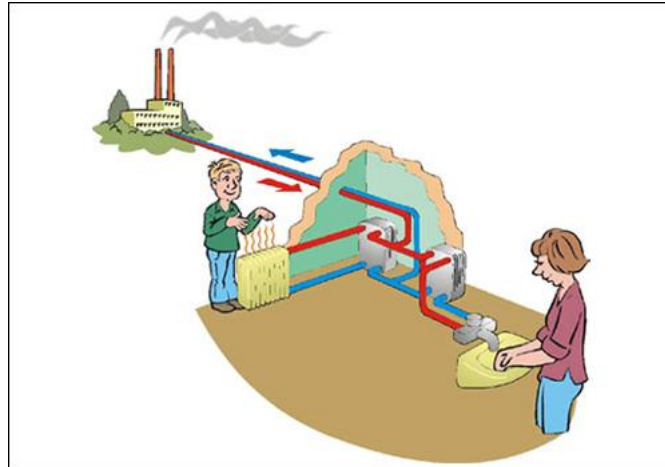


Figure 2.2 Simple presentation of a district heating system (SWEP.net)

In Denmark, the district heating consumers can receive heat either from a heating plant, either from a combined heat and power plant, called co-generation plant or shortly CHP. The heat is distributed inside each household by a water based central heating system which consists of radiators and pipes that carry the hot water throughout the building. In 2005, over 80% of DH was co-produced with electricity thus making the CHP technology the most energy efficiency and environmental friendly. Producing heat and electricity leads to a reduction in fuel consumption up to 30% compared with separate production (**Heat Supply in Denmark, 2005**). The whole idea of combining heat with power comes from the traditional electricity generation example. It is known that this type of plant is relatively inefficient; typically, only 40% of the energy consumed is converted to electricity while the rest of 60% is wasted in the form of heat loss. A combined heat and power solution gives increased energy efficiency, for the same total energy consumption and electricity output, 50% of the energy consumed is converted to district heating reducing the energy lost as waste heat to 10%. Another advantage is that there is no need to use the seawater for cooling since the water is cooled with the household's radiators. Therefore the plant can be positioned near cities, the concept being called decentralised.

The CHP plants are divided in centralised power stations which are located in large cities and decentralised which are usually found in small communities. According to Danish Energy Agency (DEA), approximately 16 centralised CHP plants and 415 decentralised CHP and DH plants were registered as being the supplier of public heat in Denmark. The produced heat is conveyed to end consumers only through the use of district heating pipes.

The following table presents, besides the public supply, the division of the private heat supply which includes enterprises and institutions.

Table 2.2 Number of CHP and DH Plants in Denmark (Danish Energy Agency)

Public heat supply (cities)			Private heat supply (enterprises and institutions)		Total	
Centralised CHP	Decentralised CHP	Decentralised DH Plants	Decentralised CHP	Decentralised DH Plants	Decentralised CHP	Decentralised DH Plants
16	285	130	380	100	665	230

It's visible that the CHP and the DH Plants, which provides the private sector, are found only in small decentralised power stations. Therefore, Denmark can be proud with a wide and varied heat sector with around 681 plants generating both electricity and heat, on small and large scale, and around 230 that produce only heat. Moreover, since 1997 Denmark become self-sufficient in terms of energy, meaning that is no longer depended on fuel imports to cover the energy consumption. Overall, this was possible due to good decisions made by politicians and planners over the last decades.

The heat supply objectives might be briefly presented as below:

- Security of supply;
- Cost efficiency;
- Environmental friendly;
- The consumers are the first priority.

Basically, following all these goals with responsibility and accuracy made possible the development of such system.

The table above can be presented also in a chart which makes more obvious the differences between the two categories of heat supply.

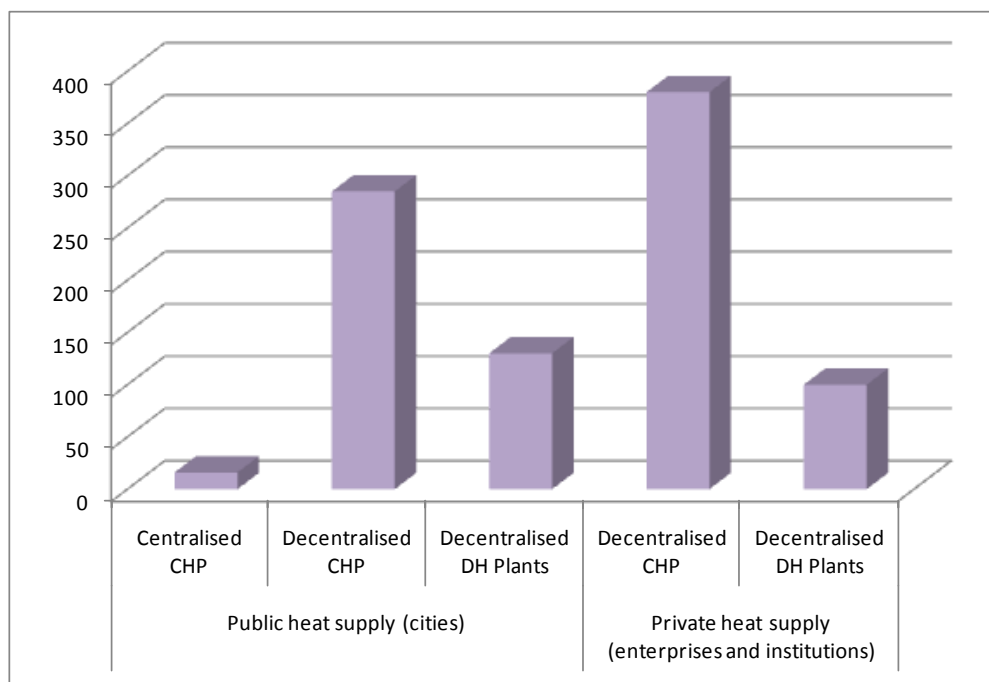


Figure 2.3 Number of CHP and DH Plants in Denmark (Danish Energy Agency)

On small scale, decentralized CHP stations seem to gain more and more field among energy generation and this is due its high efficiency. The energy losses through the transmission system are significantly reduced if the power plant is positioned closer to the end-consumers. Another important aspect is the ease control of such power station. When natural gas or biogas is used the staff supervision is not required permanently. But besides all these, a small disadvantage must be considered; in most of the cases the price paid by end-users for heat is higher than the one paid by end-users connected to a central power plant.

Composition of primary energy sources in district heating production

In terms of fuel structure used in heat generation, the most recent data available was retrieved from the DEA for the year 2008.

In the last decades, significant changes occurred also in the fuel used for district heating production. As shown in the table below, in 2008 the total fuel consumption consisted of: oil, natural gas, coal, non-renewable waste and renewable sources with the biggest share.

Table 2.3 Total fuel consumption for DH production in 2008 (Energy Statistics, 2008)

Total fuel consumption [TJ]	75,153	
Oil	2,884	3.84%
Natural gas	20,920	27.84%
Coal	16,547	22.02%
Waste, non-renewable	6,672	8.88%
Renewable energy	28,130	37.43%
Solar energy	55	0.07%
Geothermal energy	875	1.16%
Biomass	26,578	35.37%
Straw	4,983	
Wood	10,467	
Bio oil	1,606	
Waste, biodegradable	9,523	
Biogas	559	0.74%
Heat pumps	63	0.08%

Compared with previous year, in 2008 the amount of oil used declined sharply with approximate 18% while the natural gas, coal and non-renewable waste tried to maintain its position. Moreover, an encouraging growth took place in the use of renewable sources; an increase of more than 5% has been recorded (**Energy Statistics, 2008**).

The table above highlights the main categories of fuel used in district heating production. Is visible that renewable energy it's leader with more than one-third (1/3) from the total consumption, followed by natural gas and coal. As mentioned above, oil seems to lose place, is no longer the top as it used to be in the eighties; in 2008 it was at the lowest level.

Therefore, having oil at the base and renewable energy at the top confirms that Denmark is heading towards a sustainable approach.

2.1.2 The Non-Public Supply Houses

Based on Figure 1.1, the total number of households divided by the type of heating installation it is presented in a pie chart below.

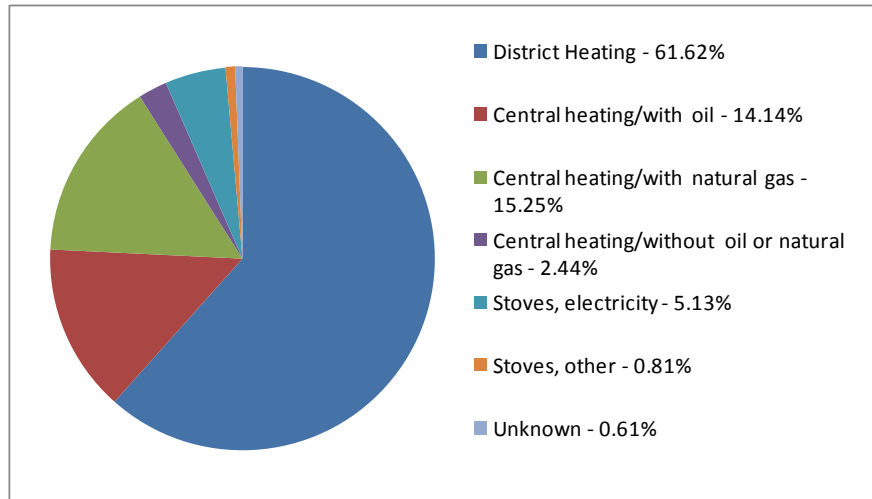


Figure 2.4 Danish Heating System (StatBank Denmark)

It can be observed that around 77% of the total private houses are connected to a public supplier, including DH and individual natural gas supply. The remaining 23% of houses which are not connected to a public supply are bind to provide their own heat by using different technologies based on electricity or fossil fuels, such as gasoil or non-fossil fuels like biomass.

As mentioned in a previous section, the heat is distributed through the house by a water-based system. In terms of DH, the hot water is sent via pipelines from the heat supplier and when it reaches the consumer circulates through radiators warming the dwelling. The radiator is equipped with a control system called thermostatic valve which can be adjusted depending on the user preferences. The same process is applied for natural gas also, with the difference in the energy transportation. Here, instead of water flow in the pipes there is natural gas sent by the gas supplier and the hot water is produced locally by a small gas-fired plant placed inside the house.

Compared with the previous two, a more different system is the one based on oil or other fuels, such as biomass. In this case, the consumer is independent in terms of heat and consequently several disadvantages may arise such as those listed below:

- The fuel must be provided in time;
- An extra room is needed in order to place the furnace and the fuel reserve;
- During heat season, the draining and filling cycles with fuel are more frequent and therefore an extra person is needed for this task (usually is a family member).

Another alternative to this system may be the electrical heat or the air-to-water installation like heat pumps. Despite the type of fuel used, all the above systems share one similarity, such as the water-based system. Thus, based on above aspects, the main purpose of the report can be outlined, which is **to replace most of oil boilers with HPs**. A heat pump is an electric device that “pumps” heat from an area with a relatively low temperature to an area with a relatively high temperature, in this case extract energy from outdoor and used it to heat water (air to water HP). **Why only oil boilers are replaced with HP?** The answer to this is that HPs can be used only in areas without public supply where the oil boilers are used. Due to the first heat supply low from 1979, the electric heating is banned in all new and existing houses where DH or natural gas supply exists (Danish Energy Authority, 2005).

The cost of heat

The cost of heat after replacing the conventional boiler is the primary concern of consumers. The investment cost is expected to be high and therefore most of them need a certain guarantee before actually give up on the old installation. The government offer a prime support through its subsidies which is encouraging followed by rising oil prices which is discouraging for most of the users (**Danish Energy Authority, 2005**).

When a conventional heat boiler is used, the consumer is not paying any more or any less for the heat then the costs to produce it, such as:

- Fuel cost;
- Operation and maintenance cost;
- Taxes on fuels; etc.

After installing an electric HP, the heat consumption will be reflected on the electricity bill.

2.1.3 The space heating and hot tap water consumption

Depending upon the house type and the number of inhabitants and their lifestyle the hot water consumption may account for more than 24% of the whole heat consumption per year while the remaining is used for space heating (**Koiv, 2001**).

As in the below graph, in 2009 the average energy consumption for space heating per household has fallen by 29.12% compared to 1980.

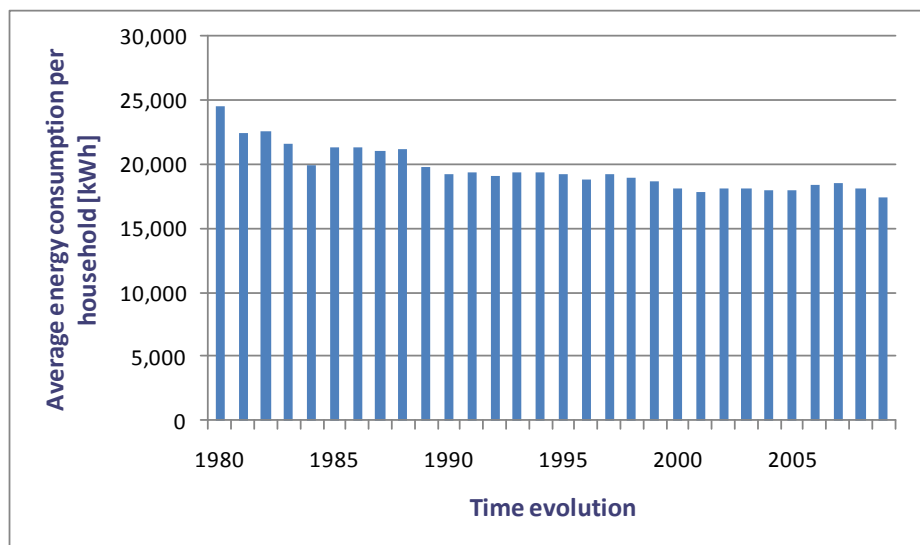


Figure 2.5 Energy Consumption for Space Heating (Danish Energy Agency)

The decrease was due to the fact that today, all citizens have access to information and education concerning the heat energy conservation methods. According to Passivhus Norden Conference 2010, Denmark would like to apply extreme heat savings measures in order to minimise even more the heat demand. A good point to start is the house restoration, which includes (**Koiv, 2001**):

- Roof renovation;
- End walls and facades insulation;

- Replacement of outer doors;
- Replacement of conventional windows with thermo glazing; etc.

Unfortunately the exact data regarding the hot tap water consumption could not be found.

2.2 Wind power in Denmark

Denmark was the first large scale user of wind power in the World and also the leader in wind turbine manufacturing until the news that wind energy is a “CO₂-free” source has spread so widely. Up till now Denmark proved to be self sufficient in terms of energy requirements, its oil and gas extracted from North Sea will continue to exceed demand until 2018 (CEPOS, 2009).

For analysis, Denmark as a whole is discussed. The 2009 data from Western and Eastern Denmark are summed in order to obtain an overview for the whole country.

In 2009, the power generation distribution was as shown in the below pie chart. The major share of electricity was produced by central power stations (62%) then followed by wind turbines (onshore and offshore) with almost 20% and by local CHP plants (more than 18%). The hydropower plants and photovoltaic (PV) accounted for less than 1% of total generation and this is due to their low potential.

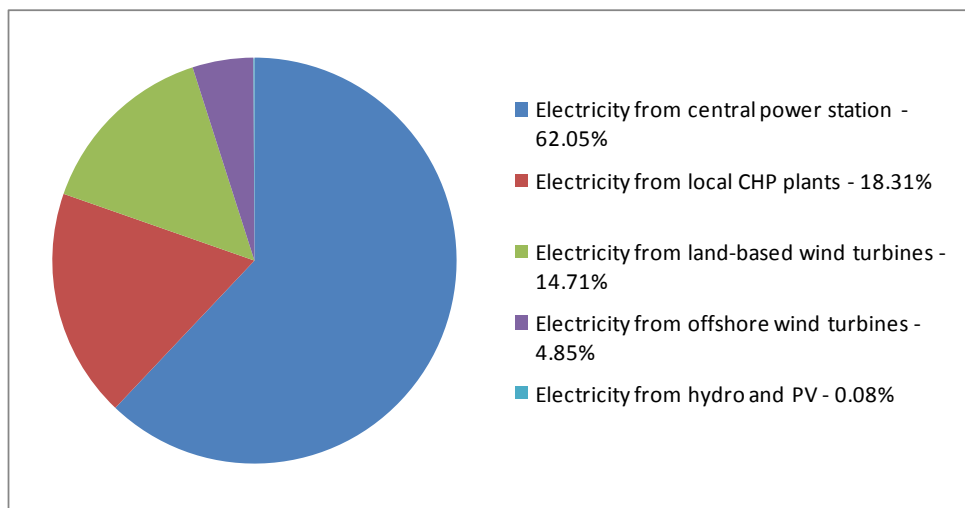


Figure 2.6 Distribution of power generation in 2009 (Environmental Report, 2010)

The figure summarizes the chief power generations specified in percentage from total production of 34,297 GWh in 2009.

In terms of wind, the output power varies from year to year and depends on how much the wind blows. Compared to previous year, the generation from wind turbines dropped with more than 300 GWh and that's because 2009 was a poor wind year (Environmental Report, 2010). Nevertheless, the share of wind generation exceeded 19% from total in 2009.

Regarding the international exchange, the Danish transmission grid is connected to power systems from the neighbouring countries, such as Norway, Sweden and Germany. As in 2008, Eastern Denmark experienced net electricity imports in 2009 due to the stable low electricity prices from Germany and Sweden. Not the same thing can be said about Western Denmark which proved to maintain its reputation

of net exporter since 2000. Overall, in 2009 Denmark was a net importer of electricity as can be seen in the below table.

Table 2.4 Net exchange (Environmental Report, 2010)

	GWh		
	DK-West	DK-East	All Denmark
Electricity imports	6,299	4,965	11,264
Electricity exports	-8,487	-2,443	-10,930

The imports are counted as a plus (positive value) while the exports are subtracted (negative value). For a better understanding please see the following graph where zero axis is used as reference.

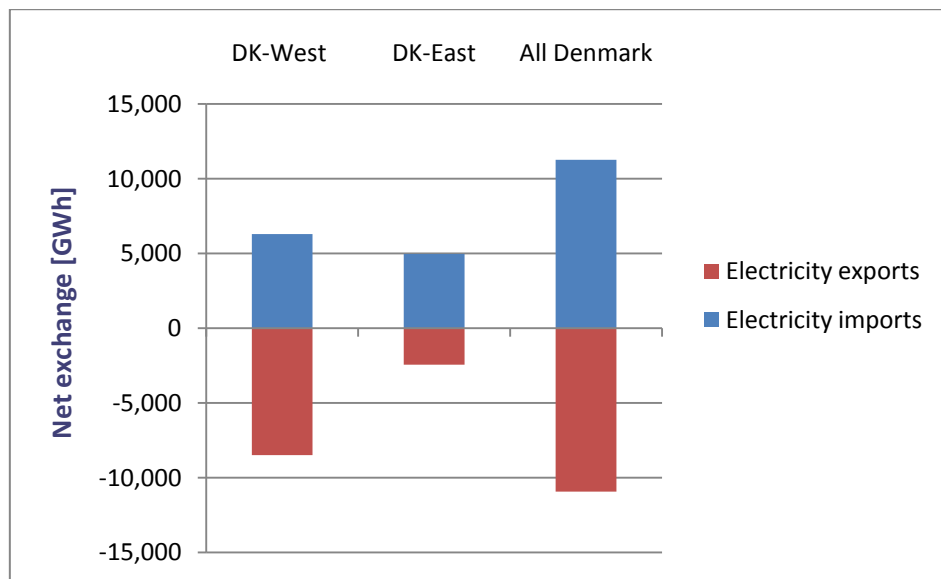


Figure 2.7 Net exchange (Environmental Report, 2010)

Based on previous information and CEPOS report, in the last years the electricity production from wind reached an average of 19%. The CEPOS report strongly supports that in 2006 only 5% was used for national consumption while the remaining 14% being exported to the neighbouring countries. The main reason of this is the lack of large scale electricity storage and its high intermittency (CEPOS, 2009). Based on this affirmation the next key question comes up: **How can Denmark make value of its wind?**

3 The smart grid

What is a smart grid?

The smart grid is an electricity network which makes use of digital technology and communication to gather information and control the generation units and loads, enabling bidirectional power flows at all voltage levels to minimize transportation losses and improve quality and reliability of supply (European Commission, 2006).

The current electricity networks with more than a century from its design, needs to be upgraded.

Today's grids form a vertically integrated scheme based on large central power stations connected to high voltage transmission system, which in turn supply power to medium and low voltage local distribution system. This means that the power flow is unidirectional.

Tomorrow's grids purpose is to host a bidirectional power flow, meeting the electricity demand growth and enabling the integration of more sustainable generation resources. Another goal is to accommodate also more decentralised generation units in order to minimise the transmissions losses while keeping the system reliability. Basically the grid will behave just like internet where all customers have access to energy supply and additional information, such as cost, daily profile and generation source.

Through the use of smart grids, the daily lives of ordinary end-users will be significantly improved; they will become much more inter-active with the networks, they will have control and visibility on their consumption and in some cases their generation.

The following figure shows an interconnection of generation, storage and consumption at all levels. Storage systems are a new element which has to be integrated to improve the security of supply and to partially decouple the generation from consumption.



Figure 3.1 Future Network Vision (European Commission, 2006)

To enable the use of smart grids is a need to integrate electronic control technologies and more power electronics.

3.1 Smart meters

Through a smart meter, the end-users will have access to information given by the central control unit regarding the electricity cost, daily profile and generation sources. Furthermore they will also be able to send accurate feedbacks regarding consumption/generation.

An important aspect of the smart meter is the communication infrastructure. The information can be sent from central unit to customers and vice versa using one the following (van Gerwen, 2006):

- Power Line Carrier (PLC, using the existing electricity grid);
- Wireless modem (GSM);
- Permanent internet connection.

The smart meter is equipped with three basic utilities as shown in Figure 3.2:

1. Switch off device;
2. Measurement and display unit; and
3. Remotely control unit.

The switch off device is used to interrupt the electricity consumption when the flow exceeds a certain maximum value at a critical time for the power system. When the flow is reduced or the system gains the capability of the demanded energy supply, the connection can be restored.

The measurement and display unit shows the instantaneous energy consumption/production for users and the information is also send to the central control unit over the communication line. Having the information about their energy usage, and getting further information from the central control unit (price, daily profile) customers are able to adjust their behaviour to cut the electricity cost. This is achievable by avoiding the periods with high prices, and therefore the consumption against the daily profile peaks will reshape the system daily profile.

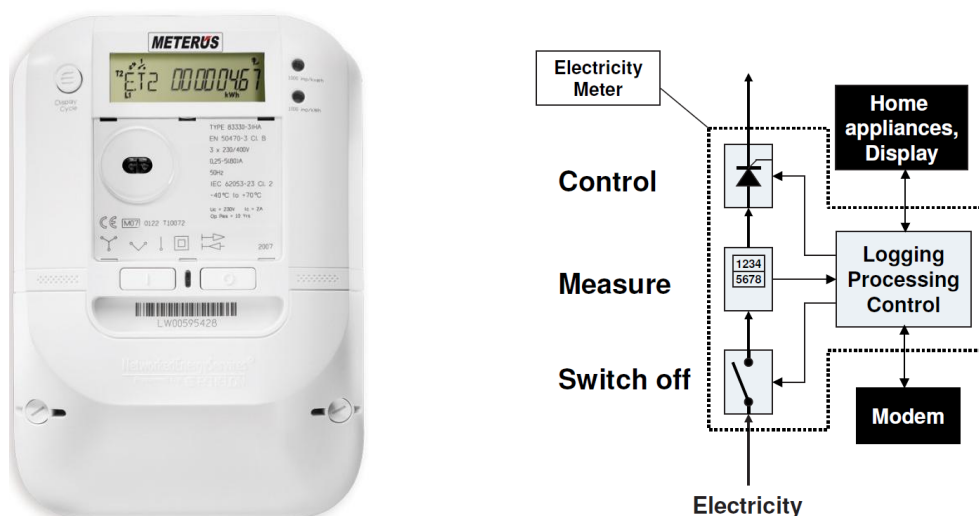


Figure 3.2 Example of European Smart Meter (left) and Typical smart meter configuration (right) (EVb Energy Solutions), (van Gerwen, 2006)

The display is also used to show the historical energy data and cost. Depending on the smart meter construction, this can be seen locally on the meter display or via a webpage which can access the data stored on the central control unit servers.

The remotely control unit is used to limit the electricity consumption. This can be triggered by the user when it is desired to reduce the cost or by the central control unit during critical grid conditions.

Who is responsible for establishing the electricity price?

Norway, Sweden, Finland and Denmark are part of the Nordic market of electricity. The border tariffs between these countries were removed when the common power exchange was created. However there is a real-time market and a system operator in each country who is in charged to set the market-clearing price.

Denmark is divided in two main power systems:

- The Western system with Elkraft as the Transmission System Operator (TSO); and
- The Eastern system with Eltra as the TSO.

Until the end of 2010 these two systems had no electrical interconnection between them.

On Elspot, which is the day-ahead market of Nord Pool, an hour by hour power contracts are traded daily for physical delivery. The price calculation is based on the balance between sellers and buyers bids in order to find the intersection point between the market's supply curve and demand curve (**Bergman, 2003**).

4 The case study

Two major case studies are analyzed in the report:

- The continuation of Existing Gasoil project, called also the reference project; and
- The New Heat Pump (air to water) project which represents the alternative project.

Both of them are modelled in COMPOSE, a techno-economic software which will be described further. The Gasoil reference project was selected based on the data from Table 1.1 which shows that in 2009 more than 14% of the total number of households in Denmark still uses oil as primary energy source for heating. More precisely, the detached houses with a heating system based on gasoil are the main focus. Unfortunately the exact number of this type of houses from the total of 14% is unknown. What is known is that in such areas the district heating and the natural gas pipes are not available and therefore a more appropriate option can be the electrical heat pump. Moreover, the alternative project can be achieved by replacing the conventional gasoil boiler with Heat Pump. In both cases a model family with an annual net heating demand of 18 MWh who lives in a detached house of 130 m² was chosen for discussions. Having a typical example, the final results of both projects can be compared in terms of cost and environment impact.

4.1 COMPOSE Software

"COMPOSE is a techno-economic energy planning software that allows for users not only to optimize the system-wide performance of their plant, or demand, but also to share data and experiences."
(Blarke)

COMPOSE or Compare Options for Sustainable Energy was developed by Morten Boje Blarke from Aalborg University in 2008. The software allows users to import projects from energyPRO or to exchange hourly profiles with EnergyPLAN or to import statistical data and projections from Energinet.dk and DEA.

COMPOSE classify the work flow into three main actions:

1. **Define** – this part is actually the part where the projects and the systems are defined;
2. **Manage** – this section includes all the assumptions that goes into the analysis of a defined project in a defined system; and
3. **Analyze** – in this part it's important to specify which project is included in the analysis in order to calculate and evaluate the results.

The units of measurement used in COMPOSE are as below. All the graphs (charts) made in COMPOSE do not have specified the unit.

Table 4.1 Default Units used in COMPOSE

Unit	
Currency	DKK
Energy	kWh
Power	kW
Mass	kg
Volume	Liter

In COMPOSE each project is a specific case study and therefore, both of the projects (the Existing Gasoil and New Heat Pump) will be outlined based on the below figure. In both cases the System is Denmark as a whole and the main subsystems analysed are the Energy System, the Economy System and the Environment System. For more information concerning the subsystems structure please see Annexe Y.

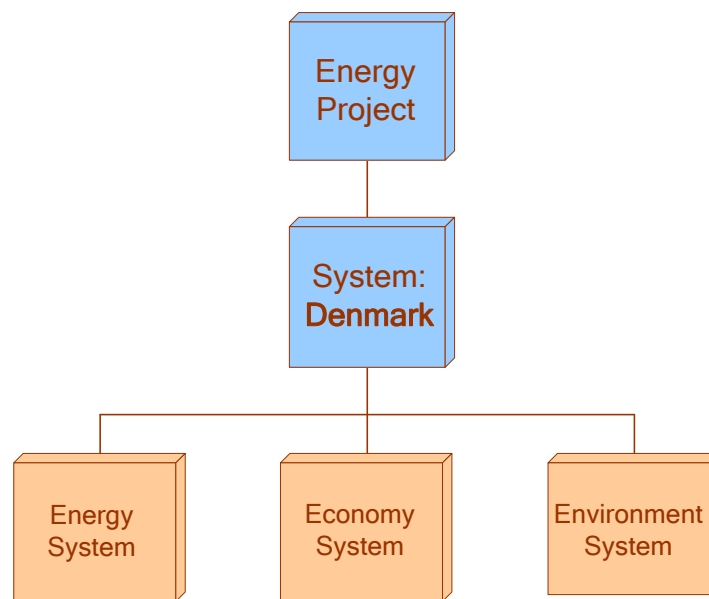


Figure 4.1 COMPOSE Structure

The Project part is divided in three main categories: Demand, Storage and Process.

- In the first, the annual demand must be specified together with the demand type (heat, electricity or cooling).
- The second one includes storage devices characterized by different capacities. They are always additional equipments meant to help the primaries to be used more efficiently.
- The last part includes the conversion technologies, such as Wind Turbines, Heat Pumps, Electric Boilers and others. In order to meet the peak loads, two of these equipments can be used simultaneously.

All three parts can be represented in a graphical form as below. Depending on the case study analyzed, the figure will be extended.

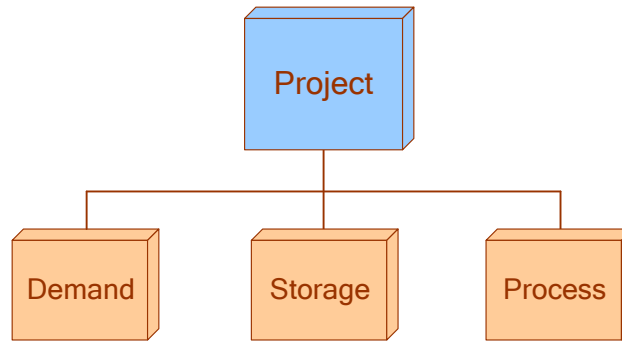


Figure 4.2 Project Structure

4.2 Reference House

The house chosen for analysis is, as mentioned before, a detached dwelling of 130 square meters with a heating system based on gasoil. The annual net heating requirement is set at 18 MWh of which 14 MWh is for space heating and the rest of 4 MWh for hot tap water. In COMPOSE, both demands are characterized by an hourly profile. The *Danish DRY Degree Hours Normalized* is used for space heating while for hot tap water the *Default Hourly Profile* which is represented by a constant value all over the year. Therefore, an improvement that can be brought to the project is to create the hourly profile for hot tap water according to predefined assumptions. As a starting point, a daily profile for a weekday and weekend day is built.

4.2.1 Daily profile of a household hot tap water consumption

Assumptions

For the analysis a model family formed of four members, two adults and two children was chosen. The family lives in a detached house of 130 m² outside the district heating area which was built in 1979. The house heat and hot tap water is provided by a gasoil boiler placed in an extra room.

Both parents have a stable job and both children are part of an obligatory schooling. Parents' working hours begins at 8:30 AM and ends at 4:30 PM all weekdays. The youngest child has 10 years old and the older 12 and both attends the secondary school lectures which programs normally starts at 8:00 AM and ends at around 2:00 or 3:00 PM. The distance between home and work or school is less than 10 km and therefore an early departure is not needed.

The house is equipped with a clothes washer and a dishwasher which use cold tap water at the start stage. Beside them, the most common cold and hot water-consuming activities for a family are the bath, the faucet, the shower, toilet and sometimes the uncontrolled leak.

In the analysis the clothes washer, the dishwasher and the toilet are only cold water-consuming and hence they are not discussed further.

In terms of bath and shower, the parents tend to take a shower every morning between 6:00 and 8:00 AM while the kids are used to bathe in the evening, before bedtime between 8:00 and 10:00 PM. During weekdays, until 7:30 AM the breakfast must be prepared and after 6:00 PM the dinner while during the weekend days, beside breakfast and dinner the lunch it's included too. The hour shower, the dinner preparation and the bath starts with an hour later, while the lunch is prepared between 1:00 and 3:00 PM.

Based on the previous assumptions, around 7 hours per day, from Monday till Friday, all family members are out and therefore the faucet is used only half of it per day per capita compared to weekend days, when the family spends most of its time home. The distribution of faucet consumption in terms of preparing breakfast, lunch and dinner for one week is presented later on. An additional consumption, such as washing hands between meals is assumed to be around 1 liter of hot water every remaining hour when the members are home.

During a week time some unpredictable activities may occur, such as sport (running or playing football or tennis) which requires a shower after or some friends coming over dinner and therefore a margin of 5% is added to the total daily hot water consumption. The unpredictable consumption is not taken into account in the daily profile.

Model

According to the Danish Building Research Institute, the annual water consumption (cold and hot) of a detached house can be determined with the following equation:

$$52 m^3 + 26 \frac{m^3}{person} \cdot number\ of\ persons$$

(Danish Building Research Institute, 2005)

Results

The total number of persons living in the house is equal with 4 and thus the annual water consumption can be determined as cubic meter or liters as below:

$$Total\ annual\ water\ consumption\ in\ m^3 = 52 + 26 \cdot 4 = 156$$

$$1 m^3 = 1000\ liters \rightarrow Total\ annual\ water\ consumption\ in\ liters = 156,000$$

From Mayer and DeOreo book, two important aspects are considered in order to determine the annual energy consumption for hot tap water.

- "Around 40% of the total water consumption is hot water"; and
- "It takes 4.187 kJ of energy to heat a liter of water by one degree" (Mayer, 1999)

$$Total\ annual\ consumption\ of\ hot\ tap\ water\ in\ m^3 = 40\% \cdot 156 = 62.4$$

$$Total\ annual\ consumption\ of\ hot\ tap\ water\ in\ liters = 40\% \cdot 156,000 = 62,400$$

The boiler has to raise the water temperature from 8 degree Celsius, which represents the cold water temperature until 55 degree Celsius, which is the maximum temperature needed by the model family and therefore the difference is 47 degrees.

$$Annual\ hot\ tap\ water\ consumption = 4.187 \cdot 62,400 \cdot 47 = 12,279,633.6\ kJ = 3,411\ kWh = 3.411\ MWh$$

By adding the hot water consumption which was calculated above to the space heating consumption which is known as 14 MWh, the total heat consumption of the model family can be set at 17.411 MWh.

The below figure enclose all the detached houses built in the last century per different intervals of years with a certain annual range of heat produced by an oil boiler. It's visible that the model house falls into the second range of annual heat consumption, between 10 and 20 MWh and between 1979 and 1998 in terms of building.

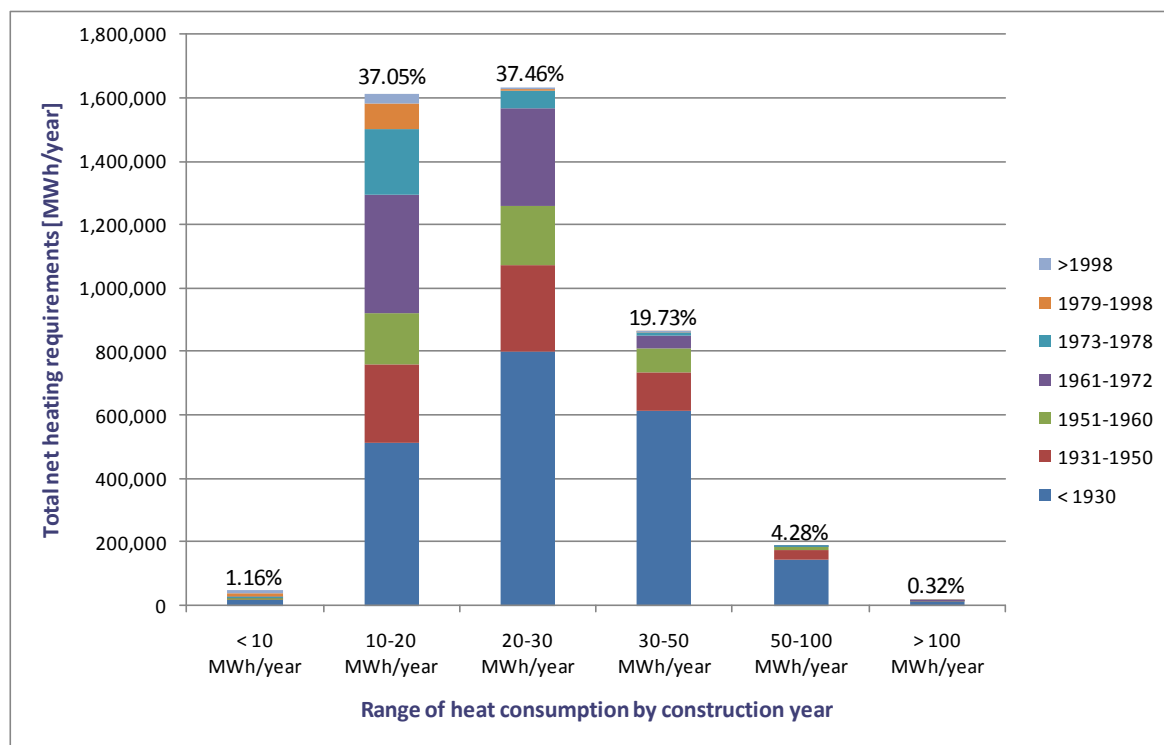


Figure 4.3 Total net heating requirements of detached houses based on oil (Möller B. H., 2010), (Möller B. , 2008), (Dyrelund, 2008)

In order to illustrate the daily profile of the hot water utilization it is important to establish how many liters are needed per day and how are they distributed. Above, the consumption was set at 62,400 liters in a common year which has a daily and weekly average of 171 liters and, respectively, 1,197 liters.

According to DeOreo article, the daily hot water consumption per capita for the main activities are as presented in the below pie chart. These data are quite useful in terms of drawing the family daily profile and not only. Can be used also as a second method for measuring the hot water consumption and thus a more accurate result can be obtained.

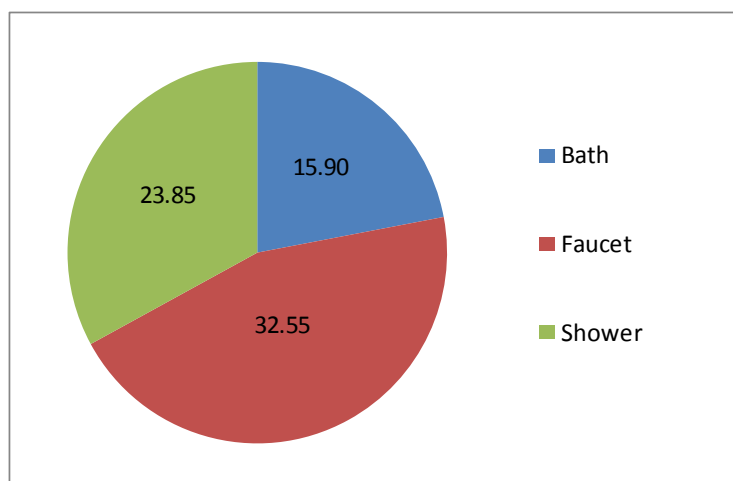


Figure 4.4 Daily hot water use per capita in liters (DeOreo)

Based on the above data and the assumptions set out, a detailed schedule of the family hot water use for each day during a week time is presented in the following table.

Table 4.2 Household average consumption of hot water in liters for each day of one week

	Weekdays					Weekend days	
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Bath	31.80	31.80	31.80	31.80	31.80	31.80	31.80
Faucet	65.11	65.11	65.11	65.11	65.11	130.22	130.22
Shower	47.70	47.70	47.70	47.70	47.70	47.70	47.70
Total	144.60	144.60	144.60	144.60	144.60	209.71	209.71
Unpredictable consumption	7.23	7.23	7.23	7.23	7.23	10.49	10.49
Total after adding the unpredictable consumption	151.83	151.83	151.83	151.83	151.83	220.20	220.20

Summing all the results obtained per each day, the daily and weekly average consumption is established at 171.37 and respectively 1,199.56 liters which is very similar to the one based on the first method.

Due to the fact that the faucet is most commonly used it is important to know its distribution hour by hour for a weekday and a weekend day. The next two tables are made based on the assumption that 1 liter of hot water is used per hour when the family members are home besides the cooking hours (during night or between meals). These hours were called remaining hours and during weekdays the number was set at 11 while during weekend days at 16. The remaining faucet, after excluding the additional consumption was divided in three parts. From Monday till Friday only one-third is needed for the breakfast preparation and two-thirds for dinner whilst Saturday and Sunday one-third for each (including lunch). For a better understanding please check Annexe X.

Table 4.3 Faucet distribution for a weekday

	Weekdays
Faucet	65.11
Remaining hours	11
Liters per remaining hour	1.00
Additional consumption	11.00
Remaining Faucet	54.11
Breakfast - 1/3 from the Remaining Faucet	18.04
Lunch	0
Dinner - 2/3 from the Remaining Faucet	36.07

Table 4.4 Faucet distribution for a weekend day

	Weekend days
Faucet	130.22
Remaining hours	16
Liters per remaining hour	1.00
Additional consumption	16.00
Remaining Faucet	114.22
Breakfast - 1/3 from the Remaining Faucet	38.07
Lunch - 1/3 from the Remaining Faucet	38.07
Dinner - 1/3 from the Remaining Faucet	38.07

Moreover with the above results the daily profile for a weekday and weekend day can be modelled. The unit set for modelling is kWh and therefore the conversion process is the same as in previous calculations.

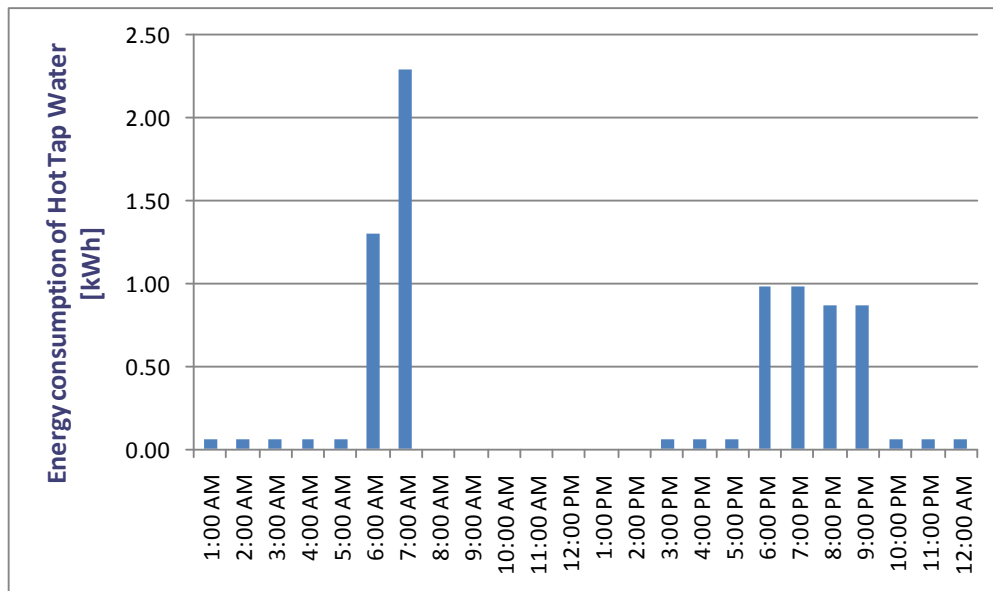


Figure 4.5 Daily profile of hot tap water consumption during weekdays

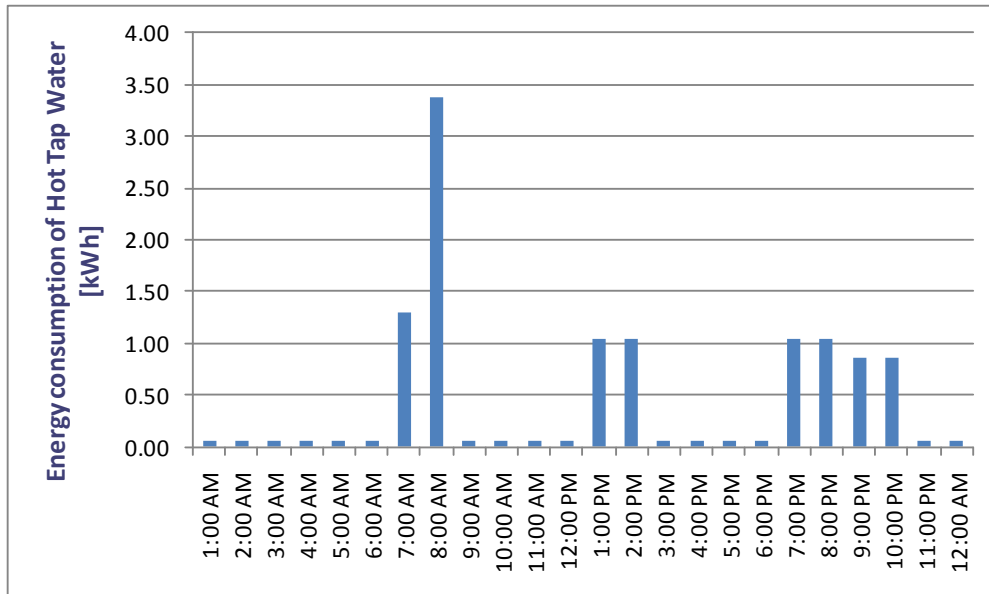


Figure 4.6 Daily profile of hot tap water consumption during weekend days

The hourly profile used in COMPOSE was achievable on the basis of the two daily profiles which were assumed to be average. The profile of 8,760 hours was conducted in Excel and then imported in COMPOSE as a Text Document.

Must be know that all previous calculations were made in order to create the daily profile for hot tap water consumption and not to determine the actual value.

4.3 Existing Gasoil project

As mentioned before, a conventional Gasoil Boiler was chosen for analysis. The heating process itself is easy to explain: the gasoil-fired boiler heats the water, which provides central heating through radiators and hot water to the taps. A key aspect is that the gasoil must be delivered by road and stored in a tank. In the worst cases, the house could run out of gasoil while waiting for the next delivery. Due to this, the tank is usually equipped with a monitoring system which measures the amount of gasoil. If the level of gasoil is below a predetermined point the supplier is automatically informed. As fossil fuel, the gasoil is an expensive finite resource and non-environmental friendly, when it's burnt a large amount of carbon dioxide is released into the atmosphere (**Home heating system**).

The following figure highlights very briefly the reference project structure as it is in COMPOSE. The space heating demand and the hot tap water demand can be found under the name *Ref Household Space Heating* and, respectively, *Ref Household Hot Tap Water*; both are represented by an hourly profile. The storage is not used and the process is composed, as expected, only from the gasoil boiler called *Existing Gasoil Boiler*. In turn, the process box is divided in four main groups: Fuel, Cost Benefit, Efficiency and Capacity. Only the fuel is characterized by an annual profile while the rest are considered constant. The boiler capacity is established at 15 kW and remains unchanged throughout the analysis. For additional information regarding the rest of the groups please check Annexe Y.

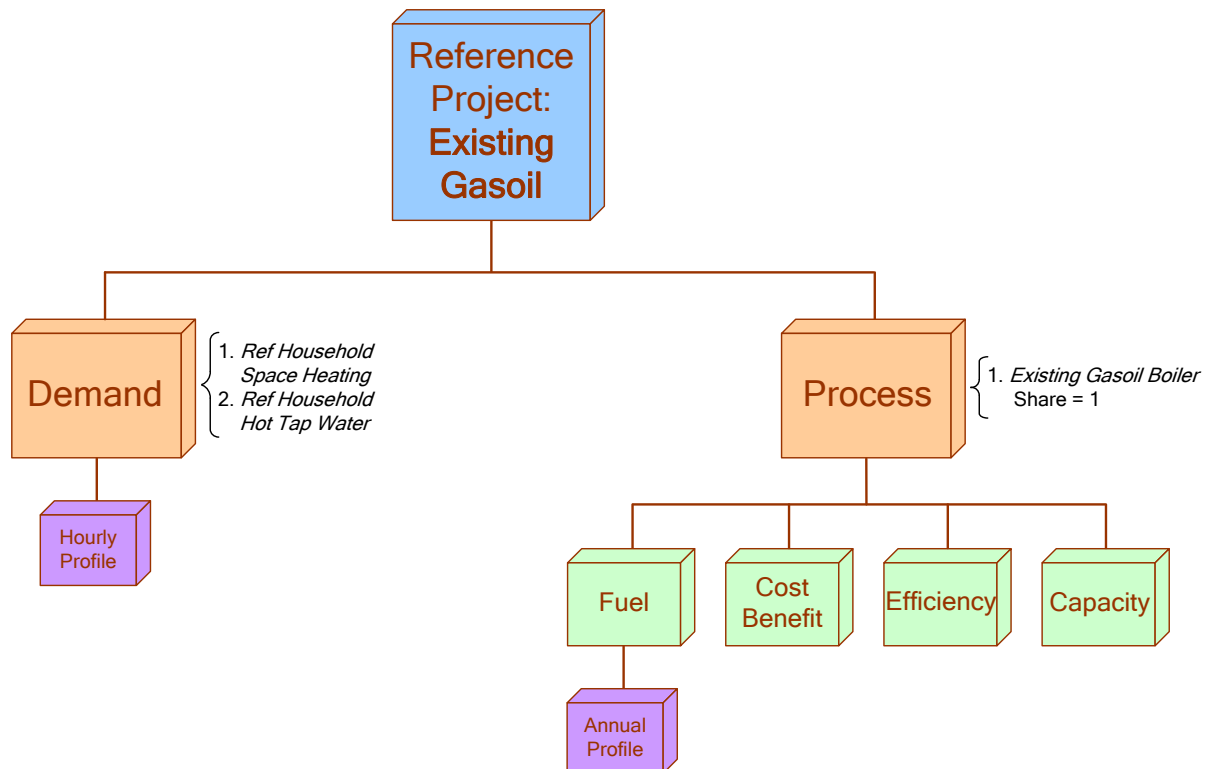


Figure 4.7 Existing Gasoil Project Structure

4.4 New Heat Pump project

As alternative project, a 4.5 kW CO₂ ECO Heat Pump from SANYO was chosen for discussions. This is an air to water device which extracts energy from air and uses it to heat the water through the use of electricity. Unlike other heat pump systems, the SANYO solution is the natural choice, hence the name of ECO. As its refrigerant, within the system it uses carbon dioxide, a natural and non-toxic gas which can operate up to temperatures below minus 20 degree Celsius (SANYO).

The working process can be explained briefly in 3 steps (Heat Pump Association):

- In first, through a heat exchanger the energy from air is transferred to the refrigerant with a low boiling point which evaporates and circulates into the closed system;
- In second step, the refrigerant pressure is raised by a compressor and thus the temperature. Then, in a second heat exchanger the refrigerant is condensed in order to release the heat to a water delivery system;
- In the third step, the refrigerant pressure is reduced by an expansion valve. As a consequence, the temperature falls too and is ready to start the cycle again.

The main features and benefits of this type of HP are presented as following (SANYO):

- Environmentally friendly;
- Provides hot water and central heating via radiators → it is compatible with all standard radiators;
- High efficiency and thus low running costs. The HP efficiency is usually given as the Coefficient of Performance (COP) which can go up to 3.75 for increased outdoor temperatures.
- Placed on an exterior wall;

- Easy to install, operate and control;
- High water temperatures, up to 65 degree Celsius;
- Low maintenance;
- Low carbon emissions.

Besides HP, a supplementary Electric Boiler (EB) of 6 kW, with a considered efficiency of 1, will be used in order to meet the house peak demands. Moreover, the alternative project is analyzed without and with thermal storage. A hot water tank is a more appropriate technology for the chosen family. For calculations, the water tank is designed with three different capacities: 250 L, 500 L and 1000 L.

The figure below highlights the structure of the alternative project as in COMPOSE. Compared to the reference project, the Demand remains the same while the Process is different. In this case the Process interacts with Storage for optimizing the HP efficiency, lifetime and overall cost. With respect to each subdivision of the Process please check Appendix Y.

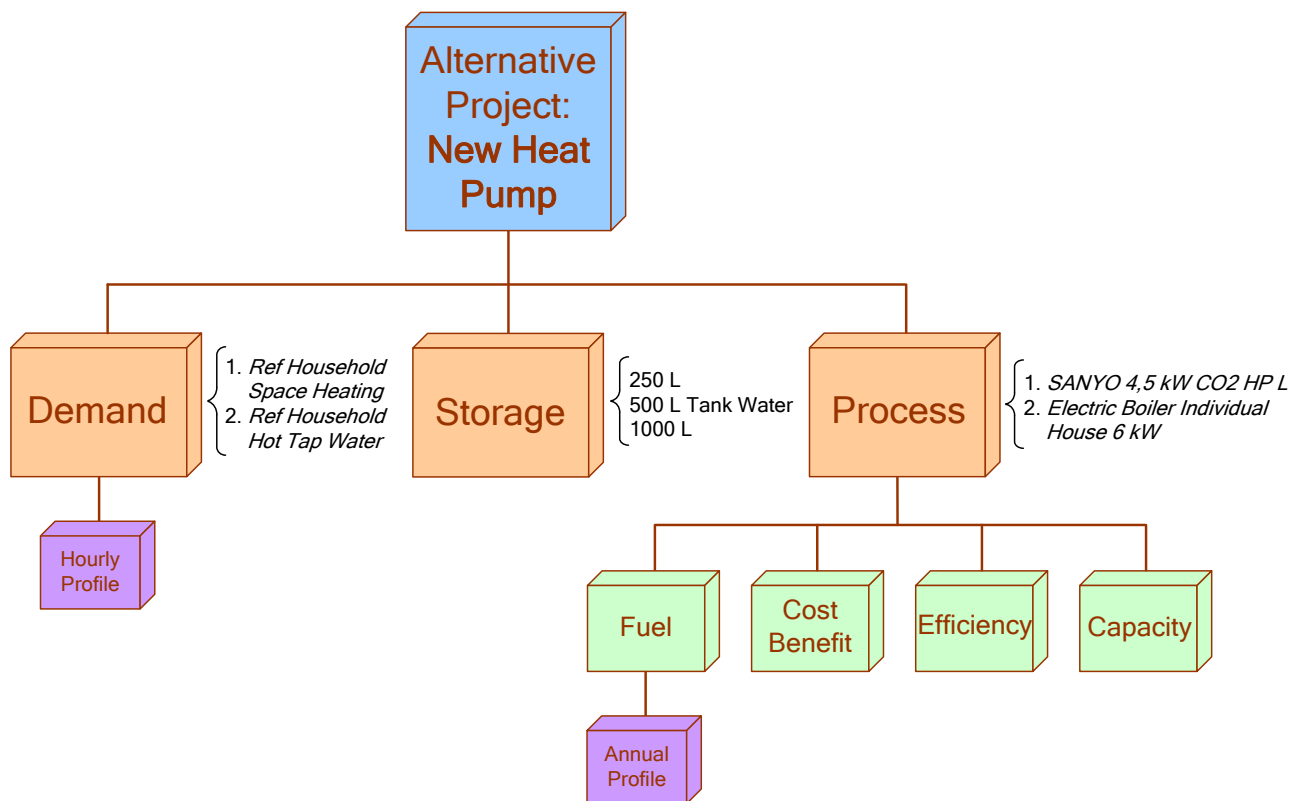


Figure 4.8 New Heat Pump Project Structure

4.5 Comparative Results

The Planning period was established at 20 years, starting with 2010. The alternative project incorporates four solutions which are compared to the reference project (Exist. Gasoil), such as: Heat Pump and Electric Boiler without storage (HP-EB) and Heat Pump and Electric Boiler with three storage capacities (HP-EB 250 L, HP-EB 500 L, HP-EB 1000 L). The most relevant results are summarized in the following graphs. The modelling was performed in COMPOSE while the output data was processed in Excel in order to combine the results for all five solution in the same graph with respect to the purpose.

The **Relocation Coefficient** shows briefly the project goodness: **How good is this project in terms of wind integration?**

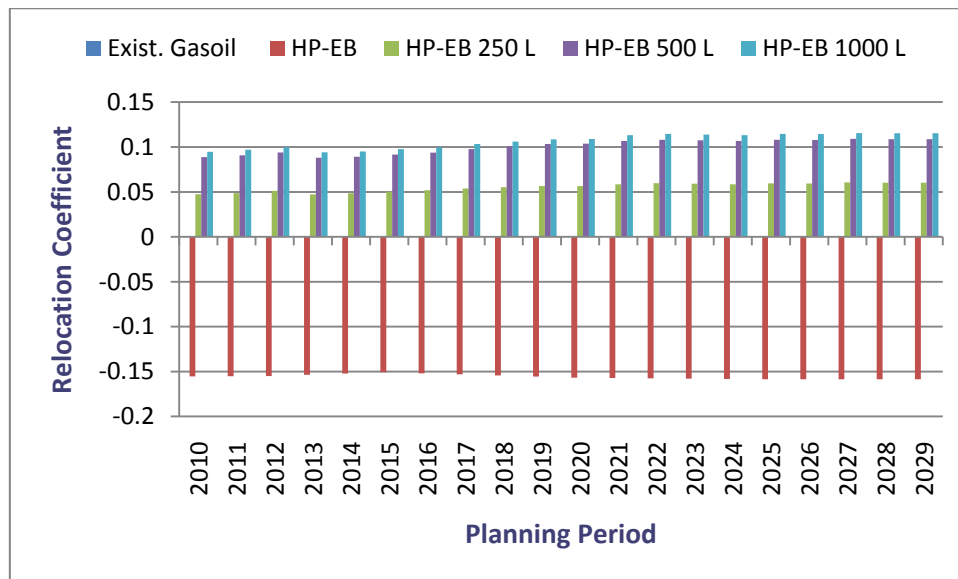


Figure 4.9 Relocation Coefficient using a 4.5 kW HP

As expected, the relocation coefficient for the reference project is equal to zero over the entire period, and this is because the heating system runs on gasoil and not on electricity. The negative values of the HP-EB without storage indicate an inappropriate solution, which makes the wind integration more difficult. When the storage tanks are used the relocation coefficients are positive, since the production and consumption of heat are decoupled. Thus, hot water can be stored during peak wind conditions and consumed when necessary.

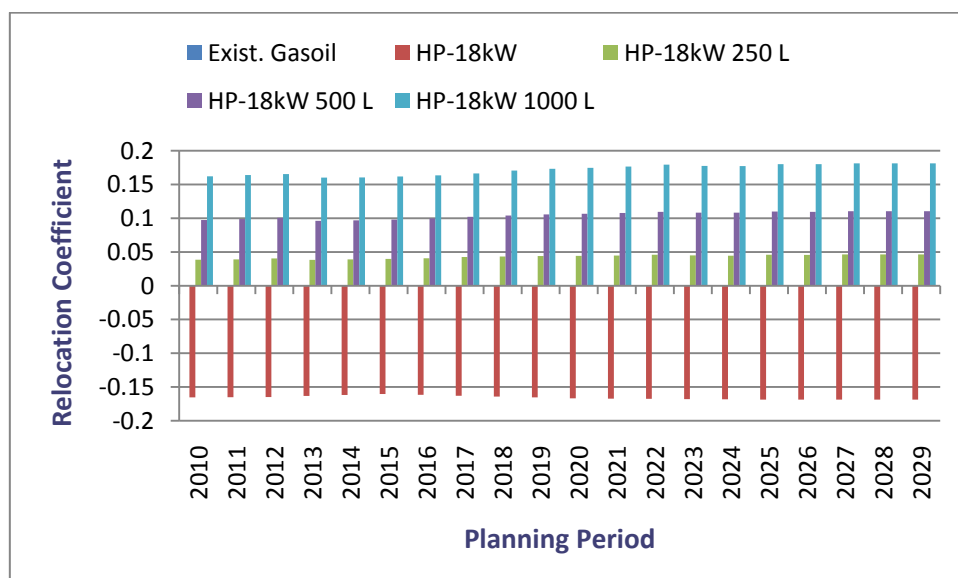


Figure 4.10 Relocation Coefficient using a 18 kW HP only

The impact on the amount of storage installed can be observed in Figure 4.9. It can be noticed that using 500 L of storage doubles the coefficient compared with the 250 L solution. However, increasing the capacity to 1000 L, the benefit over the 500 L solution is insignificant.

In order to bring the benefits of the 1000 L storage, a HP with increased power rating is necessary. For this purpose, the 4.5 kW HP with EB was replaced with an 18 kW HP only. The advantage of 1000 L storage can now be seen in Figure 4.10, where the relocation coefficient goes up to 0.18 compared with a maximum of 0.11 from the previous case, see Figure 4.9. The improvement compared with a 500 L storage tank is significant, due to the HP capability of getting cheap wind power stored in the tank with a faster conversion than before. It is interesting to notice that the relocation coefficient for the 250 L storage is smaller compared with the previous case, because of the fast charge times.

The house heat **Demand** remains constant over the time frame, 18,000 kWh per year independent on the adopted solution. The **Fuel Consumption** regarding the reference project will remain unchanged also, 22,500 kWh per year. The value could be determined by applying an efficiency of 0.8.

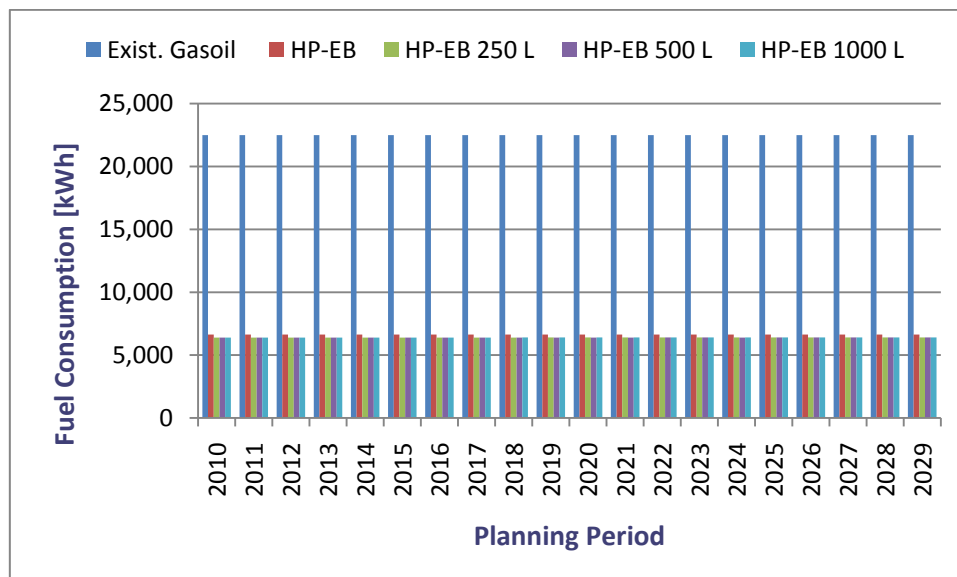


Figure 4.11 Fuel Consumption

From the above figure it is observed the increased efficiency of the HP. For the HP-EB, a 2.71 efficiency brings the fuel consumption down to approximate 6,600 kWh. For the HP-EB with storage the efficiency goes above 2.8 having a fuel consumption of approximate 6,400 kWh, regardless on water tank capacities.

The next figure emphasizes the **System-Wide Primary Energy Consumption**, which is proportional with the considered HP efficiencies. The primary energy consumption curve depends on the forecast of wind energy production for the chosen planning period. The magnitude is due to energy conversion and transportation efficiencies, considering also that there is a wind energy share which is not included in the graph.

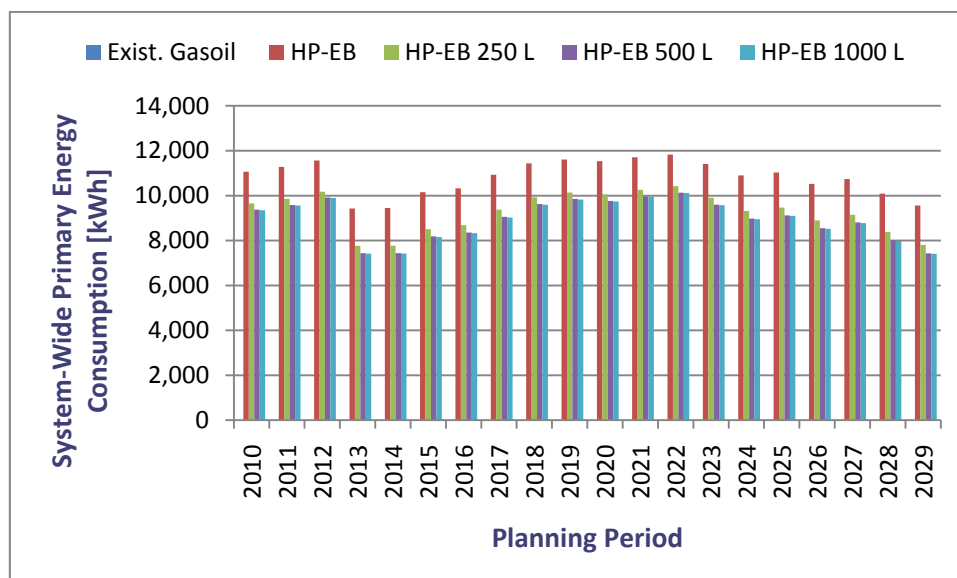
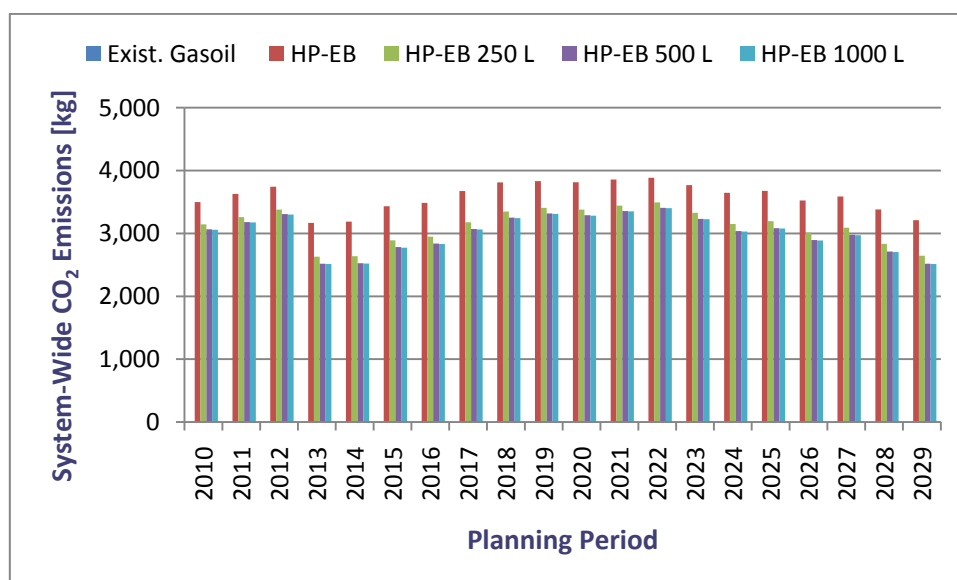


Figure 4.12 System-Wide Primary Energy Consumption

The **Local CO₂ Emissions** is a consequence of the fuel burned locally, and thus is applied only to the Existing Gasoil. Approximate 6,000 kg per year of carbon dioxide are released into the atmosphere when a gasoil boiler is used. For HP-EB the local CO₂ emissions are not present since the consumption is System-Wide based.

The below figure shows the **System-Wide CO₂ Emissions** with a similar shape as the previous graph due to the wind production forecast.

Figure 4.13 System-Wide CO₂ Emissions

Economic Fuel Cost is shown in the below graph, where the gasoil and electricity price projections were retrieved from the Danish Energy Agency and respectively NordPool. As can be seen, in 2029 the gasoil cost will be more than 16,000 DKK which represents an increase of approximately 70 percent compared to

2010. There is also an electricity price increase of around 50 percent, but still the HP-EB fuel cost is less than 3,000 DKK representing more than five times lower compared to the Exist. Gasoil.

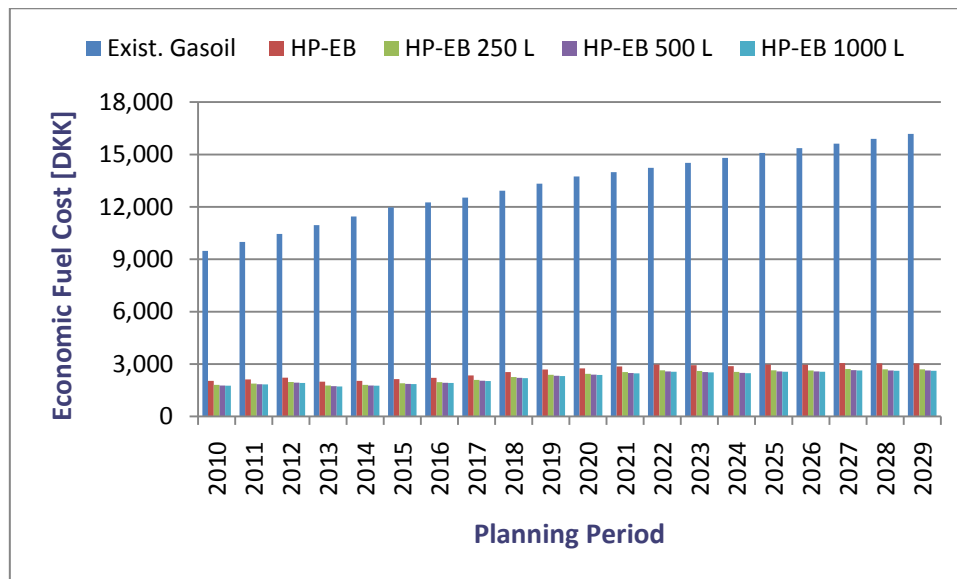


Figure 4.14 Economic Fuel Cost

The **Economic OM Cost** for the Exist. Gasoil is a fixed cost established at 800 DKK per year, while for the HP-EB it is assumed to be zero for the whole period. Summing the last two costs (fuel and OM), the **Economic Cost**, known also as **Real Cost** can be determined.

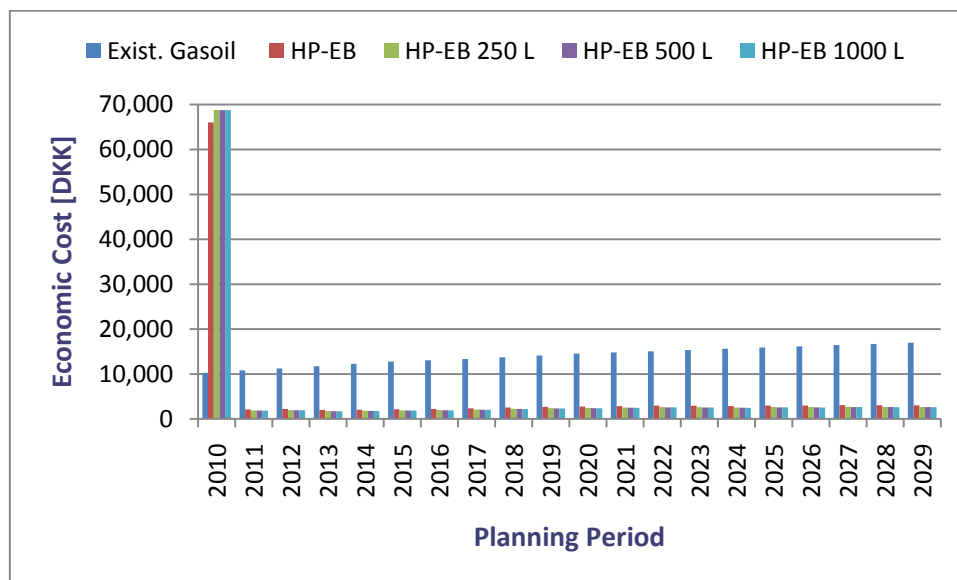


Figure 4.15 Economic Cost

It is observed from the above graph that 2010 includes the HP investment cost besides the fuel cost. However, the EB investment cost was not included. The water tanks cost is considered fixed at 3,000 DKK independent on capacity.

The **Levelized Economic Cost Per Unit Demand Sold** represents the Discounted Average Per Unit of Heat Demand, shown in the table below for all the considered solutions. From the socio-economic perspective this represents actually the price per unit of heat.

Table 4.5 Levelized Economic Cost

		Levelized Economic Cost Per Unit Demand Sold
Reference Project	Exist. Gasoil	0.7432
	HP-EB	0.4431
Alternative Projects	HP-EB 250 L	0.4278
	HP-EB 500 L	0.4253
	HP-EB 1000 L	0.4244

Table 4.5 it is also represented as graph in the below figure. It can be observed that the most disadvantageous solution is the Exist. Gasoil while the HP solutions are much more efficient.

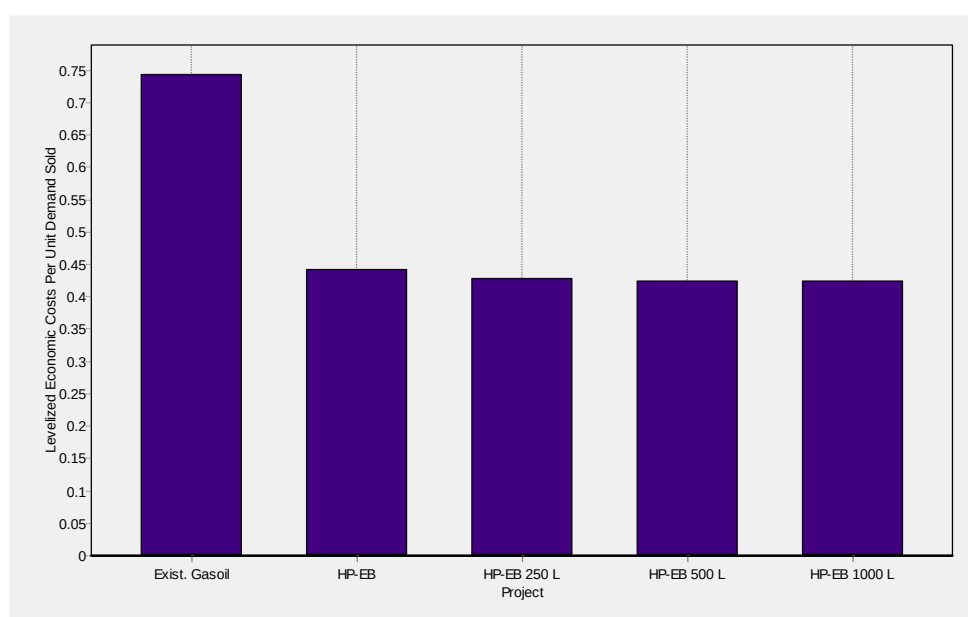


Figure 4.16 Levelized Economic Costs Per Unit Demand Sold [DKK]

The **Fiscal Cost** represents the cost paid to the Government. When people use gasoil for their private heating, the Government makes money from taxes and VAT and therefore the annual values are negatives. As shown in the below graph, every year the gasoil users give more money to the state. In 2010, a 12,000 DKK investment subsidy is included for all HP solutions. For the remaining years an approximate constant value is kept at around 6,300 DKK for HP in contrary with the Exist. Gasoil.

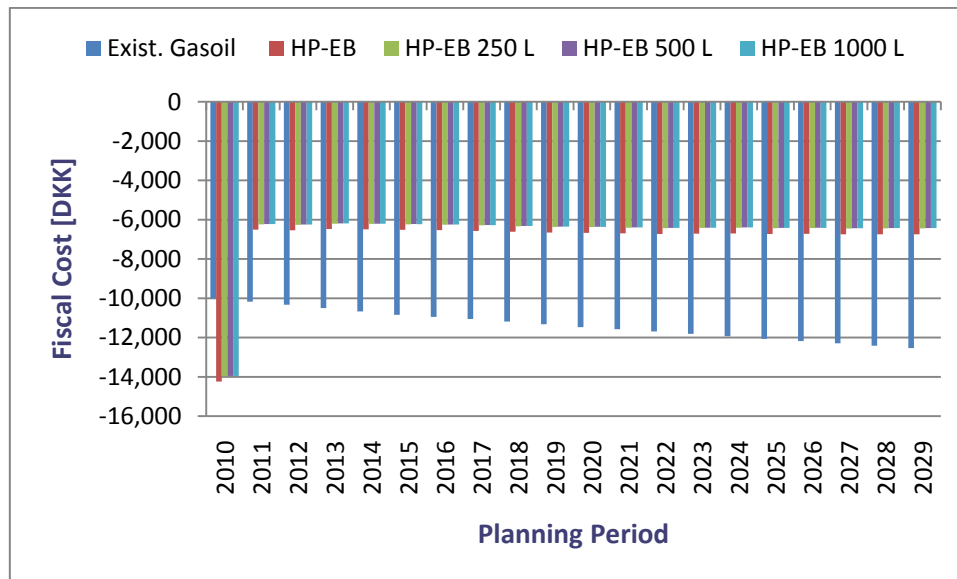


Figure 4.17 Fiscal Cost

The **Financial Cost** represents the sum between the **Real Cost** and the **Fiscal Cost**, as it is outlined in the below graph.

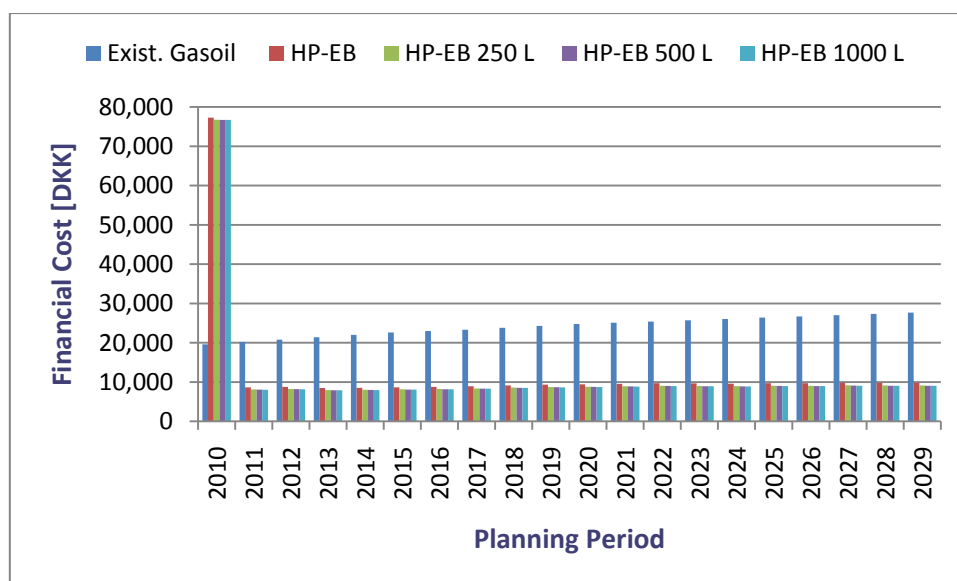


Figure 4.18 Financial Cost

It can be noticed that financial cost for the HP-EB without and with storage tends to keep a balance over the next 20 years, whereas the Exist. Gasoil is more and more expensive as the time goes.

The level of storage over a week (first week of January) can be extracted from COMPOSE, as can be seen in the next three figures. Important differences can be observed for different storage capacities. In the case of 250 L, the small volume brings the curve shape with many saturation points and fast transients due to its size. Having a 500 L tank, unlike previously, there are fewer hours where the full capacity is used and the transients are slower. Regarding the 1000 L, its shape is similar with the 500 L case; there are only two

periods in the week when the storage capacity goes above 25 kWh. No saturation points are noticed and this is due to the HP output power limitation.

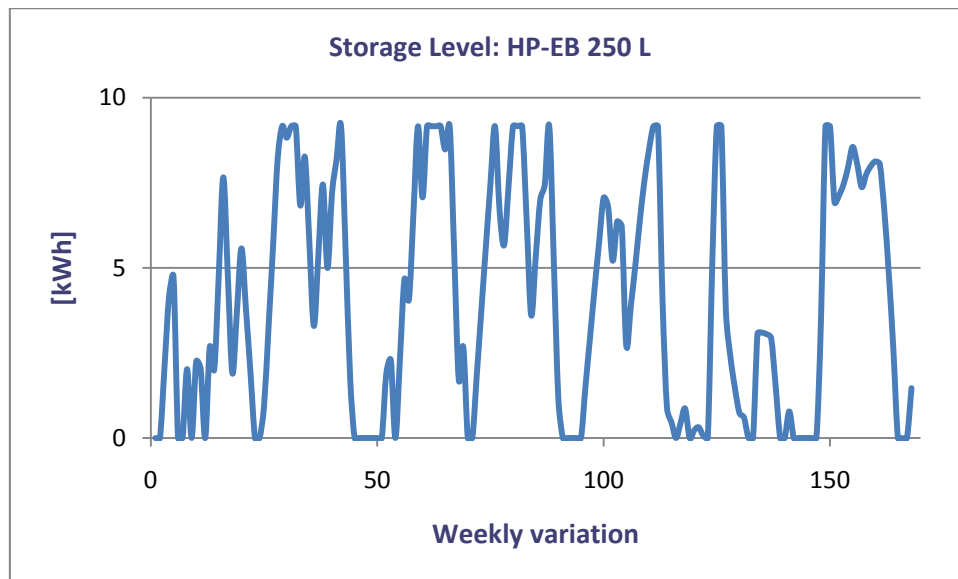


Figure 4.19 Stored energy for 250 L tank water using a 4.5 kW HP

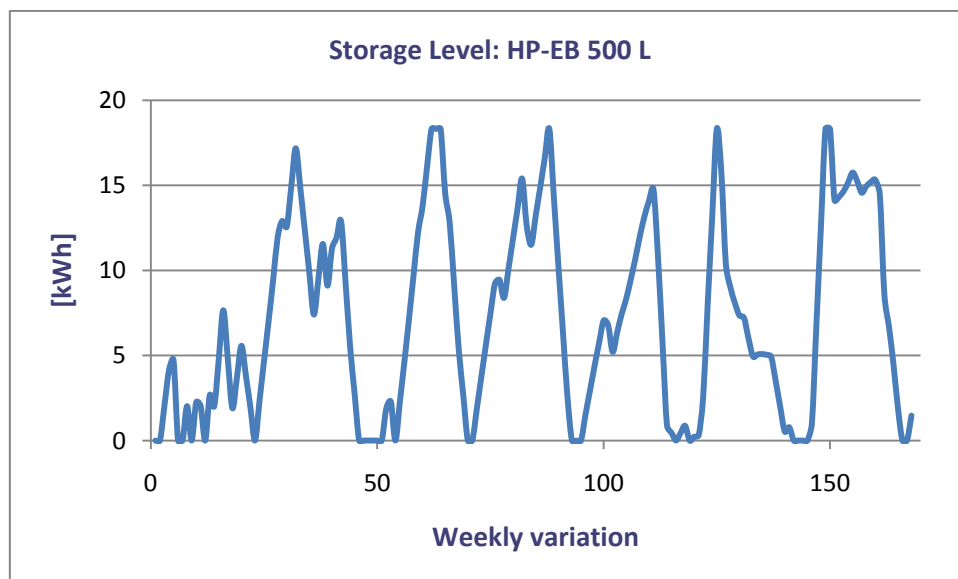


Figure 4.20 Stored energy for 500 L tank water using a 4.5 kW HP

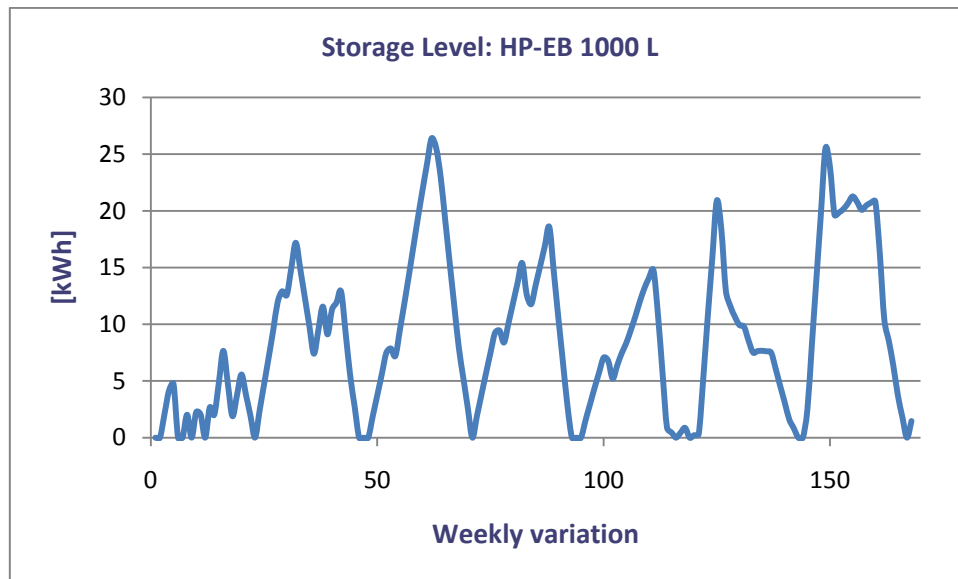


Figure 4.21 Stored energy for 1000 L tank water using a 4.5 kW HP

Replacing the considered 4.5 kW HP-EB with an 18 kW HP only, the weekly stored energy variation is shown in the following figures. It can be noticed that having an increased size HP, the storage is better used for all capacities. The 250 L storage weekly variation shows faster and increased number of transients than before, the tank being fully charged in a very short time due to the HP size.

The important benefit can be seen in the case of 1000 L, where the 18 kW HP is able to create several full charges during a week (see Figure 4.24). This was not possible with the 4.5kW HP-EB, the storage tank doesn't reach its maximum storage capacity over a week.

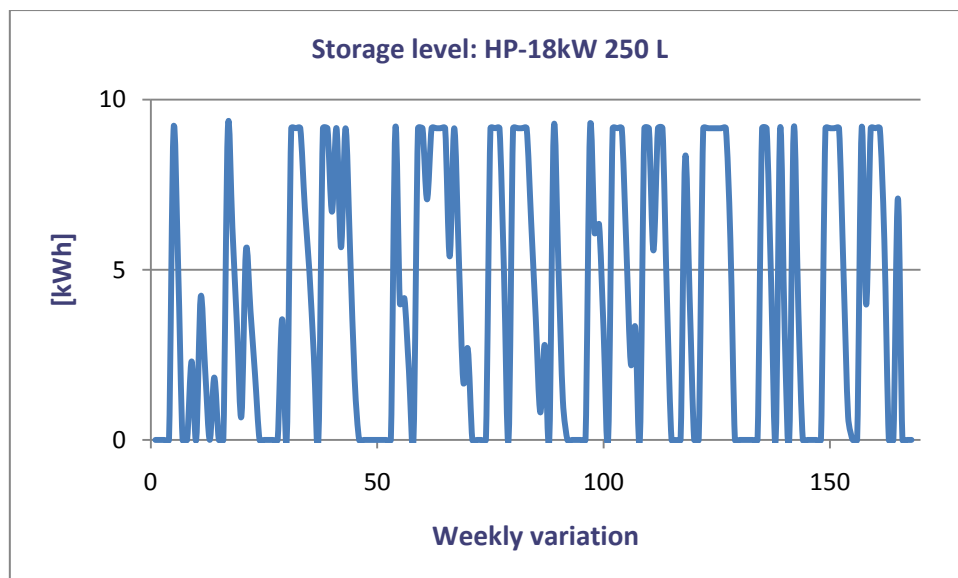


Figure 4.22 Stored energy for 250 L tank water using a 18 kW HP

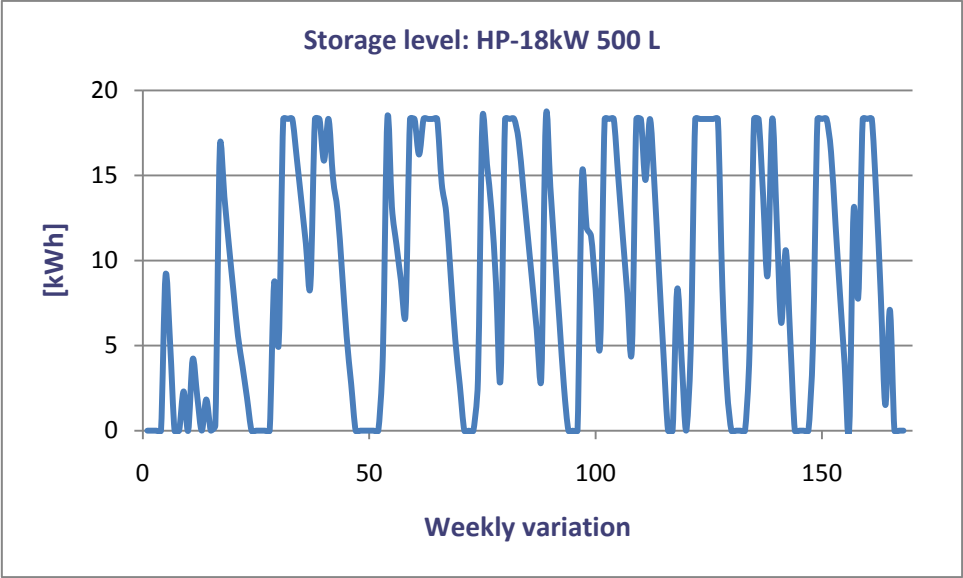


Figure 4.23 Stored energy for 500 L tank water using a 18 kW HP

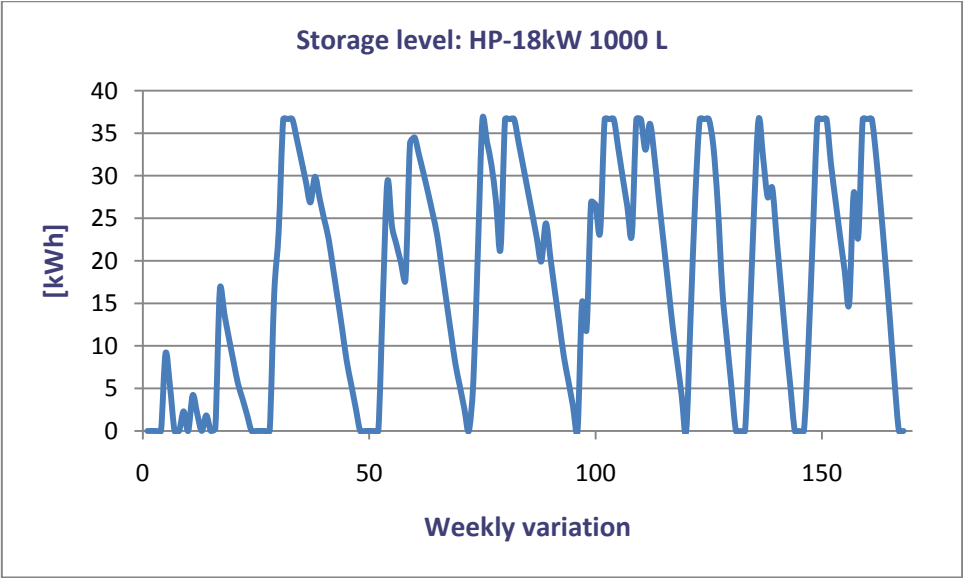


Figure 4.24 Stored energy for 1000 L tank water using a 18 kW HP

5 Conclusions and future work

To reduce the fossil fuel consumption from the existing gasoil based heating systems of the detached houses, several electrical HP solutions were discussed in the report. The usage of the HP is controlled considering the operation as part of the future smart grid, making use of the family smart meter to optimize the electricity cost. The additional hot water storage tanks were used to help the integration of wind power, increase the usage of it for the national consumption and reduce the CO₂ emissions.

Two major case studies were considered and modelled in COMPOSE: the Existing Gasoil and the New Heat Pump. An air to water Sanyo 4.5 kW HP was selected to operate with an additional electric boiler of 6 kW over a 20 years planning period.

COMPOSE calculations shows several benefits of coupling the Heat Pump with heat storage. As a result of comparison between the four alternatives with the reference project (existing Gasoil), the optimal solution in terms of cost, wind integration and environmental impact turned out to be the HP-EB with a storage tank of 500 L.

Furthermore, the HP-EB replacement with an 18 kW HP only was also considered as a better option for higher capacity storage tanks. In this case the 1000 L storage tank increases the relocation coefficient to 0.18 compared with 0.11 in the case of 500 L. Therefore, the analyze shows that an increased storage tank capacity requires an increased HP nominal power.

As future work the following points can be considered:

- Modelling of different HP sizes and storage capacities to fit different households;
- Perform a risk analyze for these solutions in COMPOSE;
- HP optimization on a weekly basis;
- In depth analyzes of HP only solutions with increased size compared with smaller size HP using additional EB.

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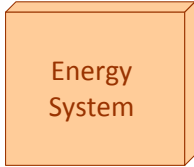
Annexe X

Energy consumption of hot tap water hour by hour for a weekday and weekend day

Hot water (kWh) weekday			Hot water (kWh) weekend day		
1:00 AM		0.05	1:00 AM		0.05
2:00 AM		0.05	2:00 AM		0.05
3:00 AM		0.05	3:00 AM		0.05
4:00 AM		0.05	4:00 AM		0.05
5:00 AM		0.05	5:00 AM		0.05
6:00 AM		1.30	6:00 AM		0.05
7:00 AM		2.29	7:00 AM		1.30
8:00 AM	12:00 AM		8:00 AM		3.38
9:00 AM	12:00 AM		9:00 AM		0.05
10:00 AM	12:00 AM		10:00 AM		0.05
11:00 AM	12:00 AM		11:00 AM		0.05
12:00 PM	12:00 AM		12:00 PM		0.05
1:00 PM	12:00 AM		1:00 PM		1.04
2:00 PM	12:00 AM		2:00 PM		1.04
3:00 PM		0.05	3:00 PM		0.05
4:00 PM		0.05	4:00 PM		0.05
5:00 PM		0.05	5:00 PM		0.05
6:00 PM		0.99	6:00 PM		0.05
7:00 PM		0.99	7:00 PM		1.04
8:00 PM		0.87	8:00 PM		1.04
9:00 PM		0.87	9:00 PM		0.87
10:00 PM		0.05	10:00 PM		0.87
11:00 PM		0.05	11:00 PM		0.05
12:00 AM		0.05	12:00 AM		0.05

Annexe Y

Common features to both projects



In COMPOSE, the Energy System is divided in three main parts:

1. **Intermittent Electricity Production** with an Annual Profile called *Denmark Wind Production* and Hourly Profile, *Wind Denmark 2009*. The annual profile was represented on the basis of DEA projections while the hourly profile using statistical data from Energinet.dk.

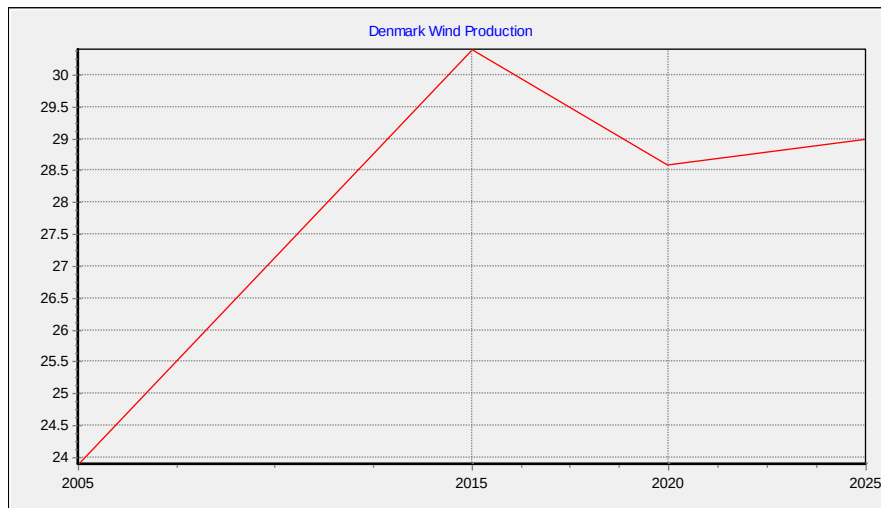


Figure 1 Annual Profile of Wind Production

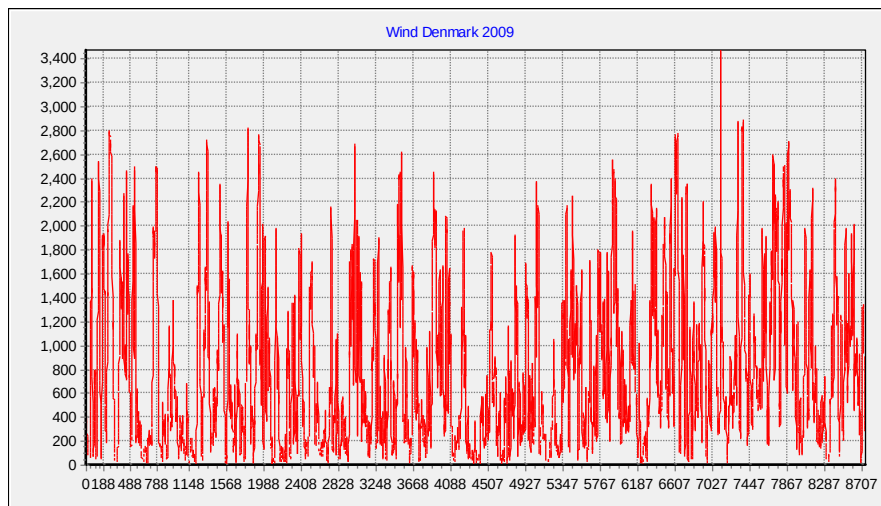


Figure 2 Hourly Profile of Wind in 2009

2. **Electricity Demand** with an Annual Profile called *Denmark Electricity Demand* and Hourly Profile, *Net electricity consumption Denmark 2009*. The annual profile was outlined based on the DEA forecasts while the hourly profile based on statistical data retrieved from Energinet.dk.

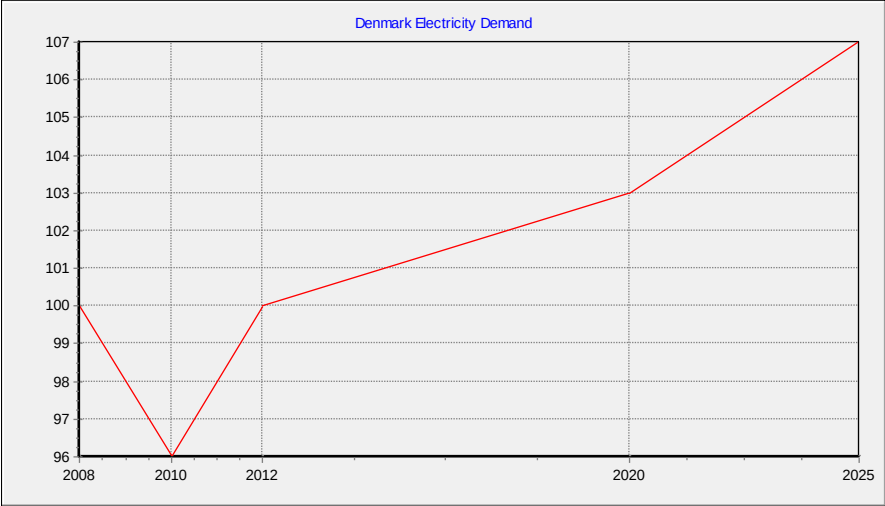


Figure 3 Annual Profile of Electricity Demand

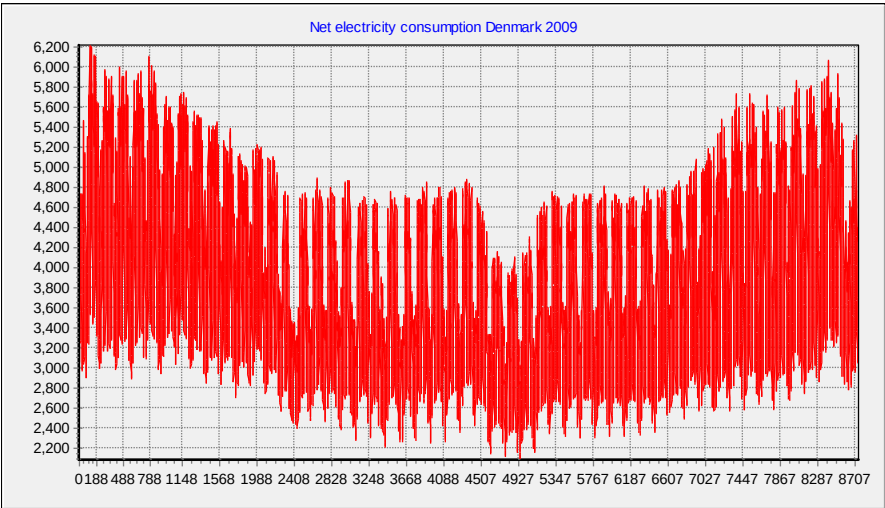


Figure 4 Hourly Profile of Net Electricity Consumption in 2009

3. **Marginal Dispatch** with Off-Shore Wind being in the Lower Threshold. The selection was made based on the Short-term Marginal Production Cost and wind proved to be the lowest.



The assumptions used are outlined in the following table.

Table 1 General Assumptions

Planning Period [years]	20
Real Economic Discount Rate	0.06
Real Financial Discount Rate	0.15
VAT Rate	0.25

Reference Project: Existing Gasoil



In COMPOSE, the Fuel information can be found under the name *Gasoil Household Heating*.

The Local CO₂ Emissions Factor is set at 0.2664 kg per kWh.

The Fuel Cost Benefit is divided in 5 categories as in the below table.

Table 2 Fuel Cost Benefit Assumptions

		Assumptions	Annual Profile
Economic Cost	<i>Gasoil w/TH ENS Projection</i>	0.3906 DKK/kWh	<i>Diesel Gasoil ENS CIF</i>
	<i>CO2 Credits ENS</i>	0.115 DKK/kg	<i>CO2 Credits</i>
Fiscal Cost [DKK/kWh]	<i>Gasoil Mineralolie-afgift</i>	0.203928916	<i>Default Annual Profile</i>
	<i>Gasoil CO2-afgift</i>	0.04096432	<i>Default Annual Profile</i>
	<i>Gasoil Svovl-afgift</i>	0.001041466	<i>Default Annual Profile</i>

Both Annual Profiles presented below follows the latest socio-economic assumptions from DEA.

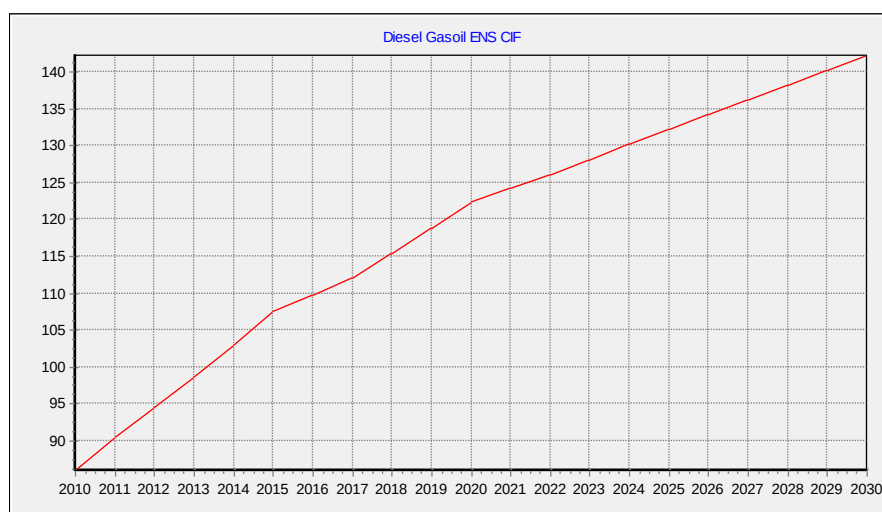


Figure 5 Annual Profile for Gasoil Cost

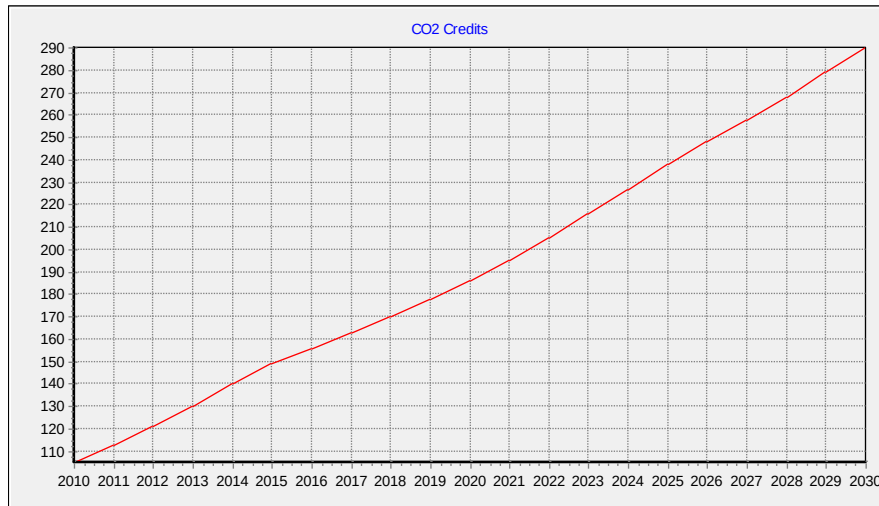
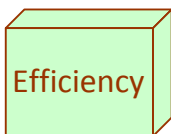


Figure 6 Annual Profile for CO₂ Cost



In COMPOSE, the Cost Benefit for the reference project is found under the name *Gasoil-boiler Fixed OM*. This is an **Economic Cost** whose value was set at 800 DKK per year. This value remains constant throughout the planning period.



The efficiency is found in COMPOSE under the name of *Gasoil Boiler* having a value of 0.8 which remains constant over the planning period.

Alternative Project: New Heat Pump

1. Heat Pump: Sanyo 4.5 kW COP HP LV



In COMPOSE, the Fuel information can be found under the name *Electricity Spot Household*.

The Local CO₂ Emissions Factor is set at 0 kg per kWh.

The Fuel Cost Benefit is divided in 6 categories as in the below table.

Table 3 Fuel Cost Benefit Assumptions

		Assumptions	Annual Profile	Hourly Profile
Economic Cost	Electricity ENS Projection	0.301 DKK/kWh	NordPool ENS Un-Weighed	Spot Market West Denmark 2009
	CO2 Credits ENS	0.115 DKK/kg	CO2 Credits	Default Hourly Profile
Fiscal Cost [DKK/kWh]	Electricity El-afgift	0.619	Default Annual Profile	Default Hourly Profile
	Electricity CO2-afgift	0.062	Default Annual Profile	Default Hourly Profile
	Electricity Distributions-afgift	0.04	Default Annual Profile	Default Hourly Profile
Financial Cost [DKK/kWh]	Electricity TH Household	0.24	Default Annual Profile	Default Hourly Profile

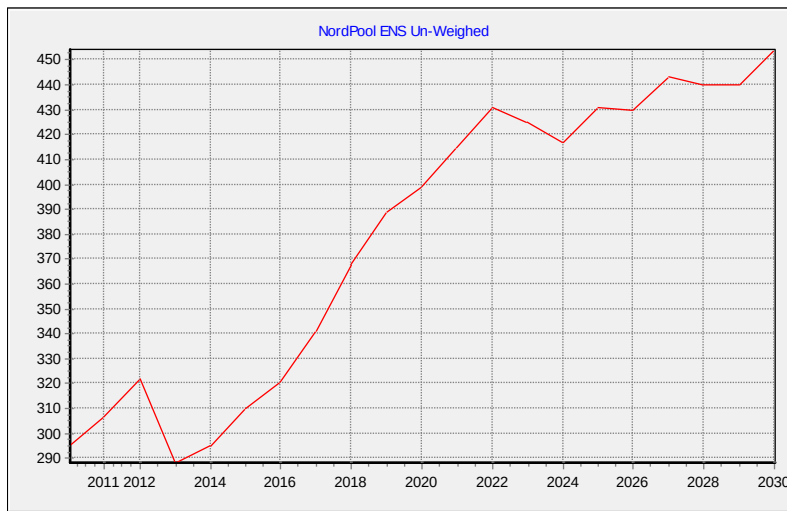


Figure 7 Annual Profile for Electricity Price

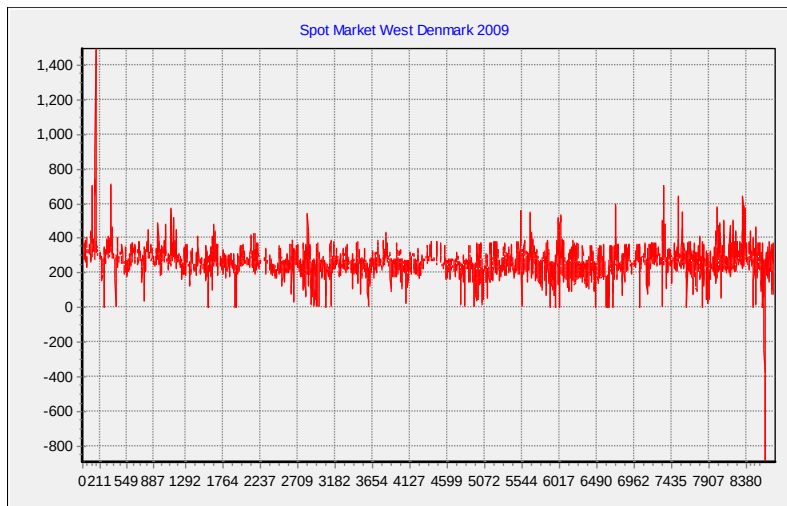
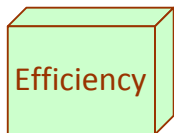


Figure 8 Hourly Profile of Electricity Price in West Denmark 2009



The hourly profile of the Heat Pump efficiency is found in COMPOSE under the name *Sanyo 4.5 kW COP*.

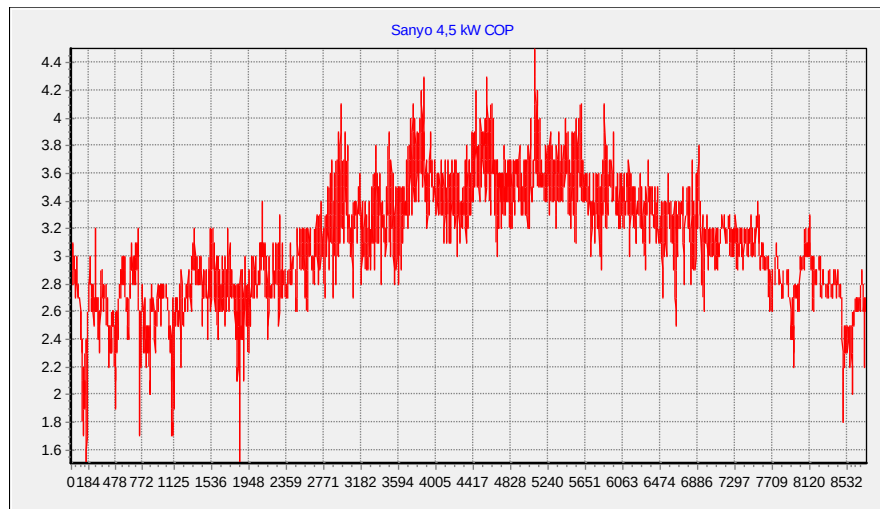


Figure 9 Hourly profile of the Heat Pump efficiency



The main cost benefits are outlined in the below table.

Table 4 Cost Benefit Assumptions

		Assumptions
Economic Cost	<i>Investment Sanyo 4,5 kW CO2 HP</i>	14,222.22 DKK/kW
	<i>Investment Storage Tank</i>	3000 DKK
Fiscal Cost [DKK]	<i>HP Investment Subsidy</i>	-12,000