Treatment of Scandinavian District Energy Systems in LEED

Energy Models for LEED EA credit 1

Sweden Green Building Council * Drottninggatan 33 * Box 161 32 * 103 23 Stockholm
info@sgbc.se * www.sgbc.se

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1 Overview

In general, most thermal district energy systems (DES) are designed for high levels of energy efficiency and to use less environmentally damaging energy sources. However, the impacts of a district energy system must be taken into account when calculating a building's energy performance. The intent of the USGBC's document entitled "Treatment of District or Campus Thermal Energy in LEED V2 and LEED 2009 – Design & Construction" is to properly account for the performance of the district or campus energy system connected to a LEED project.

Since the standard energy modeling methods for LEED are based on ASHRAE Standard 90.1 which bases performance on improvements in energy cost, both the project's energy performance and the market prices of the energy sources affect the final result.

- It is common for the DES central plants to use energy sources that are not traded on the open market. Trades are often done business to business on a local market and therefore the fuels only have market price that is applicable in the immediate surroundings.
- The investment in the infrastructure makes it possible to use inexpensive fuels such as separated municipal waste[1]. The fuel cost can be negative but requires expensive investments (100's of million dollars), for example in flue gas cleaning systems.
- District heating and cooling is traded on an open market in northern Europe. Developers of commercial premises as well as single family owners choose between different heating alternatives where district heating compete with heat pumps as well as other alternatives. The variable cost for the fuels needed to generate the electricity for heat pumps is not required for Energy & Atmosphere credit 1 while the cost for fuels used in district heating is.

These are the reasons why a proposal for an alternative method to determine the energy the DES unit price needs to be accepted for applicable projects.

This proposal builds on the Option 2 compliance path for EAc1 in the document "Treatment of District or Campus Thermal Energy in LEED V2 and LEED 2009 – Design & Construction."

In order to prove the efficiency of the DES and the use of sources of energy that are environmentally friendly, the Total Primary Energy Factor (PEF) and the Carbon Dioxide Emission Equivalents (CO_2e) for the systems can be applied to the DES. The PEF is the amount of primary energy, energy resources from the cradle, needed to provide one unit of useful energy to the consumer. The CO_2e is the amount of greenhouse gases that are released to the atmosphere. The CO_2e includes emissions from combustion and the life cycle upstream impact for the fuel. The PEF and CO_2e can also be used to proportionally assign cost to the different DES using PEF and CO_2e performance when compared to the fossil fuel alternative in the different systems. In such a way, the PEF and CO_2e can be

[1] The waste management in most municipalities in Sweden is well functioning so that most of the waste is reused, recycled and the rest is energy-recycled in combined heat and power plants. Landfill is forbidden for most waste fractions since 2002.

used to determine substitute fuel prices in order to complete the LEED requirements for Energy & Atmosphere credit 1 as it pertains to a project connected to DES.

2 Purpose

The method in this report is the suggested way of handling very large, complex Scandinavian DES networks in LEED. Sweden GBC advocates this method with the reservation that this method will only be valid for LEED 2009 – Design & Construction and not for next version of LEED (LEED 2012). Sweden GBC advocates a different method for a long-term solution for District Energy Systems described in another document.

3 Calculating the Primary Energy Factor for District Energy

DES networks in Scandinavia commonly use combined heat and power (CHP) plants in their large scale networks. The PEF equation for a CHP that describes how much primary energy (bottom of the pyramid in **Figure 1**) that is used for one unit of energy delivered to the end user can be seen in **Equation 1**. This is a commonly used method used in international environmental product declarations (EPD) and is called the "Alternative Generation Method" (AGM). It promotes the use on combined heat and power because both the heat and power gets the benefits of the saved fuel due to the use CHP compared to separate production of heat and power. The method is also use in the EU-directive that determines the definition of high efficient combined heat and power.

The industry in Sweden has chosen the Alternative Generation Method to allocate the environmental burden between heat and electricity produced in a Combined Heat and Power plant when calculating both Total Primary Energy Factors and the CO_2 emission factor.

For energy sources without market prices, this calculation will replace the default methods of determining system efficiency described in the Virtual Plant Modeling Guidance, Appendix C in the USGBC's document entitled "Treatment of District or Campus Thermal Energy in LEED V2 and LEED 2009 – Design & Construction."

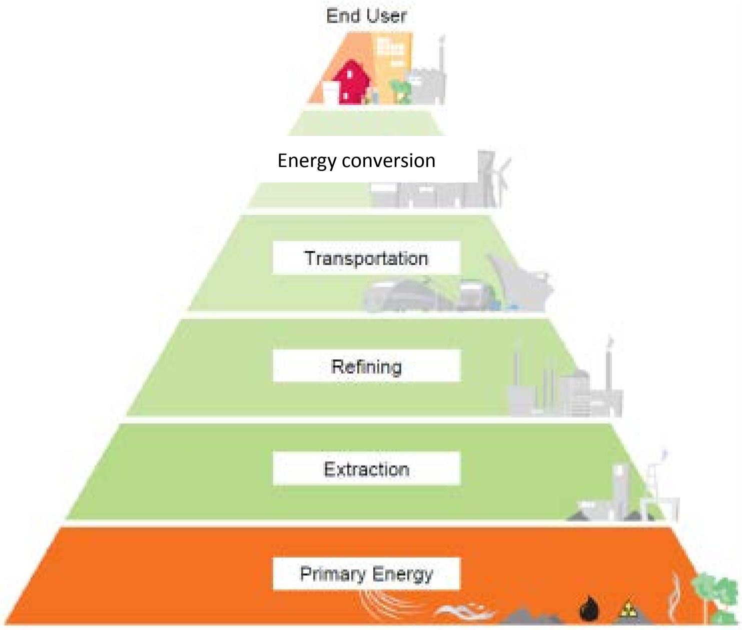

Figure 1. Primary Energy Pyramid – Primary energy, PE, is the energy of the energy resources taken from the nature before any transformation (bottom of the pyramid). The PE is then extracted, refined and transported, in different steps on the way to the end user. The primary energy factor is the factor that describes how much PE is being used for one unit of energy consumed by the end user.

4 Equation for calculating the Primary Energy Factor (PEF), including CHP allocation according to CEN Standard 15316-4-5[2]

4.1 District heating

Equation 1

$$PEF_{dh} = \frac{\sum_{i=1}^{n} E_{F,HOB(i)} * PEF_{HOB(i)} + \sum_{i=1}^{n} \alpha_{h,i} * E_{F,CHP(i)} * PEF_{CHP(i)}}{\sum_{j=1}^{n} Q_{del,j}}$$

PEF_{dh} = total primary energy factor for district heating

$E_{F,HOB(i)}$ = energy in fuel *i* used for heat production in heat only boilers (HOB), using lower heating values (LHV)

[2] Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 4-5: Space heating generation systems, the performance and quality of district heating and large volume systems.

$PEF_{HOB(i)}$ = the primary energy factor for fuel *i* used in heat only boilers (HOB), factors are found in **Table 5** in **Appendix A**

$\alpha_{h,i}$ = allocation factor for fuel *i*, i.e. the proportion of the used fuel to the CHP which will be allocated to the heat production (note: the produced heat and not the delivered heat). The rest is allocated to electricity, ($1-a_{h,i}$). The calculation is shown in **Equation 2**

$E_{F,CHP(i)}$ = total energy input from fuel i to CHP plant

$PEF_{CHP(i)}$ = the primary energy factor for fuel *i* used in CHP power plants, factors are found **Table 5** in **Appendix A**

$\sum_{j=1}^{n} Q_{del,j}$ = the delivered district heating to all customers in the district heating network. **Note**: delivered district heating means that distribution losses are taken into account.

The calculation of the allocation factor α is shown in **Equation 2**

Equation 2

$$\alpha_{h,i} = \frac{\frac{E_{h,tot}}{\eta_{h,i}}}{\frac{E_{h,tot}}{\eta_{h,i}} + \frac{E_{el,tot}}{\eta_{p,i}}}$$

$\alpha_{h,i}$ = allocation factor for fuel i, the part of the fuel and thus the environmental burden that should be allocated to the produced heat

$E_{h,tot}$ = Total amount of produced heat in the specific combined heat and power plant

$E_{el,tot}$ = Total amount of produced electricity, without deduction of auxiliary electricity, in the specific combined heat and power plant

$\eta_{h,i}$ = alternative production efficiency for heat production only with fuel *i*

$\eta_{p,i}$ = alternative production efficiency for electricity production only with fuel *i*

In **section 9.1** a calculation example can be seen.

4.2 District cooling

District cooling can be generated in various ways. Four main alternatives are presented below;

1. Free cooling

2. By using district heating or steam to produce cooling in absorption chillers[3].
3. With heat pumps using both the output of heat and cooling or
4. With chillers (inverted heat pumps),

Depending on how the district cooling is produced the calculation of the PEF varies. In all cases the PEF for the cooling can be computed by using **Equation 3** below. The different calculation procedures for the different cases are described below. In complex district cooling networks all cases can be used.

Case 1

If the temperature of the cooling source is low so that chillers are not necessary for decreasing the temperature (i.e. free cooling) the only electricity input needed is the auxiliary electricity for circulation of the cold water in the DES. The amount of electricity and its corresponding PEF is used in **Equation 3**.

Case 2

District heating is the input energy to the absorption chiller. The calculation is done by using **Equation 3** after first calculated the PEF for district heating in **Equation 1**. In best case the monthly values of the PEF for district heating should be used as input. This is due to that the cooling in many cases is produced seasonally with a heat production not representative for the whole year. This requires more detailed statistics from the supplier. If not available, yearly average can be used as a second best alternative. The amount of auxiliary electricity for circulation and corresponding PEF is also used in **Equation 3**.

Case 3

When district cooling is produced with a heat pump that uses both the heat and the cool at the same time the primary energy input has to be divided between the two energy products. This will be done by dividing the input electrical energy in proportion to the output energy of heat and cooling respectively. This is called energy allocation and is recommended in the ISO 14044 for LCA. The allocation should be derived from statistics from the DES supplier. Note that only electrical energy used to produce heat and cooling at the same time should be allocated. The amount of auxiliary electricity for circulation and corresponding PEF is also used in **Equation 3**. Approximately 2/5 of the input electrical energy is allocated to cooling and 3/5 to the heat. When the allocation is made the allocated electrical energy to the cooling production is used in **Equation 3**. There are however cases when all energy can be allocated to either the heat or the cooling. This requires more detailed information from the supplier and is described below;

Case 3a

All electrical energy is allocated to the produced cooling. This should be done when the only purpose of driving the heat pump is for cooling production. The heat is then a waste product which also sometimes decreases the COP for the produced cooling. Typically this is done during summer in networks which has other heat production alternatives that covers the heat demand.

Case 3b

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[3] District heating can be used to produce district cooling using absorptions chillers.

All electrical energy is allocated to the produced heat. This should be done when the heat source for the heat pump is the return flow of the district cooling instead of colder free heat source alternatives. In this case the heat is produced with a higher efficiency than with the alternatives and as result of the heat production cooling is produced. The cooling is free from primary energy burden.

Case 4

The calculations are straight forward using **Equation 3**. The input "fuel" is electrical energy and the primary energy input is calculated by multiplying the primary energy factor for electrical energy with the amount of electrical energy. The amount of parasitic electricity for circulation and corresponding PEF is also used in **Equation 3**.

Equation 3

$$PEF_{cooling} = \frac{\beta \cdot Energy_{el} * PEF_{el} + \sum_i \left(Energy_{heat,i} * PEF_{heat,i}\right)}{Delivered\ cooling}$$

$PEF_{cooling}$	The Primary Energy Factor for district cooling
β	The energy alloction factor is used to allocate the amount of electricity used in heat pumps with heating and cooling production at the same time. β = amount cooling / (amount cooling + amount heat).
$Energy_{el}$	The amount of electricity used to produce the cooling (including both the auxiliary electricity for circulation of the cold water in the DES and the electric energy needed for the heat pump).
PEF_{el}	Primary energy factor for electricity.
$Energy_{heat}$	The amount of heat energy used to produce cooling in absorption chillers. In best case monthly amounts are used and summarised for one year (zero for Case 1 and 2)
$PEF_{heat,i}$	Primary energy factor for the district heating used to generate cooling. In best case monthly values are used.
Delivered Cooling	The quantity of district cooling delivered from the process to the end user. **Note:** delivered cooling means that distribution losses are taken into account.

In **section 9.2** a calculation example can be seen.

5 Calculating the Carbon Dioxide Emissions for District Energy

The climate impact is measured by using Carbon Dioxide Emission Equivalents (CO_2e). CO_2e measures total greenhouse gas emission factors.

Greenhouse gas coefficient CO_2e – When calculating the carbon dioxide equivalents, (CO_2e) the greenhouse gas (GHG) emissions are summarized using the global warming potential (GWP) for each greenhouse gas. The most common used factors are the GWP_{100} factors, (the impact during 100 years compared to CO_2). The GHG summarized in this case are CO_2 (carbon dioxide); CH_4 (methane) and N_2O (nitrous oxide).

Total emission factors include precombustion, where "total" accounts for direct emissions from;

1) Combustion, and

2) Life cycle upstream impact for the fuel used at the district energy plant.

The life cycle perspective means that the emissions that occur when the fuels are extracted, transported and refined are included.

The total emission factors can be found in **Table 6** in **Appendix A**. **Error! Reference source not found.**

The total greenhouse gas emission factors for each fuel should in first case be based on country specific indexes and if such indexes have not been developed international default values can be used. There are international default values for combustion emissions and upstream emissions can be taken from life cycle assessment data bases.

The Intergovernmental Panel on Climate Change (IPCC) has set up guidelines for national greenhouse gas inventories[4].

The method used to allocate Carbon Dioxide Emissions for Combined Heat and Power is the Alternative Generation Method that can be found in the Product Category Rules (PCR[5]) which is the same method as in the EU Combined Heat and Power Directive (CHPD[6]).

The Alternative Generation Method is an allocation method that allocates the actual emissions from the CHP between electricity and heat (i.e. the emissions are addable). This method aims at describing the environmental properties of a life cycle and its subsystems. Both heat and power gets the benefit from CHP fuel savings compared to separate production of heat and power.

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[4] 2006 IPCC Guidelines for National Greenhouse Gas Inventories.
[5] PCR = Product Category Rules. PCR CPC 17 Version 1.1, 2007-10-31. The PCR-document is in compliance with GENERAL PROGRAMME INSTRUCTIONS for environmental product declarations, EPD published by The International EPD Consortium (IEC), as a part of the EPD®system.
[6] CHPD = Combined Heat and Power Directive. Directive 2004/8/EEC on the promotion of cogeneration based on useful heat demand in the internal energy market and amending Directive 92/42/EEC

The industry in Sweden has chosen the Alternative Generation Method to allocate the environmental burden between heat and electricity produced in a Combined Heat and Power plant when calculating the greenhouse gases.

6 Equation for calculating the Carbon Dioxide Emissions Equivalents (CO_2e)

6.1 District Heating

The equation for the Alternative Generation Method is shown in **Equation 2**Error! Reference source not found.. Allocation is done for each fuel used in the CHP plant. An example on how to calculate is shown in section 9.1.

Greenhouse gases emission factor

In **Equation 4** the total greenhouse gas emission factor is calculated for the district heating delivered to the customers. The method used is the Alternative Generation Method.

Equation 4

$$\kappa_{dh} = \frac{\sum_{i=1}^{n} E_{F,HOB(i)} * \kappa_{F,HOB(i)} + \sum_{i=1}^{n} \alpha_{h,i} * E_{F,CHP(i)} * \kappa_{F,CHP(i)}}{\sum_{j=1}^{n} Q_{del,j}}$$

K_{dh} = total greenhouse gas emission factor for district heating

$E_{F,HOB(i)}$ = energy in fuel i used for heat production in heat only boilers (HOB)

$K_{F,HOB(i)}$ = total greenhouse gas emission factor for the fuel i used in heat only boilers (HOB)

$\alpha_{h,i}$ = allocation factor for fuel i, i.e. the proportion of the used fuel to the CHP which will be allocated to the heat production (note: the produced heat and not the delivered heat). The rest is allocated to electricity, ($1-\alpha_{h,i}$). Factor α, see **Equation 2**.

$E_{F,CHP(i)}$ = total energy input from fuel i to CHP plant

$K_{F,CHP(i)}$ = total greenhouse gas emission factor for the fuel i used in CHP

$\sum_{j=1}^{n} Q_{del,j}$ = the delivered district heating to all customers in the district heating network. **Note**: delivered district heating means that distribution losses are taken into account.

An example on how to calculate the greenhouse gas emission factor is shown in the section 9.1.

6.2 District Cooling

As mentioned earlier in the document, district cooling can be generated in various ways and the four main alternatives are;

1. Free cooling
2. By using district heating or steam to produce cooling in absorption chillers[7].
3. With heat pumps using both the output of heat and cooling or
4. With chillers (inverted heat pumps),

Depending on how the district cooling is produced the calculation of the CO_2e varies. In case 1, 3 and 4 the CO_2e for the cooling can be computed by using **Equation 5**. To calculate the CO_2e for case 2 – Cooling generated by using district heating in absorption chillers, **Equation 3** and **Equation 4** has to be used to allocate the environmental burden to the heat used for cooling. When that is performed **Equation 5** can be used to calculate the greenhouse gas emissions.

The different calculation procedures for cases four cases are described in section 4.2. In complex district cooling networks all cases can be used.

Equation 5 $$\kappa_{dc} = \frac{\beta \cdot Energy_{el} * \kappa_{el} + \sum_i (Energy_{heat,i} * K_{dh,i})}{Delivered\ cooling}$$

K_{dc}	Total greenhouse gas emission factor for district cooling
β	The energy alloction factor is used to allocate the amount of electricity used in heat pumps with heating and cooling production at the same time. β = amount cooling / (amount cooling + amount heat).
$Energy_{el}$	The amount of electricity used to produce the cooling (including both the auxiliary electricity for circulation of the cold water in the DES and the electric energy needed for the heat pump).
K_{el}	Total greenhouse gas emission factor for electricity.
$Energy_{heat}$	The amount of heat energy used to produce cooling in absorption chillers. In best case monthly amounts are used and summarised for one year (zero for Case 1 and 2)
$K_{dh,i}$	Total greenhouse gas emission factor for the district heating used to generate cooling. In best case monthly values are used.

[7] District heating can be used to produce district cooling using absorptions chillers.

Delivered Cooling	The quantity of district cooling delivered from the process to the end user. **Note:** delivered cooling means that distribution losses are taken into account.

7 Weighting between Primary Energy Factor and Carbon Dioxide Emissions

The calculated Primary Energy Factor and Carbon Dioxide Emissions are weighted together according to the method described in this section. Different levels of PEF and CO_2e give different points. The points from each performance indicator (PEF and CO_2e) are summarized and correspond to a performance factor, called θ, which will be used to calculate a price on the district heating/ cooling.

The conceptual design of the weighting and the performance factor is described in **Figure 2**. The letters A+, A, B, C and D in **Figure 2** represent different levels of the performance factor. The baseline for the performance factor for district heating is an oil boiler located in the proposed building and has the performance factor θ_{heat} = 1.0. The baseline for the performance factor for district cooling is a chiller located in the proposed building and has the performance factor θ_{cool} = 0.6. In **Table 1.** Each indicator will give points according to different levels given by this table.**Table 1** (district heating) and **Table 3** (district cooling) the levels for each indicator and the points given for each level are shown. In **Table 2** (district heating) and **Table 4** (district cooling) the total points and how they correspond to the performance factor can be seen.

An example on how to calculate can be seen in the section 9.

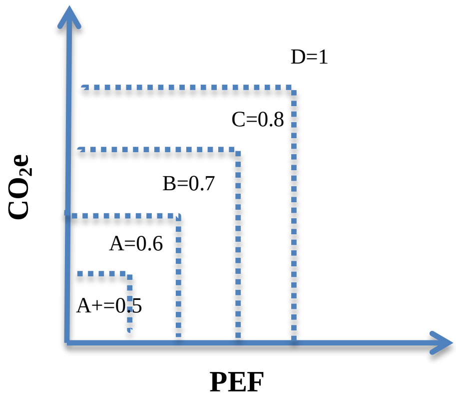

Figure 2. The figure shows how the PEF and CO_2e are weighted together and the weighting will give a performance factor (A+, A, B, C and D)

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7.1 District Heating

The point levels per indicator can be seen in **Table 1.** The total points and how they correlate to the performance factor for district heating can be seen in **Table 2**.

The threshold levels for the two indicators are based on studies of best available technology for district heating, Swedish mean district heating, oil as baseline, and the aspect that renewable energy should be promoted. When the levels are set the method is tested to see that it corresponds to fair values.

Table 1. Each indicator will give points according to different levels given by this table.

CO_2e	PEF	Points per indicator
0-35	< 0,6	1
36-75	0,6-0,9	2
76-110	0,9-1,55	3
111-150	1,56-1,7	4
151-200	1,71-2	5
200-350	2-2.5	6
>350	>2.5	7

Table 2. Summarized points from both indicators give the performance indicator.

Total points	Performance factor θ_{heat}
2	A+=0.5
3	A=0.6
4	B=0.7
5-6	C=0.8
7-8	D=0.9
9-10	E=1.0
>10	F=1.2

7.2 District Cooling

The point levels per indicator can be seen in **Table 3**. The total points and how they correlate to the performance factor for district heating can be seen in **Table 4**.

The threshold levels for the two indicators are based on studies of best available technology for district cooling, Swedish mean district cooling, chillers as baseline, and the aspect that renewable energy should be promoted. When the levels are set the method is tested to see that it corresponds to fair values.

Table 3. Each indicator will give points according to different levels given by this table.

CO_2e	PEF	Points per indicator
0-35	< 0,6	1
36-75	0,6-0,9	2
76-110	0,9-1,55	3
111-150	1,56-1,7	4

Table 4. Summarized points from both indicators give the performance indicator.

Total points	Performance factor θ_{cool}
2	A+=0.5
3	A=0.6
4	B=0.7
5-6	C=0.8

151-200	1,71-2	5
200-350	2-2.5	6
>350	>2.5	7

7-8	D=0.9
9-10	E=1.0
>10	F=1.2

8 The Equivalent Unit Price of Thermal District Energy

In order to determine the DES price for a non-open market energy source, the performance factor θ is multiplied by the local market price of the fossil alternative.

For heating: Oil is used as the fossil alternative in the calculation because of the market price availability throughout Scandinavia.

Equation 6 $$DES_{price\_heat} = \theta_{heat} \cdot local\_market\_oil_{price}$$

Note that the calculated cost for the DES unit often will be slightly higher than the actual cost paid by the end user. Most networks have a District heating price that corresponds to 50-60 % of the fuel oil price, seen in **Figure 6** in **Appendix A**.

For cooling: Electricity is used as the fossil alternative in the calculation because the baseline building uses electricity for cooling.

Equation 7 $$DES_{price\_cool} = \theta_{cool} \cdot local\_market\_electricity_{price}$$

9 Calculation example

9.1 District heating

9.1.1 CHP allocation with Alternative Generation Method

Existing combined heat and power generation plant fuelled with 100 units of hard coal for which the allocation is to be made. The CHP plant generates;

Electricity generation, net	30 units
Heat generation, net	60 units

Alternative generation efficiencies for hard coal are found in **Table 7** in **Appendix A**:

Heat generation	$\eta_{h,i} = 88\ \%$
Electricity generation	$\eta_{p,i} = 44\ \%$

By applying **Equation 2** allocation to heat is done:

$$\alpha_{h,i} = \frac{\frac{E_{h,tot}}{\eta_{h,i}}}{\frac{E_{h,tot}}{\eta_{h,i}} + \frac{E_{el,tot}}{\eta_{p,i}}} = \frac{\frac{60}{0,88}}{\frac{60}{0,88} + \frac{30}{0,44}} = 0,5 = 50\%$$

The generated heat is delivered to the DES. The distribution losses are 12 %, i.e. of 60 units of net generated heat 53 units reaches the customers.

9.1.2 Primary Energy Factor and Greenhouse gas emission factor for fuels

The primary energy factor for hard coal is 1.15 as seen in **Appendix A** , **Table 5** and the greenhouse gas emission factor is 418.5 grams/kWh as seen in **Table 6**.

9.1.3 Calculating total factors for district heating

By applying **Equation 4** the **total greenhouse gas emission** is calculated to 395 grams per kWh of district heating;

$$\kappa_{dh} = \frac{\sum_{i=1}^{n} E_{F,HOB(i)} * \kappa_{F,HOB(i)} + \sum_{i=1}^{n} a_{h,i} * E_{F,CHP(i)} * \kappa_{F,CHP(i)}}{\sum_{j=1}^{n} Q_{del,j}}$$

$$= \frac{\sum_{i=1}^{n} 0 * 0 + \sum_{i=1}^{n} 0.5 * 100 * 418.5}{53} = 395 \frac{\mathrm{g}}{\mathrm{kWh\ DH}}$$

By applying **Equation 1** the total primary energy factor for district heating is calculated;

$$PEF_{dh} = \frac{\sum_{i=1}^{n} E_{F,HOB(i)} * PEF_{HOB(i)} + \sum_{i=1}^{n} \alpha_{h,i} * E_{F,CHP(i)} * PEF_{CHP(i)}}{\sum_{j=1}^{n} Q_{del,j}}$$

$$= \frac{\sum_{i=1}^{n} 0 * 0 + \sum_{i=1}^{n} 0.5 * 100 * 1.15}{53} = 1.08$$

9.1.4 Calculating the performance factor and the DES price

By taking these absolute performance indicators and transform them in to corresponding points, in **Table 1** the result is **CO_2e = 7 points and PEF = 3 points** which gives **10 points in total**. 10 points result in a performance indicator θ_{heat} = 1.0, as can be seen in **Table 2**.

The DES_{price} is calculated using **Equation 6**;

$$DES_{price\_heat} = \theta_{heat} \cdot local\_market\_oil_{price} = 1.0 * 1.16^{8} = 1.16 \text{ SEK/kWh}$$

9.2 District cooling

The district cooling is produced in heat pumps in combined mode. Both the heat and the cooling are utilized, thus Case 3 in section 4.2 is applied where the allocation between the environmental burdens is made with energy allocation. 100 units of electricity are used to generate 240 units of cooling and 360 units of heat. In this case 2/5 of the output is cooling and 3/5 of the output energy is heat thus 2/5 of the input electricity is allocated to the cooling, $\beta = 2/5 = 0.4$.

The distribution losses to customers are less than 5 %. Thus 230 units of cooling reach the customers.

9.2.1 Primary energy factors for Nordic electricity

The primary energy factor for Nordic electricity is 1.9 and the greenhouse gas emission 227 grams per kWh as seen in **Appendix A** , **Table 5** and **Table 6**.

9.2.2 Calculating the total factors for district cooling

By applying **Equation 5** the greenhouse gas emission factor is calculated to 39.5 grams per kWh of cooling;

[8] Avergae price during 2010 including all taxes, Source SPI

$$\kappa_{dc} = \frac{\beta \cdot Energy_{el} * \kappa_{el} + \sum_i (Energy_{heat,i} * K_{dh,i})}{Delivered\ cooling} =$$

$$\frac{0.4 * 100 * 227 + \sum_i (0 * 0)}{230} = 39.5 \frac{g}{kWh\ cooling}$$

By applying **Equation 3** the total primary energy factor for district cooling is calculated to 0.32 kWh per KWh;

$$\mathrm{PEF_{cooling}} = \frac{\beta \cdot \mathrm{Energy_{el}} * \mathrm{PEF_{el}} + \sum_i (\mathrm{Energy_{heat,i}} * \mathrm{PEF_{heat,i}})}{\mathrm{Delivered\ cooling}} = \frac{0.4 * 100 * 1.9 + \sum_i (0 * 0)}{230} = 0.33 \frac{\mathrm{kWh}}{\mathrm{kWh}}$$

9.2.3 Calculating the performance factor and the DES price

By taking these absolute performance indicators and transform them in to corresponding points, in **Table 3** the result is **CO_2e = 2 points** and **PEF = 1 points, 3 points in total**. Using the conversion in **Table 4** reveals that 3 points correspond to a performance indicator, $\theta_{cool} = 0.6$.

The DES_{price} is calculated using **Equation 7**;

$$DES_{price\_cool} = \theta_{cool} \cdot local\_market\_electricity_{price} = 0.6 * 1.5 = 0.90\ SEK/kWh$$

10 Conclusion

The intent of the USGBC's document entitled "Treatment of District or Campus Thermal Energy in LEED V2 and LEED 2009 – Design & Construction" is to properly account for the performance of the district or campus energy system connected to a LEED project.

In this proposed supplement to EAc1 Option 2, the Primary Energy Factor (PEF) and Carbon Dioxide Emission Equivalents (CO_2e) is used to prove the efficiency of a DES system as well as provide a basis for deriving a unit cost for the DES when market prices on energy sources are unavailable. The rationale behind the proposed method for calculating the unit price is to effectively reflect improvement in environmental energy performance through connection to a local DES. The assigned cost of DES will proportionally reflect the improvement in PEF compared to the fossil fuel alternative.

Once the calculated DES unit prices have been applied to the output data retrieved from the LEED energy model, the project is able to prove the efficiency of the DES through cost as based on ASHRAE Standard 90.1.

A. Appendix A

Primary energy factors for fuels

In **Table 5** Error! Reference source not found.Primary Energy Factors can be seen from the Swedish District Heating Association.

Table 5 Primary Energy Factors for fuels (Swedish District Heating Association (Swedish DH)).

Fuel/energy carrier	***$PEF_{HOB\ or}$ and PEF_{chp} [MWh_p/MWh]***		
	PEF	**references**	**Example of fuel/ energy carrier**
Hard Coal	1.15	IVL 2011[9]	hard coal and bituminous coal
Heavy fuel oil	1.11	IVL 2011	fuel oil number 2 to 6
Light fuel oil	1.11	IVL 2011	fuel oil number 1
Natural Gas	1.09	IVL 2011	
Peat	1.02	IVL 2011	
Bioenergy (primary[10])	1.03	IVL 2011	forest residues, wood chips
Bioenergy (refined)	1.18	IVL 2011	biomass briquettes, wood pellets
Bioenergy (secondary[11])	0.01	IVL 2011	saw dust and other by-products from wood industry, land fill gas
Residual fuel	0.05	IVL 2011	paper-tree-plastic, coke oven gas and other waste from industries
Municipal waste[12]	0.61	IVL 2011	municipal solid waste
Electricity (input and output)	1.9	Svensk Energi	Nordic electricity mix
Industrial waste heat	0	IVL 2011	From any type of industry with surplus heat
Geothermal heat	0		Note: Does not include plant construction and disassembling
Solar heat	0		Note: Does not include plant construction and disassembling

PEF for fuels can be different for different markets depending of for example the distance of the transportation of the fuels. These numbers could be perceived as very conservative for a system involving the process of waste as heat and CHP production.

The Swedish District Heating Association along with the major customer organization and energy companies in Sweden, have developed alternative primary energy factors to be used for the Swedish market. These factors aim to better reflect the Scandinavian district energy systems as industrial waste heat and CHP processes are being treated according to the actual sources.

[9] Gode m.fl, Miljöfaktabok 2011- Uppskattade emissionsfaktorer för bränslen, el, värme och transporter, Värmeforskrapport, ISSN 1653-1248, Stockholm, April 2011
[10] Primary bioenergy means that it is biomass aimed for fuel but not refined
[11] Secondary bioenergy is biomass by-products used as fuel
[12] Swedish average factor taken from Gode et al 2012."Primärenergi i avfall och restvärme – Metodfrågor". Fjärrsynrapportnummer 2012:5. Stockholm,2012.

It is also to be noted that there is an ISO standard currently under development which aims to standardize the factors when calculating the PEF.

Table 6 Error! Reference source not found. shows the general emission factors, g CO_{2e} per kWh of fuel. When calculating the carbon dioxide equivalents, (CO_{2e}) the greenhouse gas (GHG) emissions are summarized using the global warming potential (GWP) for each greenhouse gas. The most common used factors are the GWP_{100} factors, (the impact during 100 years compared to CO_2). The GHG summarized in this case are CO_2 (carbon dioxide); CH_4 (methane) and N_2O (nitrous oxide). They are divided in combustion emissions and emission occurring prior to the combustion, i.e. upstream emissions. Tier 1 represents international emission factors and Tier 2 represents national emission factors.

Table 6. Greenhouse gas emissions, total emission factors combustion emissions and upstream emissions specified for Swedish conditions

Fuel/energy carrier		***$K_{F(i)}$ (kg CO_{2e} /MWh)***			
	Total Emission factor	**Tier 1**	**Combustion emissions, references**	**Tier 2**	**Upstream emissions, references**
Hard Coal	418.5	357	SEPA[13]	61.5	IVL 2011
Heavy fuel oil	301.2	280	SEPA	21.2	IVL 2011
Light fuel oil	291.2	270	SEPA	21.2	IVL 2011
Natural Gas	249.2	207	SEPA	42.2	IVL 2011
Peat	433	393	SEPA	40.0	IVL 2011
Bioenergy (primary[14])	15.6	9	SEPA	6.6	IVL 2011
Bioenergy (refined)[15]	24.3	9	SEPA	15.3	IVL 2011
Bioenergy (secondary[16])	14.1	9	SEPA	5.1	IVL 2011
Residual fuel[17]	89.5	87	IVL 2011	2.5	IVL 2011
Municipal waste[18]	93.6	90	SEPA	3.6	IVL 2011
Electricity (input and output)	227	227	Nordic countries[19] (Svensk Energi)	n.a	Nordic countries (Svensk Energi)
Industrial waste heat	0	0	By definition in PCR	0	By definition in PCR
Geothermal heat	0	0	AGFW FW 309	0	AGFW FW 309
Solar heat	0	0		0	Does not include the plant construction etc.

[13] Swedish environmental protection agency, SEPA
[14] Primary bioenergy means that it is biomass aimed for fuel but not refined, e.g forest residues, wood chips
[15] Assumed to be biomass briquettes (upstream). Wood pellets and other refined biofuels can also be used in this case.
[16] Secondary bioenergy is biomass by-products used as fuel, e.g. land fill gas, saw-dust, barque
[17] Residual fuel is a great variety of residues that are used as fuel. In this case the factor is paper-tree-plastic waste, e.g. refused derived fuels
[18] Swedish average factor taken from Gode et al 2011.
[19] The value is when all electricity with guarantee of origin sold to customers are excluded from the electricity mix.

The efficiencies for heat-only and electricity-only production, shown in **Table 7**, are based on standard ISO conditions[20] using the lower heating value. The efficiencies are valid for appliances built after 2006. The alternative electrical efficiencies are net-efficiencies valid for electricity production in condensing mode. The alternative heat efficiencies are net-efficiencies for heat-only boilers.

Table 7. The alternative production efficiencies used in the Alternative Generation Method. Source: CHPD[21].

Fuel	Alternative electricity efficiencies	Alternative heat efficiencies
Lignite	0.418	0.88
Hard Coal	0.442	0.88
Heavy fuel oil	0.442	0.89
Light fuel oil	0.442	0.89
Natural Gas	0.525	0.90
Peat	0.390	0.86
Bioenergy (primary)	0.330	0.86
Bioenergy (refined) 22	0.390	0.86
Bioenergy (secondary) 23	0.250	0.86
Residual fuel	0.250	0.80
Waste as fuel	0.250	0.80

[20] 15°C ambient temperature, 1.013 bar, 60 % relative humidity. Note that a correction factor due to the regional climate should be used for the electrical efficiencies. 0.1 %-point efficiency loss for every degree above 15°C, 0.1 %-point efficiency gain for every degree under 15°C.
[21] CHPD = Combined Heat and Power Directive. Directive 2004/8/EEC on the promotion of cogeneration based on useful heat demand in the internal energy market and amending Directive 92/42/EEC
[22] Assumed to have the same efficiency as peat.
[23] Assumed to have the same efficiency as agricultural fuels

In **Table 8** the calculated total emission factors for CO_2e as well as the PEF can be seen, the absolute performance indicators. The performance factor for each heating alternative can also be seen in the table. The absolute performance of the heating alternatives listed in **Table 8** can be seen plotted in **Figure 3**. In **Figure 4** the performance factor for heat, α_{heat}, are shown for the same heating technologies.

Table 8. Calculation of performance factor for different technologies.

Heating alternative	**Absolute performance**		**Points**		**Total points**	**Performance factor θ_{heat}**
	PEF	*CO_2e*	*PEF*	*CO_2e*		
Electricity (Nordic)	1.9	227	5	6	11	1.2
Heat from Natural gas (individual boiler)	1.2	279	3	6	9	1
Heat from Natural Gas (DH)	1.3	298	3	6	9	1
Individual Oil boiler	1.3	345	3	6	9	1
Heat from Coal (CHP)	0.8	276	2	6	8	0.9
Heat from Waste(DH)	0.8	127	2	4	6	0.8
Heat from Natural Gas (NGCC)	0.5	113	1	4	5	0.8
heat from Heat Pump(COP =3)	0.8	91	2	3	5	0.8
Heat from Average Swedish DES	0.96	99	2	3	5	0.8
Heat from Biomass (DH)	1.3	19	3	1	4	0.7
Heat from Biomass (individual. pellet burner)	1.5	31	3	1	4	0.7
Heat from Heat pump (DH, COP = 3.5)	0.6	74	2	2	4	0.7
Heat from Waste (CHP)	0.4	64	1	2	3	0.6
Heat from Swedish average DH (PB 1a)	0.9	61	2	2	4	0.7
Heat from Biomass (CHP)	0.6	9	1	1	2	0.5
Heat from Industrial waste heat	0.1	13	1	1	2	0.5

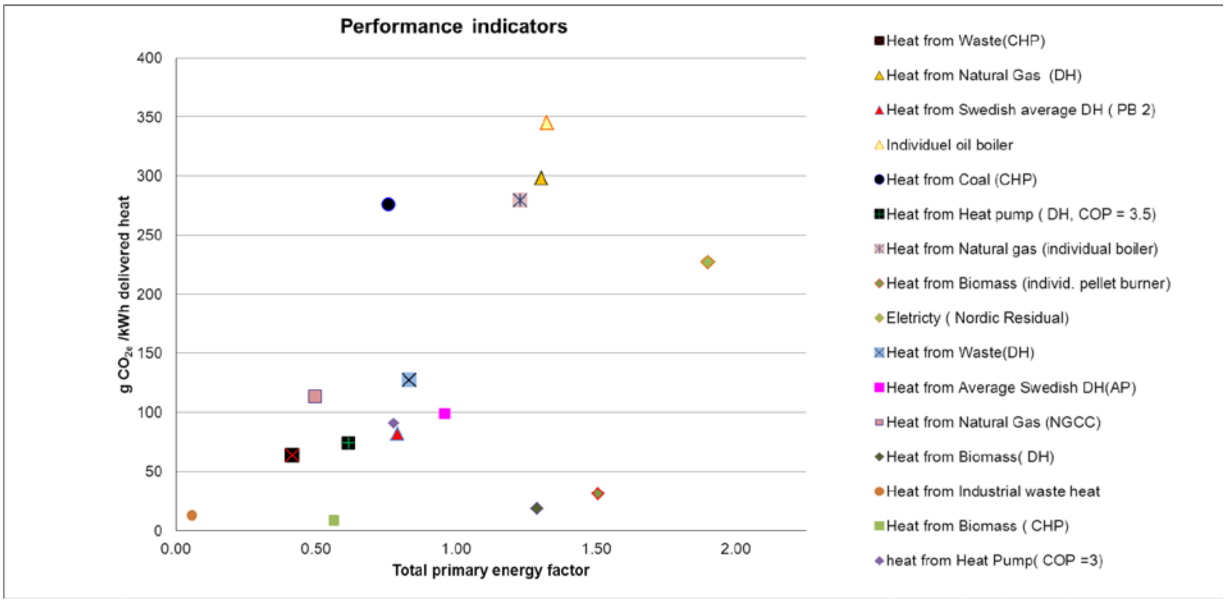

Figure 3 The calculated performance indicators for a number of technologies based on design data. On the y axis the CO_2e is shown and on the X-axis the PEF is shown.

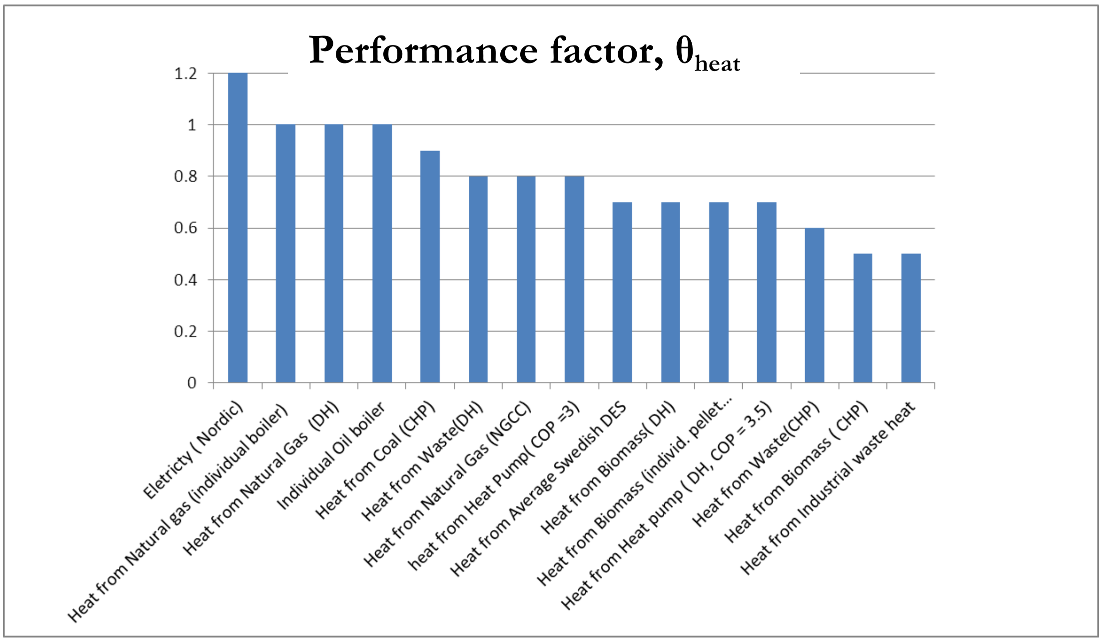

Figure 4 The calculated performance factor, θ_{heat} for a number of technologies based on design data and weighted performance indicators according to the methodology in **Table 1**.

Figure 5 shows the distribution of the performance factor for over 300 Swedish district heating networks. As can be seen most of the district heating networks have a performance factor below 1.0 and over 45 % has a factor of 0.8. As seen in **Figure 6** in reality most Swedish district heating network have a price that corresponds 50-60 % of the price from oil heating (90 % boiler efficiency).

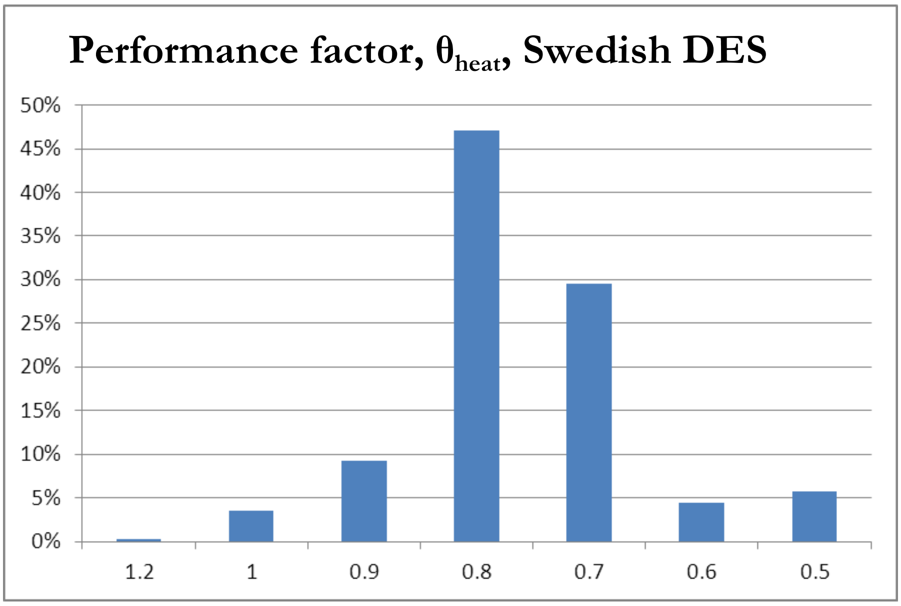

Figure 5 The distribution of the performance factor for over 300 Swedish district heating networks.

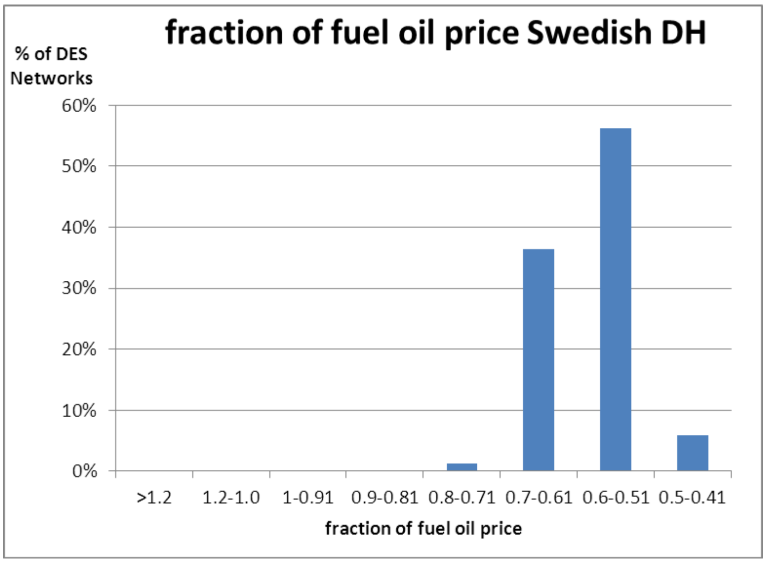

Figure 6 The distribution of the relative price for over 300 district heating networks in Sweden compared to the price of fuel oil. NOTE; real prices during 2010.

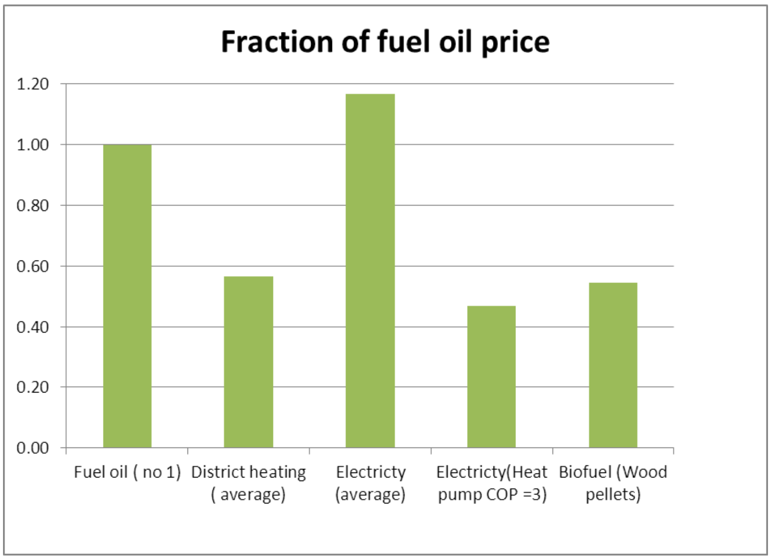

Figure 7. The relative price of heat from different energy sources compared to the price of fuel oil (heat from fuel oil with 90 % boiler efficiency). NOTE; Real prices during 2010.

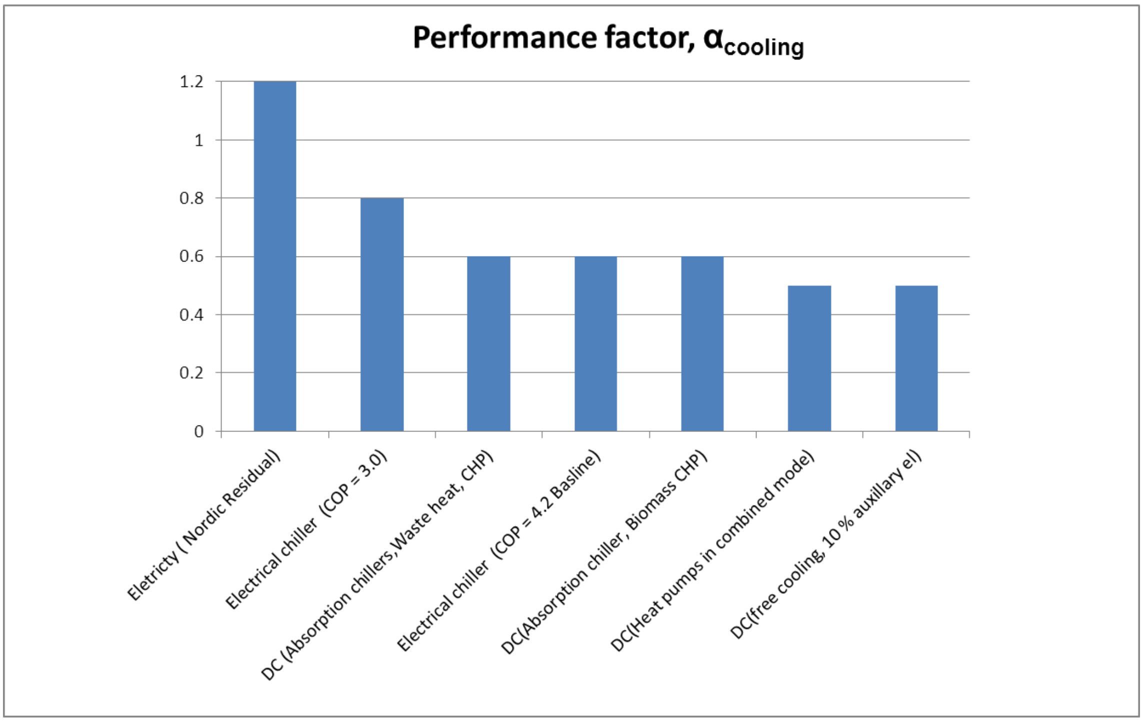

Figure 8. The performance factor, $\theta_{cooling}$, for different cooling technologies.