Industrial Energy Mapping: THERMCYC WP6

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Publication date: 2015

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):

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Project number: 929
Version: Final 1, 2015-02-24
Prepared by: BHU, FBU, FMH
Prepared for: Technical University of Denmark, DTU
Quality assured by: FMH
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Executive Summary

This report contains an evaluation of the potential waste heat sources in Denmark. The evaluation is based on data from Statistics Denmark on the 15 Danish sectors (the 15 sectors are grouped in five categories that have similar consumption/production patterns). Besides the 15 sectors, the accessible heat from three natural energy sources is also included in the evaluation. The quantification of the potential waste heat is based on a number of approaches such as, professional experience within Viegand Maagøe, input from project partners, theoretical calculations, case studies, input from suppliers, input from end-users etc.

It must be emphasized that the total energy consumption used in this study covers all end-users and utility companies and therefore the total energy consumption can be higher than what can be found in other statistic. By including both utility companies and end-users a double counting of net energy input can occur, if e.g. the output from the utility company is used as energy input to the end-users.

The total potential for heat recovery is calculated to 212 PJ per year (excluding natural energy sources) which correspond to 13% of the net energy input for end users and producers.

The large potential is firstly within the transport (36%), secondly within utility (28%), industry (23%), buildings (11%) and finally the construction sector where the potential is relatively small.

The potential for waste heat in the transport sector originates from exhaust gas (high temperature from 200°C to 400°C), engine and charge air cooling (low temperature below 80°C).

In the utility sector, 43 % of the waste heat originates from condensate from steam power plants which is accessible at a temperature of 20 °C. The remaining 57 % of the waste heat originates primarily from exhaust gas at temperatures from 120°C to 180 °C.

In the industrial sector 91 % of the waste heat is accessible at temperatures below 100°C. The low temperature waste heat originates mainly from evaporation, distillation, cooling/refrigeration and space heating.

In the building sector all the waste heat is accessible at temperatures below 100°C and originate primarily from refrigeration/cooling and exhaust from boilers.

The potential of waste heat in the construction sector is estimated to be relatively low due the fact the majority of the installations are temporary.

The potential for utilising “waste heat” from natural resources is theoretically close to infinite, but economically unfeasible. At the stage of completing the report, there has not been sufficient information to evaluate the low temperature potential that is also economically feasible, so the focus in this report is primarily regarding the temperatures from these natural resources. Solar can supply heat at temperatures up to 100°C, geothermal energy can supply heat at temperatures up to 90 °C and air/water average around 2°C during colder seasons and 17 °C in warmer seasons.

When looking across all the sectors there are two major energy sources. One of them originates from cooling/refrigeration, condensate and various industrial processes all below 60 °C and the other major waste heat source comes in the form of exhaust gas from various combustion and heating processes.
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1 Introduction

Low-temperature heat sources are available in many applications, ranging from waste heat from marine diesel engines, industries and refrigeration plants to biomass, geothermal and solar heat sources. There is a great potential for enhancing the utilization of these heat sources by novel cycle design and use of multi-component working fluids. These advancements will not only improve the performance of existing technologies, but also enable the utilization of low temperature heat sources, which are currently not utilized due to technical or economical infeasibility. The project THERMCYC aims to devise innovative solutions for utilizing low-temperature heat sources at performances superior to state-of-the-art. The overall project goal is to derive solutions that result in the savings of 15% of the energy consumption in Danish industry and shipping. The project results will provide the scientific basis needed for implementation of technologies utilizing low-temperature energy sources in Denmark, thereby contributing to the development of the future society with no use of fossil fuels and with high shares of intermittent, renewable energy sources with electricity being the main energy carrier.

This report is a pre-study for the Work Packages 6. The main objective of the study is to estimate the total available waste heat and potential heat energy in Denmark. All business sectors as well as relevant heat energy sources will be assessed. The results will provide a basis of the focus areas for the subsequent activities in the project.

2 Methodology

Figure 1 Overall methodology for identification of waste heat and potential heat energy

As figure above shows that an overview of energy consumption by business sectors, then by each process within the sector is carried out. The energy consumption data is obtained via the database by Statistics Denmark\(^1\). It should be emphasised that the data from Statistics

\(^1\) http://www.statistikbanken.dk/: ENE2HA: Energiregnskab i fælles enheder (detaljeret) efter anvendelse og energitype (2012)
Denmark all users both production and end users. Therefore if the total energy input is compared to the total consumption eq. stated by the Danish Energy Agency energy then it is significantly higher because it contains production where an energy conversion takes place.

The share of energy in each sector and each process that is lost as waste heat is then estimated as well as the amount of useful waste heat. In the evaluation of the accessible temperatures from the individual processes, it is assumed that the temperature shares the temperature of the waste heat from the process and towards a cooling device e.g. the cooling tower or the surroundings but not the temperature after an eventual cooling process.

![Figure 2 illustration of the waste heat temperature](image)

The evaluation of accessible waste heat potential and the related temperatures are, for a majority (also in the references) of the cases, based on practical experience from the present status of the unit of operations in terms of what can be accessed and at what temperatures. This approach covers the entire sector with averages values, therefore it would not be possible to relate an amount of waste heat to the total consumption and temperature. At this stage this practical approach is found more useful in order to get an overview on which a more detailed selection can be done.

It is also important to note that waste heat recovery potentials are evaluated separately and therefore there will be deviations connected in the sum of the heat recovery potential, because the activities can affect each other.

Besides the energy and temperature then medium of the heat sources is given. The medium can vary with a process, the most common ones are given.

For solar thermal and geothermal heat sources, the review of existing literature on their potential in Denmark is carried out in order to assess the suitable areas for utilizing solar thermal and geothermal energy. The potential available solar thermal energy is calculated based on assumptions of efficiencies and suitable areas.

The exergy calculations are made with the following assumptions:

- Only physical exergy is used, all other potential exergy contributions are neglected.
- The reference temperature of the media is determined as the averages temperature of the potential temperature interval.
- Pressure are all at atmospheric
- Dead state are defined as:
  - Temperature: 10 °C
  - Pressure: atmospheric
- Fluids can be cooled to 10°C above the reference temperature
- Gasses can be cooled to 30°C above the reference temperature
- All fluids are treated as water and all gasses are treated as air
Due to the fact that this is an estimation of waste heat potential and the lack of existing studies on waste heat from business sectors other than the industry, it should be noted that the results consists uncertainties. The final results however can provide the basis for deciding subsequent focus areas of the project.

3 Sectors and categories

The main sectors are defined according to the classifications in Statistics Denmark, with the exception that trade and transport are separated into two sectors, in addition, geothermal, solar thermal, air and water are included to obtain an overview of potential heat sources. The number of companies (units), which the data collection is based on in given in the parenthesis next to each sector. This part of the THERMCYC project will map out the energy consumption, the low temperature heat sources from these sectors shown below:

1. Households
2. Agriculture, forestry and fishing (32,571)
3. Mining and quarrying (218)
4. Manufacturing (15,524)
5. Utility services (4,485)
6. Construction (31,300)
7. Trade (57,686)
8. Information and communication (14,962)
9. Financial and insurance (9,169)
10. Real estate activities and renting of non-residential buildings (24,838)
11. Dwellings (2,560)
12. Other business services (48,346)
13. Public administration, education and health (24,676)
14. Arts, entertainment and other services (23,241)
15. Transport (11,822)
16. Geothermal
17. Solar thermal
18. Air and water

The main processes that consume energy differ from sector to sector, however some are more or less similar; therefore the sectors are divided into categories where the same processes apply. The numbers refers back to the list of sectors shown above. These 8 main categories are:

- Industry: 2,3,4,7
- Buildings: 1,8,9,10,11,12,13,14
- Utility services: 5
- Construction: 6
- Transport incl. maritime: 15
- Geothermal: 16
- Solar thermal: 17
- Air and water: 18
4 Industry
The Industry category includes the following 4 sectors:

- Agriculture, forestry and fishing
- Mining and quarrying
- Manufacturing
- Trade

According to projects on industrial waste heat potential and mapping of commercial energy consumption in Denmark, the industry is often regarded as consisting the above 4 sectors. In this project, the above sectors are also grouped together, because the input energy is distributed to the similar operation units in these sectors as well as to keep the consistency with the other projects in Denmark.

4.1 Methodology and references
Mapping of commercial energy consumption (Kortlægning af erhvervslivets energiforbrug) (2008)\(^2\) has assessed the energy consumption from the Danish industry, which includes the 4 sectors mentioned above. The main processes that produce waste heat and the percentage of consumption by each process are defined according to the report and the excel sheets supporting the report; the percentage of the waste heat as well as actual usable waste heat is then factored in, this ensures only accessible waste heat is being accounted for. The percentage of waste heat and available waste heat is based on the report Analysis of better industrial waste heat utilization (Analyse af mulighederne for bedre udnyttelse af overskudsvarme fra industrien) (2013)\(^3\) and expert consultations. The Figure below demonstrates the methodology used to identify the useful waste heat energy in Industry category.

---


Exclusions

Some secondary heat energy may be neglected, due to the fact that in the industry it is assumed that process heat would have a much greater potential for waste heat than heat from secondary energy sources. Therefore waste heat generated by ventilation and fans and lighting are not taken into consideration in this category, whereas they would be taken into account in the Building category.

Energy consumed by work travels by vehicle is also not taken into the account here, as the largest potential of waste heat by vehicles would be found in the Transport category.

4.2 Industrial supply and processes
The main sources of waste heat can be found as the heat loss from the following unit operations:

Supply:
- Boiler losses
- Heating and boiling
- Cooling and Refrigeration
- Space heating

Production:
- Melting
- Other heat
- Compression
- Drying

Figure 3 Methodology used to identify waste heat energy in the industry category

- % of total energy/fuel consumption is used in each process
- Kortlægning af erhvervslivets energiforbrug (2008) and other relevant sources
- % of waste heat in each process that is not utilised already
- Analyse af mulighederne for bedre udnyttelse af overskudsvarme fra industrien (2013) and other relevant sources
- Temperatures of the useful waste heat identified in steps above
- Various papers, sources and experiences from industry experts
- Waste heat energy per each degree of temperature by subsectors, processes and in total
- Temperature interval and exergy

Temperatures

Waste heat
• Evaporation
• Distillation
• Combustion

**Boiler losses**

Boilers are used in all the sectors to produce heat at different pressures for different applications. The losses is primarily from the flue gas, which are the only loss that is taking into account here, but other losses will be there, such as heat losses from the boiler surface and blowdown losses.

The largest consumers are in the refinery, food and beverages industries.

*Waste heat energy:* Boiler losses accounts for varying amount of consumption in each sub-sector, typically between 5% and 20% of the total fuel consumption in that subsector, except in fishery

Industrial waste heat report estimated that 47% of the loss in the exhaust gases can be recovered; however half of this amount has already been recovered.

**Temperature:** 160-250°C

**Medium of waste heat:** Flue gas

*Assumptions/limitations:* The limitations in the utilization primary due to the lack of the use of full cooling sources and an acceptable return of the investment. It is assumed that the waste heat is caused by both a lack of cooling and a surplus of oxygen.

**Heating/boiling**

Heating and boiling occurs in a large number of the manufacturing industries. The typical energy consumer in relation to heating and boiling are the oil refineries sector, but also the food, beverage, textile, chemical, concrete, and metal industries are using heating and boiling in their processes.

*Waste heat energy:* The most commonly found processes in the Industry category are process heating and boiling. Energy consumption of fuels and electricity by heating and boiling process varies largely from branch to branch. It can be as high as 93% of all fuel consumption goes to heating and boiling in production of metal to none in furniture industry.

The Industrial waste heat report estimates that 10% of the waste heat can be extracted and out of which 50% of waste heat is already utilized.

**Temperature:** Waste heat from heating or boiling process in the industry typically has a temperature of approx. 70-90°C in average.

**Medium of waste heat:** The waste heat medium is often in the form of water, which removes the energy from a process.

*Assumptions/limitations:* The big challenges in utilizing waste heat from these processes are partly that waste heat is not currently removed in a way that makes it accessible and partly due to the lack of suitable cooling media.
Drying

Drying is very common in the food, paper, chemical concrete and brick industry. The drying process occur in many different ways ranging from spray drying and fluid bed drying to cylinder drying and drying in dehumidified air.

Waste heat energy: Drying can use a significant part of an industry’s energy consumption depending on the branch type. Much of the waste heat in the drying processes is lost into the surroundings, either directly or through a cooling system. Industrial waste heat report evaluated that 50% of energy used in this process can be categorised as waste heat, out of which 50% is already being utilized.

Temperature: The temperature of the waste heat is typically in ranged between 80 and 100°C. In some cases such as in the textile industry process temperature from drying could vary between 125 °C to 225 °C and in other cases where the drying air is caring over waste product that are treated in a scrubber then the waste heat temperature drops to around 30-40°C

Medium of waste heat: Warm humid air

Assumptions/limitations: Typically temperatures are assumed to be an averaged waste heat temperature. The limitation in utilizing waste heat from dryers are that a big part of it not controlled in an accessible way, another challenge is that the drying air can be contaminated which makes heat recovering more challenging. Drying with air often requires transportation of larges air volumes, which therefor requires relatively large space for heat recovery systems

Evaporation

Evaporation is primarily used in the in the food, beverages, pharmaceutical and chemical industries. The evaporator designs come in many different configurations from multistage thermal evaporators to mechanical driven re-compression evaporators.

Waste heat energy: Evaporator can use a significant part of an industry’s energy consumption depending on the branch type.

The primary surplus heat from evaporation is found in the product condensate. The energy content of the condensate is approx. 50% of the primary steam supplied at a temperature of about 40- 50°C (multistage evaporation). The condensate is then cooled in cooling towers down to approximately 20 °C. It is estimated that a maximum of approximately 10% of the plants are utilizing waste heat already, which gives 90% of the waste heat is still available.

Temperature: 35-50°C in average.

Medium of waste heat: Hot water.

Assumptions/limitations: The energy content of the condensate is calculated based on the assumption that 1 MVR and 3 TVR is the most commonly found setup at the present. The trend is going away from only TVR towards more and more MVR. It should be noted that
there are still some evaporation processes that are done purely with TVR as well as some with only MVR. The main limitation in utilizing waste heat from the evaporators is finding useful applications for the heat.

**Distillation**

The majority of the distillation plants are to be found in the oil refinery industry, but it can also to a minor extend be found in the food ingredients and chemical industries. The refinery industry primarily uses multistage distillation columns, but in the other industries a variety of distillation configuration can be found.

**Waste heat energy:** The distillation process can consume up to 20% of the total fuel consumption, but varies very much from sector to sector.

The primary surplus heat from the distillation included in the product condensate. The energy content of the condensate is in the order of 100% of the primary steam supplied at a temperature of about 40 °C. 50% of waste heat from the distillation is already recovered (for example, for evaporation plants), the remainder is cooled in cooling towers.

**Temperature:** approx. 40-60 °C.

**Medium of waste heat:** The volatile part of the product in the form of vapour. Depending on the partial pressure the volatile part of the product can also be found in the form of condensate.

**Assumptions/limitations:** The main limitation in utilizing waste heat from the destination process is finding useful applications for the heat.

**Furnaces**

The amount of energy used in furnaces depends on the business type or the subsector of the industry, most of the subsectors do not use furnaces but cement/brick industry uses most of its energy in furnaces, accounting for 94% of its fuel usage.

**Waste heat energy:** In the process of heating in a furnace, heat is lost through the exhaust gas which can have a temperature up to 200-250°C. This exhaust gas can be cooled to condensing temperature depending on the fuel and the cooling media/system. Industrial waste heat report estimates that 20% of the energy used in this process is given out as accessible waste heat, and out of which 50% can still be utilised.

**Temperature:** approx. 200-250°C.

**Medium of waste heat:** Flue gases.

**Assumptions/limitations:** 90% of the energy consumed in subsector “230020 Manufacturing of concrete and bricks” comes from manufacturing cement and bricks, and 10% from other activities, the energy consumption distribution for this subsector is based on mainly manufacturing of cement and bricks.
Melting

Melting process is commonly found in metal, glass, ceramics and concrete industries. 73% of the total fuel consumption is used in this process in glass industry and 55% in the industry of metal products, only 0-5% in the other subsectors\(^2\).

Waste heat energy: Waste heat is already recovered well because the melting processes are energy intensive and it is economically worthwhile to utilize surplus e.g. preheating of raw material. It is estimated that 20% of the input energy can be captured as waste heat. However, industrial waste heat report estimated that only about 10% of the waste heat energy is not utilised\(^3\).

Temperature: 300-400 °C

Medium of waste heat: Flue gases

Assumptions/limitations: Finding useful and economical applications for the utilization of waste heat.

Other heating processes

The energy consumption of other heating processes is much individualised in the Industry category. For examples industries working with hardening, annealing and singeing are included here.

Waste heat energy: The waste heat from other heating processes are usually over 150°C is stated that 50% of energy used in this process can be categorised as waste heat, out of which 50% is already being utilized\(^3\).

Temperature: 150-200°C.

Medium of waste heat: Cooling water and flue gases.

Assumptions/limitations: -

Compressed air

Compressed air plants are installed in almost all industry sectors in a wide variety of sizes, types, configurations and production levels. The large consumers of energy in compressed air are food, chemical, pharmaceuticals, refinery, plastic, glass and machinery industries.

Waste heat energy: For heat recovery from compressed air, it is assumed that approximately 90% of electricity consumption is exploitable as waste heat. Of the installed systems in the industry, the industrial waste heat report states that only about 20% have heat recovery\(^3\).

Temperature: Typically from 60°C to 80°C\(^4\).

\(^4\) [https://www.carbontrust.com/media/31715/ctg057_heat_recovery.pdf](https://www.carbontrust.com/media/31715/ctg057_heat_recovery.pdf)
Medium of waste heat: Cooling water or air.

Assumptions/limitations: -

**Cooling and Refrigeration plants**

Cooling and Refrigeration plants are installed primarily in the food, beverages, chemical and pharmaceutical industries in a wide variety of sizes, types, configurations and production levels. The large plants are seen in the manufacturing industries.

Waste heat energy:

For heat recovery from the refrigeration system, the industrial waste heat report\(^3\) estimates that approximately 400% of electricity consumption for the cooling and refrigeration plants is exploitable as waste heat.

The Industrial waste heat report\(^3\) estimates that out of the total amount of waste heat, the oil cooling contributes with 5% (at approx. 40°C) and de-superheating 5% (up to 140°C depending on pressure and refrigerant) in screw compressors (total 10%) and for reciprocating compressors de-superheating account for 10%. The remaining 90% of the waste heat is located in the condenser at temperature of approximately 30°C. It is estimated that a maximum of approximately 10% of plants have utilized waste heat from the condensers, oil cooling and de-superheating already.

**Temperature:** 90% of the waste heat is in the condenser at 20-40°C, 10% of the waste heat can be as high as 140°C.

**Medium of waste heat:** Cooling water or air.

**Assumptions:** Only the low grade heat from the condensers at 20-40°C is used because this account for the majority of the waste heat from the cooling and refrigeration plant.

**Space heating**

Space heating is used in all sectors.

**Waste heat energy:** For manufacturing sector, it is evaluated that 33% of the energy consumed for space heating is given out as waste heat, and out of which 40% of the waste heat is already recovered, leaving 60% of the energy to be utilised\(^5\).

**Temperature:** approx. 20-30°C

**Medium of waste heat:** Warm air.

**Assumptions:** It is assumed that only the waste heat from the manufacturing industry can be recovered. Waste heat from space heating in services sectors is assumed to be very limited to none. Services sectors are mostly operated in buildings, i.e. offices, shops, and restaurant

\(^{5}\) Industry expert evaluation, Peter Maagøe, June 2014.

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etc. According to Danish Building Regulations BR 10\(^6\), all new buildings must have heat recovery as part of their HVAC system. It is assumed that all the waste heat from the new buildings would be already recovered due to the Building Regulations, and some of the aged buildings are naturally ventilated, heat recovery is not possible. The rest of the aged buildings with outdated mechanical ventilation system are neglected, because the proportion of such buildings is difficult to estimate.

4.3 Agriculture, forestry and fishing
In the table below the amount of waste heat from the agriculture, forest and fishing sector can be seen.

<table>
<thead>
<tr>
<th>Process</th>
<th>Boiler losses</th>
<th>Heating/boiling</th>
<th>Drying</th>
<th>Other heat</th>
<th>Compression</th>
<th>Refrigeration</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
</tr>
<tr>
<td>01000 Agriculture</td>
<td>430</td>
<td>-</td>
<td>188</td>
<td>257</td>
<td>-</td>
<td>1.443</td>
<td>2.318</td>
</tr>
<tr>
<td>02000 Forestry</td>
<td>2</td>
<td>8</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>-</td>
<td>15</td>
</tr>
<tr>
<td>03000 Fishing</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>18</td>
<td>-</td>
<td>-</td>
<td>19</td>
</tr>
<tr>
<td>Total</td>
<td>433</td>
<td>9</td>
<td>188</td>
<td>257</td>
<td>22</td>
<td>1.443</td>
<td>2.352</td>
</tr>
</tbody>
</table>

4.4 Mining and quarrying
In the table below the amount of waste heat from the extraction of oil, gas, gravel, stone and service to mining and quarrying can be seen.

<table>
<thead>
<tr>
<th>Process</th>
<th>Boiler losses</th>
<th>Heating/boiling</th>
<th>Drying</th>
<th>Evaporation</th>
<th>Furnace</th>
<th>Compressed air</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
</tr>
<tr>
<td>0600000 Exaction of oil and gas</td>
<td>588.2</td>
<td>87.6</td>
<td>876.0</td>
<td>6757.5</td>
<td>25.0</td>
<td>0.1</td>
<td>8.334</td>
</tr>
<tr>
<td>080090 Exaction of gravel and stone</td>
<td>70.5</td>
<td>10.5</td>
<td>105.0</td>
<td>810.3</td>
<td>3.0</td>
<td>14.5</td>
<td>1.014</td>
</tr>
<tr>
<td>090000 Service to mining and quarrying</td>
<td>3.1</td>
<td>0.5</td>
<td>4.7</td>
<td>36.0</td>
<td>0.1</td>
<td>0.9</td>
<td>45</td>
</tr>
<tr>
<td>Total</td>
<td>662</td>
<td>99</td>
<td>986</td>
<td>7604</td>
<td>28</td>
<td>16</td>
<td>9394</td>
</tr>
</tbody>
</table>

4.5 Manufacturing
In the table below the amount of waste heat from the food, beverage, tobacco, textile, wood, paper refinery etc. industry can be seen.

<table>
<thead>
<tr>
<th>Process</th>
<th>Boiler losses</th>
<th>Heating/boiling</th>
<th>Drying</th>
<th>Evaporation</th>
<th>Furnace</th>
<th>Compressed air</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
</tr>
<tr>
<td>0600000 Exaction of oil and gas</td>
<td>588.2</td>
<td>87.6</td>
<td>876.0</td>
<td>6757.5</td>
<td>25.0</td>
<td>0.1</td>
<td>8.334</td>
</tr>
<tr>
<td>080090 Exaction of gravel and stone</td>
<td>70.5</td>
<td>10.5</td>
<td>105.0</td>
<td>810.3</td>
<td>3.0</td>
<td>14.5</td>
<td>1.014</td>
</tr>
<tr>
<td>090000 Service to mining and quarrying</td>
<td>3.1</td>
<td>0.5</td>
<td>4.7</td>
<td>36.0</td>
<td>0.1</td>
<td>0.9</td>
<td>45</td>
</tr>
<tr>
<td>Total</td>
<td>662</td>
<td>99</td>
<td>986</td>
<td>7604</td>
<td>28</td>
<td>16</td>
<td>9394</td>
</tr>
</tbody>
</table>

\(^6\) Danish Building Regulations BR 10 [http://bygningsreglementet.dk/br10/0/42](http://bygningsreglementet.dk/br10/0/42)
<table>
<thead>
<tr>
<th>Process</th>
<th>Branch</th>
<th>CA</th>
<th>CB</th>
<th>CC</th>
<th>CE</th>
<th>CF</th>
<th>CH</th>
<th>CI</th>
<th>CK</th>
<th>CL</th>
<th>CM</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler losses</td>
<td>73,5</td>
<td>2,7</td>
<td>0,5</td>
<td>0,4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>10.2</td>
<td>30.5</td>
</tr>
<tr>
<td>Other heat</td>
<td>Viegand Maagøe</td>
<td>[THERMCYC] 17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refrigeration</td>
<td>183,1</td>
<td>56,5</td>
<td>23,7</td>
<td>333,0</td>
<td>39</td>
<td>92,1</td>
<td>1,49</td>
<td>4,9</td>
<td>6,1</td>
<td>2,491</td>
<td>703</td>
<td></td>
</tr>
<tr>
<td>Space heating</td>
<td>183,1</td>
<td>56,5</td>
<td>23,7</td>
<td>333,0</td>
<td>39</td>
<td>92,1</td>
<td>1,49</td>
<td>4,9</td>
<td>6,1</td>
<td>2,491</td>
<td>703</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>801,3</td>
<td>275,5</td>
<td>76,4</td>
<td>1,033</td>
<td>158,2</td>
<td>1,196</td>
<td>1,809</td>
<td>317</td>
<td>803</td>
<td>1,196</td>
<td>803</td>
<td></td>
</tr>
<tr>
<td>Grand total</td>
<td>3,588</td>
<td>2,457</td>
<td>726</td>
<td>5,018</td>
<td>1,775</td>
<td>1,451</td>
<td>2,788</td>
<td>317</td>
<td>803</td>
<td>1,196</td>
<td>803</td>
<td></td>
</tr>
</tbody>
</table>
4.6 Trade

In the table below the amount of waste heat from the whole sale, retail trade, accommodation and food services industry can be seen.

Table 4 Waste heat by processes in trade

<table>
<thead>
<tr>
<th>Process</th>
<th>Boiler losses</th>
<th>Heating/boiling</th>
<th>Drying</th>
<th>Compression</th>
<th>Refrigeration</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
</tr>
<tr>
<td>G Wholesale and retail trade</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>450010 Sale of motor vehicles</td>
<td>80</td>
<td>7</td>
<td>36</td>
<td>45</td>
<td>269</td>
<td>435</td>
</tr>
<tr>
<td>450020 Repair and maintenance of motor vehicles etc.</td>
<td>46</td>
<td>4</td>
<td>21</td>
<td>30</td>
<td>181</td>
<td>282</td>
</tr>
<tr>
<td>460000 Wholesale</td>
<td>292</td>
<td>38</td>
<td>254</td>
<td>139</td>
<td>2.505</td>
<td>3.227</td>
</tr>
<tr>
<td>470000 Retail sale</td>
<td>76</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>6.801</td>
<td>6.886</td>
</tr>
<tr>
<td>I Accommodation and food service activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>550000 Hotels and similar accommodation</td>
<td>7</td>
<td>11</td>
<td>-</td>
<td>-</td>
<td>761</td>
<td>780</td>
</tr>
<tr>
<td>560000 Restaurants</td>
<td>30</td>
<td>28</td>
<td>-</td>
<td>-</td>
<td>1.809</td>
<td>1.867</td>
</tr>
<tr>
<td>Total</td>
<td>530</td>
<td>97</td>
<td>310</td>
<td>214</td>
<td>12.326</td>
<td>13.478</td>
</tr>
</tbody>
</table>

4.7 Industry summary

The summary of the industrial waste heat mapping can be seen in the two following figures. Figure 4 shows the total amount of waste heat from each process and the related temperature intervals. From the figure it can be seen that the majority of waste heat is to be found at evaporation and refrigeration. The high amount of waste heat from evaporation is from the food sector, with a temperature interval of 35-50°C. The high amount of refrigeration is caused by the large usage of refrigeration in many industrial sectors. High temperature waste heat from boiler losses, furnace, melting and others could be interesting to focus on.

![Industry Category Chart](image)

*Figure 4 waste heat, temperature interval from the different industrial processes*
Figure 5 shows that 91% of the waste heat potential in industry is below 100°C and that the majority is below 50°C. The figure also shows that there is a minor part of the potential higher than 150°C and some of the temperature is as high as 400°C.

![Industry category chart](image)

**Figure 5 industrial sum and cumulative**

5 Buildings

Several business sectors have a similar energy consumption pattern due to the fact that their work or activities are mainly based in office, residential or public buildings, therefore the main processes that give out waste heat would be similar. Building category hence includes the following sectors:

- Households
- Information and communication
- Financial and insurance
- Real estate activities and renting of non-residential buildings
- Dwellings
- Other business services
- Public administration, education and health
- Arts, entertainment and other services

5.1 Methodology and references

The methodology used for this category is similar to the one applied for Industry category. The waste heat energy is found based on the energy consumption distribution of different
processes that give out waste heat, but the processes in Building category are different from those in the Industry.

5.2 Building supply and equipment
The main source of waste heat can be found as the heat loss from the following building supplies and equipment:

- Boiler losses
- Space heating
- Refrigeration
- Ventilation and fans
- Air compression
- IT, electronics and electrical
- Cooling
- Hot water

**Boiler losses**
There are individual boilers for space heating or water heating in buildings depending on whether the area or the building is connected to district heating, the energy consumption by boiler varies. Boilers can be found in schools, larger companies and institutes, individual houses etc. Therefore boiler losses accounts for approximately 5% of the total fuel consumption in households and private dwellings, and approx. 8% for the commercial buildings, offices and public buildings.

**Waste heat energy**: Typically 47% of the energy in boiler loss can be categorised as useful waste heat. It is estimated that 50% of the useful waste heat is not yet utilised. This is based on the same evaluation as in industry.
Temperature: The temperature of waste heat generated from boiler loss is estimated to be around 40 – 100 °C.

Medium of waste heat: Exhaust gases.

Assumptions/limitations: The limitations are due to the lack of focus and return of investment. It is assumed that condensation to some extend is utilized in the case of natural gas as an energy source.

Space heating

Space heating can account up to 70% of the fuel consumption and up to 100% of the district heating consumption depending on the business sector.

Waste heat energy: It is evaluated that there is however no waste heat potential in space heating.

Assumptions/limitations: According to Danish Building Regulations BR 10, all new buildings must have heat recovery as part of their HVAC system. It is assumed that all the waste heat from the new buildings would be already recovered due to the Building Regulations, and because most of the aged buildings are naturally ventilated, heat recovery is not plausible, therefore waste heat potential in space heating is assumed to be very limited to none. This is consistent with the Industry category. It should be noted that there is an unknown amount of waste heat in this process unaccounted for.

Refrigeration/Cooling

The energy consumption of refrigeration and cooling varies, but typically higher in sectors where professional kitchens are found, such as public institutes, universities, school etc. This process consists of waste heat given out in commercial and household refrigerators and freezers.

Waste heat energy:

Same as the refrigeration in the Industry category, 400% of the electricity consumption can be categorised as waste heat, and 90% of that is 20 - 40 °C. About 50% of the waste heat can be utilized.

Temperature: Refrigeration and cooling in commercial or household refrigerators and freezer generate heat from the condensers at approx. 20 - 40 °C. Same as in the industry

Medium of waste heat: Water or air

Assumptions/limitations:

Ventilation and fans

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7 Expert estimation from energy audit experiences, Peter Maagøe, Viegand Maagøe, October 2014. Viegand Maagøe | [THERMCYC]
Ventilation and fans are to be found in almost all the industry in building category. Electricity consumption by ventilation and fans varies depending on the business sector.

Waste heat energy: It is evaluated that there is no amount of waste heat that can be utilised from ventilation and fan. Ventilation and fans consume electricity and part of it is lost as heat which cannot be easily utilised.

Compressed air

The waste heat temperature and medium from compressed air are assumed to be same as in the industry category.

Waste heat energy: It is estimated that there is little to no energy consumed by compressed air in the business sectors under Building category.

IT, electronics and electrical

IT, electronics and electrical installations can account up to 47% of the electricity consumption depending highly on the business sector and if the business sector is innovation-driven8 9.

Waste heat energy: It is estimated that up to 40% of the electricity consumption ends up as waste heat, out of which 10% may not be able to be recovered10.

Temperature: The dissipated heat by IT equipment, electronics, and electrical installations vary from 20 °C in household electronic appliances to as high as 85 °C11 for datacentre equipment.

Medium of waste heat: The waste heat is typically given out by equipment into the surrounding, therefore making surrounding air warmer. However different media can be used to transfer the waste heat energy.

Assumptions/limitations: In reality, heat given out by IT, electronics or electrical equipment is the internal heat gains to the buildings, therefore most of it ends up lost to the surroundings. However, a large amount of heat is given out by printers, servers etc. large equipment often concentrated in one area, 40% of the total heat given out is evaluated to come from these large equipment in concentrated area, where it is assumed no specially dedicated ventilation system is set up. Therefore it is assumed that 40% of the total waste heat from IT equipment is available and 90% of the heat can be utilised if ventilation system is set up to recover the heat from the hot air in order to heat up other areas etc.

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10 Expert estimation from energy appraisal experiences, Anne Svendsen, Viegand Maagøe, August 2014.
Others

All the rest of the electricity consumption except by the end-use mentioned above are summed up in “Others”. For example, this category can include the following:

- Electricity consumed by pumps
- Electricity consumed by other electric motors
- Electricity consumed by portable heating fans
- Other unidentified consumers of electricity

Due the fact that many different end-uses are covered here, it is difficult to estimate the amount of the waste heat not knowing the energy consumption distribution per end-use, therefore waste heat from “others” is neglected.

Hot water

Approx. 20% of the district heating consumption is used for heating water\(^{12}\). In office buildings the hot water consumption is relatively low compared to households.

**Waste heat energy:** The waste heat potential is therefore estimated to be 0% in most business sectors with the exception of households (see assumption below), where 20% of the consumption is estimated to be given off as waste heat and 50% of that should be able to be utilised\(^{10}\).

**Temperature:** The waste heat generated from heating hot water is typically 20- 40°C.

**Medium of waste heat:** Water

**Assumptions:** For households and dwellings, it is assumed that 80% of heating consumption is influenced by degree day and mainly accounting for space heating, and 20% is not affected by degree days, and therefore accounting for hot water consumption. However for other business sectors under this category, it is assumed all district heating consumption is used for space heating according to industrial consumption report\(^{2}\).

### 5.3 Households

In the table below the amount of waste heat from households can be seen.

**Table 5 Waste heat by end-use in households**

<table>
<thead>
<tr>
<th>Process</th>
<th>Boiler losses</th>
<th>Refrigeration</th>
<th>IT, electronics and electrical</th>
<th>Hot water</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit TJ</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
<td>TJ</td>
</tr>
<tr>
<td>Households</td>
<td>5.172</td>
<td>16.242</td>
<td>1.234</td>
<td>1.390</td>
<td>24.038</td>
</tr>
</tbody>
</table>

### 5.4 Information and communication

In the table below the amount of waste heat from the information and communication sector can be seen.

\(^{12}\) [http://groentregnskab.albertslund.dk/node/282](http://groentregnskab.albertslund.dk/node/282)

Viegand Maagøe | THERMCYC
Table 6 Waste heat by end-use in information and communication

<table>
<thead>
<tr>
<th>Process</th>
<th>Boiler losses</th>
<th>Refrigeration/cooling</th>
<th>Compression</th>
<th>IT, electronics and electrical</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>JA Publishing, television and radio broadcasting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>580010 Publishing</td>
<td>2.3</td>
<td>16.7</td>
<td>0.2</td>
<td>17.6</td>
<td>37</td>
</tr>
<tr>
<td>580020 Publishing of computer games and other</td>
<td>0.6</td>
<td>1.5</td>
<td>0.0</td>
<td>1.6</td>
<td>4</td>
</tr>
<tr>
<td>590000 Motion picture and television programme production, and sound recording activities</td>
<td>3.7</td>
<td>22.7</td>
<td>0.2</td>
<td>4.5</td>
<td>31</td>
</tr>
<tr>
<td>600000 Radio and television broadcasting</td>
<td>3.0</td>
<td>18.1</td>
<td>0.1</td>
<td>3.6</td>
<td>25</td>
</tr>
<tr>
<td>JB Telecommunications</td>
<td>7.6</td>
<td>380.8</td>
<td>-</td>
<td>297.0</td>
<td>685</td>
</tr>
<tr>
<td>JC IT and information service activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>620000 Computer programming, consultancy and related activities</td>
<td>9.3</td>
<td>180.0</td>
<td>-</td>
<td>140.4</td>
<td>330</td>
</tr>
<tr>
<td>630000 Information service activities</td>
<td>0.8</td>
<td>39.8</td>
<td>-</td>
<td>31.0</td>
<td>72</td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
<td>660</td>
<td>0</td>
<td>496</td>
<td>1,183</td>
</tr>
</tbody>
</table>

5.5 Financial and insurance
In the table below the amount of waste heat from the financial and insurance sector can be seen.

Table 7 Waste heat by end-use in financial and insurance

<table>
<thead>
<tr>
<th>Unit</th>
<th>Boiler losses</th>
<th>Refrigeration/cooling</th>
<th>IT, electronics and electrical</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>K Financial and insurance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>640010 Monetary intermediation</td>
<td>5.3</td>
<td>39.8</td>
<td>16.6</td>
<td>61.8</td>
</tr>
<tr>
<td>640020 Mortgage credit institutes, etc.</td>
<td>7.9</td>
<td>12.8</td>
<td>5.3</td>
<td>26.0</td>
</tr>
<tr>
<td>650000 Insurance and pension funding</td>
<td>2.6</td>
<td>18.5</td>
<td>7.7</td>
<td>28.9</td>
</tr>
<tr>
<td>660000 Other financial activities</td>
<td>1.5</td>
<td>3.6</td>
<td>1.5</td>
<td>6.6</td>
</tr>
<tr>
<td>Total</td>
<td>17.3</td>
<td>74.8</td>
<td>31.2</td>
<td>123.3</td>
</tr>
</tbody>
</table>

5.6 Real estate activities and renting of non-residential buildings
In the table below the amount of waste heat from real estate and non-residential buildings sector can be seen.

Table 8 Waste heat by end-use in real estate and renting

<table>
<thead>
<tr>
<th>Unit</th>
<th>Boiler losses</th>
<th>Refrigeration/cooling</th>
<th>Compression</th>
<th>IT, electronics and electrical</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA Real estate activities and renting of non-residential buildings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>680010 Buying and selling of real estate</td>
<td>5.1</td>
<td>11.8</td>
<td>2.8</td>
<td>5.7</td>
<td>25.4</td>
</tr>
<tr>
<td>680030 Renting of non-residential buildings</td>
<td>19.9</td>
<td>41.6</td>
<td>10.0</td>
<td>20.0</td>
<td>91.5</td>
</tr>
<tr>
<td>Total</td>
<td>24.9</td>
<td>53.4</td>
<td>12.8</td>
<td>25.7</td>
<td>116.9</td>
</tr>
</tbody>
</table>

5.7 Dwellings
In the table below the amount of waste heat from the dwelling sector can be seen.

Table 9 Waste heat by end-use in dwellings

24
5.8 Other business services

In the table below the amount of waste heat from other business services can be seen.

*Table 10 Waste heat by end-use in other business services*

<table>
<thead>
<tr>
<th>Unit</th>
<th>TJ</th>
<th>TJ</th>
<th>TJ</th>
<th>TJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>Boiler losses</td>
<td>Refrigeration/cooling</td>
<td>Compressors</td>
<td>IT, electronics and electrical</td>
</tr>
<tr>
<td>MA Consultancy etc.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>690010 Legal activities</td>
<td>1.9</td>
<td>8.3</td>
<td>0.8</td>
<td>8.7</td>
</tr>
<tr>
<td>690020 Accounting and bookkeeping activities</td>
<td>4.2</td>
<td>14.4</td>
<td>1.4</td>
<td>15.1</td>
</tr>
<tr>
<td>700000 Business consultancy activities</td>
<td>10.7</td>
<td>2.5</td>
<td>0.3</td>
<td>2.7</td>
</tr>
<tr>
<td>710000 Architectural and engineering activities</td>
<td>14.0</td>
<td>41.7</td>
<td>4.2</td>
<td>43.8</td>
</tr>
<tr>
<td>MB Scientific research and development</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>720001 Scientific research and development (market)</td>
<td>0.8</td>
<td>3.0</td>
<td>0.3</td>
<td>3.2</td>
</tr>
<tr>
<td>720002 Scientific research and development (non-market)</td>
<td>1.7</td>
<td>5.9</td>
<td>0.6</td>
<td>6.2</td>
</tr>
<tr>
<td>MC Advertising and other business services</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>730000 Advertising and market research</td>
<td>5.1</td>
<td>10.4</td>
<td>1.0</td>
<td>10.9</td>
</tr>
<tr>
<td>740000 Other technical business services</td>
<td>4.2</td>
<td>2.6</td>
<td>0.3</td>
<td>2.7</td>
</tr>
<tr>
<td>750000 Veterinary activities</td>
<td>2.1</td>
<td>2.3</td>
<td>0.2</td>
<td>2.4</td>
</tr>
<tr>
<td>N Travel agents, cleaning, and other operational services</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>770000 Rental and leasing activities</td>
<td>6.5</td>
<td>10.1</td>
<td>1.0</td>
<td>10.6</td>
</tr>
<tr>
<td>780000 Employment activities</td>
<td>3.4</td>
<td>7.6</td>
<td>0.8</td>
<td>8.0</td>
</tr>
<tr>
<td>790000 Travel agent activities</td>
<td>1.3</td>
<td>3.1</td>
<td>0.3</td>
<td>3.2</td>
</tr>
<tr>
<td>800000 Security and investigation activities</td>
<td>5.3</td>
<td>1.2</td>
<td>0.1</td>
<td>1.3</td>
</tr>
<tr>
<td>810000 Services to buildings, cleaning and landscape activities</td>
<td>39.7</td>
<td>9.3</td>
<td>0.9</td>
<td>9.7</td>
</tr>
<tr>
<td>820000 Other business service activities</td>
<td>4.2</td>
<td>4.5</td>
<td>0.4</td>
<td>4.7</td>
</tr>
<tr>
<td>Total</td>
<td>105</td>
<td>127</td>
<td>13</td>
<td>133</td>
</tr>
</tbody>
</table>

5.9 Public administration, education and health

In the table below the amount of waste heat from the public administration, education and health sector can be seen.

*Table 11 Waste heat by end-use in public administration, education and health*
5.10 Arts, entertainment and other services

In the table below the amount of waste heat from the arts, entertainment and other service can be seen.

Table 12 Waste heat by end-use in arts, entertainment and other services

<table>
<thead>
<tr>
<th>Unit</th>
<th>TJ</th>
<th>TJ</th>
<th>TJ</th>
<th>TJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_5 Arts, entertainment and other services</td>
<td>Boiler losses</td>
<td>Refrigeration/Cooling</td>
<td>IT, electronics and electrical</td>
<td>Total</td>
</tr>
<tr>
<td>900000 Theatres, concerts, and arts activities</td>
<td>4.9</td>
<td>28.4</td>
<td>5.7</td>
<td>39</td>
</tr>
<tr>
<td>910001 Libraries, museums and other cultural activities (market)</td>
<td>0.4</td>
<td>3.0</td>
<td>0.6</td>
<td>4</td>
</tr>
<tr>
<td>910002 Libraries, museums and other cultural activities (non-market)</td>
<td>4.2</td>
<td>43.9</td>
<td>8.8</td>
<td>57</td>
</tr>
<tr>
<td>920000 Gambling and betting activities</td>
<td>0.4</td>
<td>2.1</td>
<td>0.4</td>
<td>3</td>
</tr>
<tr>
<td>930011 Sports activities (market)</td>
<td>4.3</td>
<td>35.7</td>
<td>7.1</td>
<td>47</td>
</tr>
<tr>
<td>930012 Sports activities (non-market)</td>
<td>3.7</td>
<td>21.4</td>
<td>4.3</td>
<td>29</td>
</tr>
<tr>
<td>930020 Amusement and recreation activities</td>
<td>3.2</td>
<td>14.7</td>
<td>2.9</td>
<td>21</td>
</tr>
<tr>
<td>SA Other service activities</td>
<td>5.4</td>
<td>12.6</td>
<td>4.2</td>
<td>22</td>
</tr>
<tr>
<td>940000 Activities of membership organisations</td>
<td>7.2</td>
<td>2.7</td>
<td>0.9</td>
<td>11</td>
</tr>
<tr>
<td>960000 Other personal service activities</td>
<td>6.2</td>
<td>18.2</td>
<td>6.1</td>
<td>30</td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
<td>183</td>
<td>41</td>
<td>264</td>
</tr>
</tbody>
</table>

5.11 Buildings summary

The summary of the building waste heat can be seen in the two following figures. Figure 7 shows the total amount of waste heat from each process and the related temperature inter-
vals. From the figure it can be seen that the majority of waste heat is to be found at refrigeration/cooling. One of the main reasons is that this process is very common and has a relatively high potential for heat recovery.

Figure 7 building waste heat, temperatures and processes

Figure 8 shows that in the building category the waste heat recovery potential is below 80°C, with the majority below 40°C. The reason for the relatively low temperature of all the building related processes are that temperature requirements of the main energy use is quite low.
6 Utility services

The utility service category includes supply of electricity, natural gas, district heating, etc. via permanent infrastructure. That also includes the operation of electrical and gas facilities that generate controls and distributes electricity or gas and the supply of steam and air conditioning. The following four sectors are included in this category:

- Electricity supply
- Steam and hot water supply
- Gas supply
- Water supply, sewerage and waste management

6.1 Methodology and references

The waste heat energy is found based on the energy consumption distribution of different processes that give out waste heat, but the processes in Utility category are greatly different from the previous categories as well as within the category. Electricity and heating supply do not share the same processes with for example sewerage management. Detailed methodology is described under every subsector of utility services.

6.2 Electricity supply

For electricity supply, we concentrate on electricity generated by the conventional power plants (exclude electricity from all renewable energy sources), specifically combined heat and power (CHP) plants in Denmark, as there is almost no sole power plant left in Denmark. Approx. 26% of the energy consumed to produce electricity come from renewable sources and the rest from conventional power plants. There is approx. 99.5% of the electricity out of all electricity produced by conventional power plants is produced by CHP plants. The few power plants or smaller installations that only produce electricity are mainly used for backup.

In Denmark electricity is produced on:

- Steam power plants
- Gas turbines
- Combined cycles
- Combustion engines

Data from Energistyrelsens Energiproducenttælling (2012) is used to estimate the percentage of fuel consumption by each technology and the amount of waste heat produced. Temperature intervals are then calculated based on assumption or based on literature review.

Steampower plants

Waste heat energy: Most of the input energy is consumed by steam power plants in CHP plants, approx. 75.8% of the fuel consumption is used here, out of which 69% of the energy is given out as heat, and 64% of the heat is already utilised as heat production.

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14 Energistyrelsens Energiproducenttælling, 2012 (EEPT)
Temperature: 2/5 of the waste heat is in 5-20 °C water in condenser, and 3/5 of the waste heat energy is in 135-180 °C flue gas.\textsuperscript{15} 

Medium of waste heat: Water and flue gas

Assumptions/limitations: The waste heat of the flue gas is probably not useful due to corrosion. The condenser waste heat is probably not relevant to use in practice.

Gas turbines

Waste heat energy: Gas turbines consume 3,9% of the input fuel in the sector, out of which 71% of the energy is given out as heat, and 64% of the heat is utilised as heating supply.\textsuperscript{14}

Temperature: 120-140 °C\textsuperscript{16}

Medium of waste heat: Flue gas

Assumptions/limitations: Assumed that all gas turbines are CHP plants, and that the exhaust gasses therefore are cooled to the minimum temperature limit.

Combined cycles

Waste heat energy: 13,2% of the fuel is used in combined cycles in this sector, out of which 66% of the energy is given out as heat, and 74% of the this heat energy is already utilised.\textsuperscript{14}

Temperature: 2/5 of the waste heat is in 5-20 °C water in condenser, and 3/5 of the waste heat energy is in 135-180 °C flue gas.\textsuperscript{15}

Medium of waste heat: Water and flue gas

Assumptions/limitations: -

Combustion engines

Waste heat energy: approx. 7% of the input fuel is used in combustion engines, out of which 62% of the energy is given out as heat, but 82% of the heat is already being utilised.\textsuperscript{14}

Temperature: 120-140 °C (see assumptions/limitations)

Medium of waste heat: Flue gas

Assumptions/limitations: Assuming that natural gas is burned in both gas turbines and combustion engines and both are CHP plants, it is assumed that the exhaust gasses are cooled to the minimum temperature limit. The temperature limit is depending on the fuel so with the assumptions above it is expected that the temperature limit is the same as gas turbines.

\textsuperscript{15} Nag, Power Plant Engineering, third edition, page 374
\textsuperscript{16} Saravanamutto et al., Gas Turbine Theory, sixth edition, page 92
6.3 Steam and hot water supply

This section includes the production, collection and distribution of steam and hot water for the production of heating, power and other objects as well as production and distribution of air condition i.e. cooled air and water for cooling purposes.

In Denmark heat is generated from:

- Boilers
- Heating elements
- Waste heat from Industrial processes
- Solar thermal

Data from Energistyrelsens Energiproducenttælling (2012) is used to estimate the percentage of fuel consumption by each technology and the amount of waste heat produced. Temperature intervals are then calculated based on assumption or based on literature review.

Boiler

Waste heat energy: Boiler accounts for 90.9% of the energy consumption in heating supply\textsuperscript{14}. All of this energy is converted into heat, however 93% of the heat is already utilised for supplying heat\textsuperscript{14}.

Temperature: 120-180\textdegree C\textsuperscript{15,16}

Medium of waste heat: Flue gas

Assumptions/limitations: -

Heating element

Waste heat energy: Approx. 1.5% of the energy consumption is given out as heat by the heating element and all of this waste heat energy can be utilised\textsuperscript{14}.

Temperature: 50-100\textdegree C

Medium of waste heat: Water

Assumptions/limitations: When level of utilization is very high, temperature range assumed to be in the vicinity of the district heating water return temperature.

Waste heat from Industrial processes

Waste heat energy: approx. 6.72% of energy in heating supply comes from industrial waste heat, which are 99% utilised in district heating supply\textsuperscript{14}.

Temperature: 50-100\textdegree C

Medium of waste heat: Water
Assumptions/limitations: When level of utilization is very high, temperature range assumed to be in the vicinity of the district heating water return temperature.

Solar thermal

Waste heat energy: Approx. 0.81% of the energy consumption in heating supply comes from solar thermal energy, and 98% of it is already utilised\(^1\).

Temperature: 50-100°C

Medium of waste heat: Water

Assumptions: When level of utilization is very high, temperature range assumed to be in the vicinity of the district heating water return temperature.

Table 13 Waste heat by end-use in electricity, steam and hot water supply

<table>
<thead>
<tr>
<th>Unit Description</th>
<th>Process</th>
<th>Steam power plants</th>
<th>Gas turbines</th>
<th>Combined cycles</th>
<th>Combustion engine</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>350010 Production and distribution of electricity</td>
<td>37.353</td>
<td>1.272</td>
<td>4.537</td>
<td>1.553</td>
<td>44.713</td>
<td></td>
</tr>
<tr>
<td>350030 Steam and hot water supply</td>
<td>2.104</td>
<td>2</td>
<td>32</td>
<td>7</td>
<td>2.145</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>39.457</td>
<td>1.274</td>
<td>4.568</td>
<td>1.559</td>
<td>46.858</td>
<td></td>
</tr>
</tbody>
</table>

6.4 Gas supply

In the subsector Gas Supply, it can be seen from the raw data obtained from Statistics Denmark\(^1\) that the production and importation of nature gas in this sector equals to the nature gas consumption in all other business sectors and households combined plus the exportation. Its own fuel consumption is very small, and there is fuel loss during distribution and transportation as such, but no waste heat is generated. It is therefore assumed that there is no waste heat potential in the Gas Supply subsector, as the fuel is consumed and converted by the end users\(^1\).

6.5 Water supply

In the water supply there are no significant heat sources and there for no further work has been done to this sector.

6.6 Sewerage

In Denmark there are more than 1.400 sewerage plants that treat waste water from households, institutions and industry.

\(^1\) Calculations based on the energy consumption data from Statistics Denmark

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Waste heat sources in the sewerage sector are identified as:

- Treated waste water
- Surplus heat from biogas production
- Sludge for disposal
- Drying of sludge
- Air in the oxidation process

Only the first three sources stated above are evaluated to have a significant potential and therefore they are the only three where the potential is calculated. The remaining sources are mentioned as alternative options.

In the calculations it is assumed that the fluid products are cooled to 10°C and the gas products are cooled to 40 °C.

The waste heat is estimated on the basis of interviews with technical managers from waste water treatment plants, records from Ministry of the Environment and experiences from Viegand Maagøes reporting of energy savings from several projects within this sector.

**Treated waste water**

The total amount of water being treated at waste treatment plant is approximately 800 mill. m³ (see Figure 9), each year almost 100% is being discharged to the water environment. On top of that the Danish industry is discharging approximately 45 mill. m³ each year (see Figure 10). Data is based on “punktkilderapporten2012”\(^{18}\) which includes large waste water treatment plants and large industries. The remaining waste water treatment plants and industries are neglected at this stage, because the contribution from each of them is minor. The temperatures of the treated water that are leaving the plants is between 8-18°C, with an average temperature of 12°C\(^{19}\) (low temperatures in the winter). Based on the amount of water and the assumed temperature the heat content is equivalent to 7.1 PJ per year.

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\(^{18}\) Punktkilder 2012, Miljøministeriet/Naturstyrelsen, 2013

\(^{19}\) Interview with Bjarne Christensen from Vand Center Syd, on the 22th of September 2014
Surplus heat from biogas production:

A side effect of the waste water treatment is a biogas production. The biogas is most cases used to produce electricity on a gas motor and the waste heat from the motor is then used to produce heat for buildings, production and in some cases for district heat. The amount of biogas produced on a yearly basis is determined on the amount of dry matter in sludge for biogas production which is approximately 105.000 ton/ per year and a specific number of 400 Nm³ biogas/ton dry matter in the sludge (Randers Spildevand A/S 399 Nm³ biogas/ton dry matter in the sludge). The specific number is based on data from approximately 25 waste

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20 Punktkilder 2012, Miljøministeriet/Naturstyrelsen, 2013, bilag 3 page 15
21 Punktkilder 2012, Miljøministeriet/Naturstyrelsen, 2013, bilag 3 page 23
Viegand Maagøe | [THERMCYC]
water treatment biogas plants. The production of biogas from the Danish waste water treatment plants can then be calculated to approximately 42 mill Nm\(^3\)/year. The biogas has an averages heating value of 23 GJ/1000 Nm\(^3\). The efficiency of the biogas motor is quite high because both electricity and heat are produced on the motor. The overall motor/heat efficiency is in the area of 80-96% depending on the cooling conditions on the individual sites. If there is a good cooling condition the efficiency can exceed 100%. Fumes from the motor are in the area of 60-65 °C (depending on cooling conditions). The temperature of the fumes from the gas motor is in the area of the dew point which is around 60°C. With an assumed cooling to 40°C the condensation point is being reached and therefore an efficiency improvement of 10-15% is with reasonable. If an average of 10% is used then this is equivalent to 0.1 PJ per year at a temperature of 60-65°C.

**Sludge for disposal**

The total amount of sludge from Danish waste water plants is found to be approximately 500.000 ton/year. The sludge is leaving the waste water plants has temperature of approximately 30 °C. Based on these assumptions the potential energy content in the sludge is 0.04 PJ/year.

**Drying of sludge**

From the dewatering process the sludge is being treated (dried) directly on the waste water treatment plants or is transported to other drying facilities. Air is used to condensate the water in the drying air. The air that is leaving the drying facilities has a temperature on approximately 40°C.

**Air in the oxidation process**

Approximately 40 % of the waste water treatment plants are using bottom aeration. In this process blowers are used to blow air from the bottom basing and up through the waste water. The blowers have to overcome the static pressure of the water. In the process of pressurizing, the air is heated to more than 100°C. The temperature does not have a positive effect of the oxidation process and therefore heat recovery from the air is an option. However the energy in the air is to a large extent being transferred to the water and which can be recovered in the treated waste water (as described in the section about treated waste water) and therefore the potential for heat recovery in not taking in to account here.

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22 Interview with Thomas Sørensen from Danva 2/10 2014
24 Notat: Standardfaktorer for brændværdier og CO2 -emissioner - indberetning af CO udledning for 2013, Energistyrelsen, 2014
25 Krav til gaskvalitet, Bilagsrapport til: Afsætning af renset og opgradere, biogas via naturgasnettet, Klientrapport, Juni 1994
At the waste water treatment plants with bottom aeration approximately 50%\(^{27}\) of the electrical energy is used in the aeration blowers.

**Figure 11 Waste heat by processes in sewerage sector**

<table>
<thead>
<tr>
<th>Unit</th>
<th>TJ</th>
<th>TJ</th>
<th>TJ</th>
<th>TJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treated waste water</td>
<td>7.100</td>
<td>100</td>
<td>40</td>
<td>7.240</td>
</tr>
<tr>
<td>Surplus heat from biogas production</td>
<td>7.100</td>
<td>100</td>
<td>40</td>
<td>7.240</td>
</tr>
<tr>
<td>Sludge for disposal</td>
<td>7.100</td>
<td>100</td>
<td>40</td>
<td>7.240</td>
</tr>
</tbody>
</table>

### 6.7 Waste management and material recovery

Waste management in Denmark is well in control and no longer a major environmental issue, as waste landfill has stopped since 1997 and a majority of the waste has been contributing to supply electricity and heat. In 2007 waste is responsible for 20% of Denmark’s total district heating production and 4.5% of the total electricity production. Approx. 67% of the embedded energy in waste is converted to district heating while 15% is converted to electricity\(^{28}\). Steam power plants, boilers and combined cycles are typically used to convert energy from waste into electricity or heat\(^{29}\). According to Statistics Denmark, the fuel consumption in this sector is mainly the biodegradable and non-degradable waste plus a trivial amount of other fuel types. Sector’s own electricity and heating consumption is not taken into account.

In Denmark most of the waste is being converted into electricity or heat by:

- Steam power plants
- Boilers
- Combined cycles

Data from Energistyrelsens Energiproducenttælling (2012) is used to estimate the percentage of fuel consumption (in this case only the biodegradable and non-degradable waste) by each technology and the amount of waste heat produced. Temperature intervals are assumed to be same as in the electricity and heating supply because of the same technologies used.

**Steam power plants**

**Waste heat energy:** Majority of the input energy is consumed by steam power plants in waste management sector, approx. 76% of the fuel consumption is used here, out of which 82% of the energy is given out as heat, and 83% of the heat is already utilised as heat supply\(^{29}\).

**Temperature:** 2/5 of the waste heat is in 5-20 °C water in condenser, and 3/5 of the waste heat energy is in 135-180 °C flue gas.

**Medium of waste heat:** Water and flue gas

**Assumptions/limitations:** Temperature and medium are assumed same as steam power plants in electricity supply.

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\(^{28}\) [http://www.ens.dk/undergrund-forsyning/vedvarende-energi/bioenergi/affaldsforbraending](http://www.ens.dk/undergrund-forsyning/vedvarende-energi/bioenergi/affaldsforbraending)

\(^{29}\) Energistyrelsens Energiproducenttælling, 2012 (EEPT)
Boiler

Waste heat energy: Boiler accounts for 10% of the energy consumption in waste incineration\textsuperscript{14}. All of this energy is converted into heat, however 77% of the heat is already utilised for supplying heat\textsuperscript{14}.

Temperature: 120-180°C

Medium of waste heat: Flue gas

Assumptions/limitations: Temperature and medium are assumed the same as boiler in steam and hot water supply.

Combined cycles

Waste heat energy: 14% of the fuel is used in combined cycles in this sector, out of which 84% of the energy is given out as heat, and 71% of this heat energy is already utilised for supplying heat\textsuperscript{14}.

Temperature: 2/5 of the waste heat is in 5-20 °C water in condenser, and 3/5 of the waste heat energy is in 135-180 °C flue gas.

Medium of waste heat: Water and flue gas

Assumptions/limitations: Temperature and medium are assumed the same as combined cycles in electricity supply.

<table>
<thead>
<tr>
<th>Table 14 Waste heat by systems in waste management and material recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
</tr>
<tr>
<td>Process</td>
</tr>
<tr>
<td>Waste management and materials recovery</td>
</tr>
</tbody>
</table>

6.8 Utility summary

The summary of the utility waste heat can be seen in the two following figures. Figure 13 shows the total amount of waste heat from each process and the related temperature intervals. From the figure it can be seen that the majority of waste heat is at the steam power plants. The reason for this is that steam power plants are the most common process in the Danish utility system. Waste heat from the flue gas has a relatively high temperature (135-180°C).
Figure 13 shows that the utility and roughly be divided into a high temperature category and a low temperature category, with the majority of waste heat in the high temperature category. In the high temperature category temperature interval is from 120°C to 180°C.

Figure 13 total utility waste heat and cumulative waste heat
7 Construction
This section includes general construction and specialized construction. It includes construction, repair, restoration and maintenance, additions and alterations, construction of prefabricated construction on installation site and the construction of a more temporary nature.

In the construction sector, much of the energy consumption that ends up as waste heat is consumed in temporary installations, shelters, containers and offices which are normally removed after construction and renovation.

In Figure 14 a typical energy distribution on a construction site can been seen. From the figure it is clear that the majority of the energy consumption is thermal. Because of the nature of the construction sites it is not possible to control the flow of waste heat at this stage.

![Typical energy consumption on construction sites](image-url)

Some waste heat could be utilised from the consumption in the permanent offices for construction companies and contractors etc. However there is no clear distinction between the energy consumption on construction sites and in permanent office buildings, therefore it was not possible to evaluate the amount of waste heat that can be utilised.

8 Transport
This sector usually includes activities related to passenger and freight transport by trains, vehicles, ships, planes or in the pipeline and associated business such as terminal and parking facilities, cargo handling, storage, etc. It also includes rental of transport equipment with driver or operator and postal and courier activities.

8.1 Methodology and references
The waste heat energy is found based on the energy consumption distribution of different processes that give out waste heat, the processes in maritime and in land transport by trucks

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are similar, but the temperatures are different. See the detailed methodology under the sub-sections.

8.2 Air transport
Due to the lack of information and data, this study will not estimate waste heat from transport by air.

8.3 Water transport
The main processes (or sources to thermal waste heat) in this subsector is:

- Charge Air Cooling/Scavenge air cooling
- Exhaust gas thermal energy
- Heat to engine coolant/Jacket cooling water
- Electricity and district heating consumption

Charge Air Cooling/Scavenge air cooling

*Waste heat energy:* In maritime sector the charge air cooling account for 16% of the fuel consumption\(^{31}\). 20 % of the energy consumed in this process can be utilisable waste heat. It is assumed that approx. 5% of this energy is already utilised\(^ {32} \).

*Temperature:* The temperature of the waste heat from charge air cooling is approx. 90-170 °C\(^ {32} \).

*Medium of waste heat:* Air

*Assumptions/limitations:* -

Exhaust gas thermal energy

*Waste heat energy:* In maritime sector the thermal energy in the exhaust gas account for 25% of the fuel consumption\(^ {31} \). 50% of the energy can be utilisable waste heat and it is assumed that 10% of the utilisable waste heat is already being recovered\(^ {32} \). New ships in Maersk container fleet have waste heat recovery system that utilizes the potential of exhaust gas thermal energy. Restriction is the dew point of sulphuric acid in the fuel that does not allow exhaust gas temperature to be lower than approx. 160 °C\(^ {32} \).

*Temperature:* The temperature of waste heat from exhaust gas is typically 200-400 °C\(^ {32} \).

*Medium of waste heat:* Hot exhaust gas.

*Assumptions/limitations:* -

Heat to engine coolant/Jacket cooling water

\(^{31}\) Inputs from MAN Diesel & Turbo, August 2014.
\(^{32}\) Inputs and estimates from Maersk, September 2014.
In most ships part of the main engine jacket cooling water is used to produce freshwater on board the ship.

**Waste heat energy:** In maritime sector jacket cooling water system account for 6% of the fuel consumption\(^3\), out of which 95% can utilised as waste heat. Approx. 70% of this waste heat is already being used today\(^3\).

**Temperature:** The temperature is approx. 80 - 130 °C\(^3\).

**Medium of waste heat:** Water

**Assumptions/limitations:** -

**Electricity and district heating consumption**

The electricity and district heating consumption are assumed to be mainly used by offices that support the maritime sector. End-use is similar to those in Building category, therefore the electricity and district heating consumption by each end-use is based on estimations for “Public administration” subsector. These processes are included in the calculation:

- Refrigeration/cooling
- IT, electronics and electrical

**8.4 Road transport**

Due to the lack of information and data, this study will not estimate waste heat from transport by land with exception of trucks.

The energy consumption data is obtained from Statistics Denmark for road and pipeline transport of goods. It is assumed that all diesel fuel in this subsector is consumed by road transport of goods, hence trucks. The fuel consumption of Danish trucks abroad is not accounted for, as the sum would far exceed the Danish Energy Agency’s Projection (2014), as shown below. In 2012 trucks have a total energy consumption of approx. 20 PJ, this fits with the data for transportation by trucks within Denmark.
Typically commercial vehicles lose approximately 52% of the fuel energy in a form of heat, and the rest 48% of fuel is utilized for driving the vehicle or lost to frictions. The figure below shows the fuel energy distribution on a commercial vehicle.

**Figure 16 Fuel consumption distribution and losses based on a commercial vehicle**

**Charge Air Cooling**

- **Waste heat energy**: 8% of the fuel consumption is given out as heat in charge air cooling.
- **Temperature**: The temperature of the waste heat from charge air cooling is approx. 90-170 °C.
- **Medium of waste heat**: Air
- **Assumptions/limitations**: Assumed same temperature interval as in maritime sector and 3% of the waste heat can be utilised.

**Exhaust gas thermal energy**

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34 http://www.nowasteproject.eu/home.php
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Waste heat energy: The highest amount of heat is lost in the exhaust gas. 29% of the fuel consumption is given out as heat.

Temperature: The temperature of waste heat from exhaust gas is approx. 200-330 °C\textsuperscript{35}.

Medium of waste heat: Hot exhaust gas.

Assumptions/limitations: Assumed the temperature interval lie within that of maritime sector and 40% of the waste heat can be utilised.

Heat to engine coolant

Waste heat energy: 15% of the fuel consumption is given out as heat here.

Temperature: The temperature is approx. 80 – 85 °C\textsuperscript{35}.

Medium of waste heat: Water

Assumptions/limitations: Assumed the temperature interval lie within that of maritime sector and 1% of the waste heat can be utilised.

8.5 Transport summary

The summary of the transport sector waste heat can be seen in this section. Figure 17 to Figure 22 show Figure 21 waste heat and the related temperature intervals for the different sectorsthe total amount of waste heat from each process and the related temperature intervals.

Table 15 Waste heat by processes and end-use in transportation

<table>
<thead>
<tr>
<th>Unit</th>
<th>TJ</th>
<th>TJ</th>
<th>TJ</th>
<th>TJ</th>
<th>TJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>H Transportation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charge Air Cooling/ scavenge air cooling</td>
<td>38</td>
<td>1.819</td>
<td>24</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Exhaust gas thermal energy</td>
<td>52.501</td>
<td>8.247</td>
<td>27</td>
<td>14</td>
<td>73.743</td>
</tr>
<tr>
<td>Heat to engine coolant/Jacket water</td>
<td>54.320</td>
<td>8.271</td>
<td>27</td>
<td>14</td>
<td>75.622</td>
</tr>
<tr>
<td>Refrigeration/cooling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IT, electronics and electrical</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>12.991</td>
<td>54.320</td>
<td>8.271</td>
<td>27</td>
<td>14</td>
</tr>
</tbody>
</table>

\textsuperscript{35} V. Dolz, et al. (2012) HD Diesel engine equipped with a bottoming Rankine cycle as a waste heat recovery system. Part 1: Study and analysis of the waste heat energy

42
Figure 17 process waste heat and temperature intervals from road transport by trucks

Figure 18 sum of waste heat from road transport by trucks and the cumulative waste heat as a function of the temperature.
There is a large potential of waste heat in transport sector which includes only the water transport and road transport by trucks. Most of the waste heat energy lies in exhaust gas and the temperature of which is quite high compared to other sources of waste heat. Waste heat from 80 °C up to 160 °C can be found in charge air cooling and heat to engine cooling.
9 Geothermal

In terms of mapping the geothermal potential in Denmark a number of different studies have been conducted. The studies has been initiated both by the Danish department of energy and EU. The studies has been conducted mainly by DONG Energy, Hovedstadsområdets Geotermiske Samarbejde (HGS), De Nationale Geologiske Undersøgelser for Danmark og Grønland (GEUS) og Dansk Fjernvarmes Geotermiselskab. In Annex II a literature study has been made within the Thermcyc project, with the focus on the Danish Geothermal potential.

At this stage only detailed studies has been conducted locally and therefore an exact overview of the geothermal energy potential in Denmark is not possible to give.

It should also be mentioned that EA energianalyse, COWI, GEUS and Dansk Fjernvarmes Geotermiselskab is conducting a resource assessment of geothermal potential in Denmark. The assessment is expected to be completed during the summer 2015. Furthermore then GEUS is making an update of the geological map of Denmark.

The Danish underground contains very large geothermal resources in the form of deep or shallow soil geothermal energy. All geothermal energy in Denmark is in a global context categorized as low temperature, due to the nature of the Danish underground. The geothermal temperature can vary from 8°C up to 90°C, depending on a number of local conditions.

Deep geothermal energy is characterized by relatively high temperature and deep wells. In Denmark the geothermal gradient is approximately 30 °C/km calculated from the surface, but can have large local variations. Due to the nature of the Danish reservoirs geothermal heat can be extracted from depth up to 3 km, resulting in a production temperature of up to 90 °C. Energy in the deep geothermal reservoirs is primarily generated by radioactive decay from a number isotopes and the heat conducted from the core of the earth.

Shallow soil geothermal energy: This is characterized by low temperature and shallow installations. The temperature is in the range of 8-11 °C and the installation depth is in the range of 0-100 m. The energy is primarily generated from the radiation from the sun and only to a minor extent from the heat flux from the ground.

Based on the evaluation of the different studies it is clear that there is a huge energy potential for utilizing geothermal energy. In the case of deep geothermal energy there is a potential of reaching temperatures up to 90 °C, with a thermal gradient of 30 °C/km. The energy that can be extracted and the temperatures that can be reached are very much depending on regional and local reservoir conditions. Based on the summary of resources over the Danish area, resources as high as 20 GJ/m² can be found. The summarized map of resources is the sum of several sub maps of different geological formations.

The big challenges that deep geothermal energy exploration is facing is gathering sufficient and reliable data. Geothermal pre-investigations and exploration drilling are very costly, in the area of 65 mio. DDK. The relatively high pre-investigations costs acts as a bottleneck in order to determine the deep geothermal potential in Denmark. Deep geothermal energy with the present technologies is only suited for large users or user networks such as district heating.

With regards to the shallow soil geothermal energy the the temperature levels is in the area of 8-11 °C. The heat content is also in this context very large. The potential is here depending on local thermal conditions, local legislation, type of extraction technology, equipment
prices and development and local energy prices. The utilisation of shallow soil geothermal energy is most suited for smaller consumers with the current technical systems.

10 Solar thermal
As solar thermal does not involve different energy consuming processes as in the industry and such, the different types of solar thermal are identified with feasibility to the location available. The solar atlas for Denmark\(^\text{36}\) is used to crosscheck the suitability of location on top of buildings. All unbuilt and unused land is assumed to be available for installing solar thermal. The locations available and suitable to install solar thermal are then divided into five groups according to the Danish geographic distribution of buildings and land. The five main groups are: residential, agricultural, industrial, commercial and public.

This chapter discusses only the solar thermal potential on top of the existing solar thermal installations in Denmark. It should be noted that in reality the coverage of solar thermal devices has a direct impact on the geothermal potential, as the solar radiation absorbed by ground can be greatly reduced if a large area of land is being covered by solar thermal installations, however in this study geothermal and solar thermal are treated as independent potentials, in order to give an overall picture of total potential energy can be extracted from each. If both geothermal and solar thermal potentials are to be investigated further in this project, measures would be carried out to avoid double counting of potentials.

The suitable area in Denmark for solar energy installation includes installation on roofs, facades and land. The area is available residential, agricultural, industrial and commercial sectors\(^\text{37}\). The public sector is assumed to be primarily the open land areas. The study\(^\text{37}\) defines suitable areas, as areas with a minimum radiation of 80% of the countries maximum annual solar radiation. In Denmark the maximum solar radiation is achieved for areas with a 40° tilt towards south and is 1200 kWh per m\(^2\) and year\(^\text{38}\).

The conversion of solar radiation into heat depends on the used technology and temperature difference between ambient and solar collector fluid. Based on the efficiency curves for uncovered, standard flat plate and evacuated tube collectors\(^\text{39}\) the amount of usable energy can be determined. The efficiencies for standard flat plate and evacuated tube collectors in different sectors are typically as follows:

\[\text{Table 16 Assumed solar thermal technologies and efficiencies for different sectors}\]

<table>
<thead>
<tr>
<th>Type of collectors</th>
<th>Sectors</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard flat plate</td>
<td>Residential</td>
<td>38%</td>
</tr>
<tr>
<td></td>
<td>Public</td>
<td>40%</td>
</tr>
<tr>
<td>Evacuated tubes</td>
<td>Agriculture</td>
<td>28%</td>
</tr>
<tr>
<td></td>
<td>Industrial</td>
<td>28%</td>
</tr>
<tr>
<td></td>
<td>Commercial</td>
<td>40%</td>
</tr>
</tbody>
</table>

Solar thermal collectors in the residential sector are primarily used for domestic hot water and space heating, where typically temperatures of 50° to 80°C are achieved with flat plate

\(^{36}\) [http://www.energyroof.dk/](http://www.energyroof.dk/)

\(^{37}\) Potential for Building Integrated Photovoltaics; IEA - PVPS T7-4: 2002


\(^{39}\) Jan Erik Nielsen; European Solar Thermal Association; 2006
collectors\textsuperscript{40}. Low temperature process heat for the agricultural and industrial sector is obtained with evacuated tube collectors. As the solar radiation in Denmark consists of a high share of diffuse solar radiation, other technologies such as and Linear Fresnel type collectors cannot be used. An achievable temperature for process heat in Northern Europe is found to be between 80°C and 100°C with evacuated tube collectors. The public sector is assumed to provide primarily district heating at temperatures of 70°C to 75°C. \textsuperscript{41, 42, 43}

Table 17 Potential solar thermal energy by sectors

<table>
<thead>
<tr>
<th>Unit</th>
<th>Residential</th>
<th>Agricultural</th>
<th>Industrial</th>
<th>Commercial</th>
<th>Public</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>TWh/year</td>
<td>26</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>106</td>
<td>146</td>
</tr>
<tr>
<td>TJ/year</td>
<td>91,877</td>
<td>16,160</td>
<td>14,109</td>
<td>21,980</td>
<td>380,796</td>
<td>524,922</td>
</tr>
</tbody>
</table>

The summary of mapping solar thermal potential can be seen in the two following figures. Figure 21 shows the total amount of waste heat from sector and the related temperature intervals. From the figure it can be seen that the majority of accessible heat is at the residential and public sector.

The potential in residential sector is high because of the large number of residential buildings.

The potential in public sector is high mainly because large central solar systems built on open land are included in this sector and also to a minor extent there are a great amount of public buildings with large suitable surface areas. The temperature and the interval are determined based on a normal production for the district heating.

\begin{center}
\includegraphics[width=\textwidth]{figure21.png}
\end{center}

\textit{Figure 21 waste heat and the related temperature intervals for the different sectors}

\textsuperscript{40} W. Weiss, Romme M. (2008); Process Heat Collectors: State of the Art within Task 33/IV;
\textsuperscript{41} Werner Weiss, AEE – Institute for Sustainable Technologies; Peter Biermayr, Vienna University of Technology; Potential of Solar Thermal in Europe
\textsuperscript{42} IEA, 2012, Paris; Technology Roadmap: Solar Heating and Cooling
\textsuperscript{43} http://www.energiøresund.dk/billeder/filer/Rapporter/MarstalFjernvarme.pdf
Figure 22 shows clearly that the majority is below 70°C, but temperatures up to 100°C by the use of evacuated tube collectors.

Figure 22 sum of waste heat from the solar thermal sector and the cumulative waste heat as a function of the temperature.

11 Air and water
Air and water are sources of abundant low temperature heat energy and therefore it has been chosen to include them in this study. Both air and water can be compared to geothermal and solar energy to some extent, because the energy sources are based on reservoirs large enough to cover the Danish energy consumption. Here it is only a matter of technical and economical limitations.

Therefore it is chosen to illustrate the potential for the utilisation only by the temperatures and the yearly variation of the two sources.
The average air temperature in Denmark varies from 1.2 °C in February to 17.4 °C in July, with average variation for night to day from 4.1 °C to 9.2 °C.

In the figure below shows the monthly average water temperature for Copenhagen. The temperature varies from 2 °C in the winter months to 17 °C in the summer months.

As shown in the following figure the water temperature of Copenhagen’s coast is more or less representative of entire Denmark’s with a -2 °C difference in several areas. Therefore it is assumed that Copenhagen’s monthly water temperature can be a representative of Denmark’s coastal water temperature with the exception of East, and North-West coast of Jutland, as well as West coast of Zealand, which would be assumed 2 °C lower. Therefore heat from water can vary from 0 -17 °C throughout a year, with highest heat potential during July and August.

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44 http://www.dmi.dk/vejr/arkiver/normaler-og-ekstremer/klimanormaler-dk/vejrnormal/
45 http://www.mitrejsevejr.dk/l/vejret-danmark-vejrudsigt-temperatur-klima.php

Viegand Maagøe | [THERMCYC]

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Figure 25 Danish water temperature 01/09/2014

http://www.dmi.dk/hav/udsigter/havprognoser/#danmark
12 Results

Quantitative results of the study are presented in this section. The waste heat potentials are related to sectors and temperatures as well as exergy. It should be emphasised that the numerical results are based on estimations which contain uncertainties and cannot be taken as fact for how much waste heat there is in Denmark.

12.1 Total energy consumption and waste heat

In the following table, the total energy consumption is shown together with the total available waste heat estimated from each section. The savings in each sector ranches from 32/33 % in the trade and mining and quarrying sector to 3% in the Dwelling sector.

The high waste heat recovery potential in the mining and quarrying sector is primarily caused by the high energy consumption of evaporators.

In the trading sector the high waste heat recovery potential is caused by the relatively high amount of cooling which have a high amount of waste heat at a relatively low temperature.

The waste heat in the information and communication is caused by a large amount of refrigeration in combination with a high amount of electronics.

Dwelling is quite low, which are caused by a high amount of individual systems and a big contribution from district heat. The main reason of the difference between households and dwellings, which are alike in many ways, is that the proportion of the electricity consumption is less than in the household sector. A large amount of the electricity is related to refrigeration and cooling which have a relatively high potential for heat recovery.

As mentioned in section 2 the savings are estimated as individual savings and therefore that accumulative savings will be attached with some uncertainty, because the savings can have an effect on each other.

Table 18 shows the energy consumption and waste heat recovery potential in the different sectors.

<table>
<thead>
<tr>
<th>Reference No.</th>
<th>Sectors</th>
<th>Total Energy Consumption, TJ</th>
<th>Total available waste heat, TJ</th>
<th>Waste heat, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Households</td>
<td>272.889</td>
<td>24.038</td>
<td>9%</td>
</tr>
<tr>
<td>2</td>
<td>Agriculture, forestry and fishing</td>
<td>36.844</td>
<td>2.352</td>
<td>6%</td>
</tr>
<tr>
<td>3</td>
<td>Mining and quarrying</td>
<td>28.544</td>
<td>9.394</td>
<td>33%</td>
</tr>
<tr>
<td>4</td>
<td>Manufacturing</td>
<td>108.704</td>
<td>22.578</td>
<td>21%</td>
</tr>
<tr>
<td>5</td>
<td>Utility services</td>
<td>534.399</td>
<td>58.462</td>
<td>11%</td>
</tr>
<tr>
<td>6</td>
<td>Construction</td>
<td>19.581</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>7</td>
<td>Trade</td>
<td>41.961</td>
<td>13.478</td>
<td>32%</td>
</tr>
<tr>
<td>8</td>
<td>Information and communication</td>
<td>6.946</td>
<td>1.183</td>
<td>17%</td>
</tr>
<tr>
<td>9</td>
<td>Financial and insurance</td>
<td>2.539</td>
<td>123</td>
<td>5%</td>
</tr>
<tr>
<td>10</td>
<td>Real estate activities and renting of non-residential buildings</td>
<td>2.264</td>
<td>117</td>
<td>5%</td>
</tr>
<tr>
<td>11</td>
<td>Dwellings</td>
<td>953</td>
<td>24</td>
<td>3%</td>
</tr>
<tr>
<td>12</td>
<td>Other business services</td>
<td>10.681</td>
<td>378</td>
<td>4%</td>
</tr>
<tr>
<td>13</td>
<td>Public administration, education and health</td>
<td>30.783</td>
<td>3.177</td>
<td>10%</td>
</tr>
<tr>
<td>14</td>
<td>Arts, entertainment and other services</td>
<td>6.295</td>
<td>264</td>
<td>4%</td>
</tr>
<tr>
<td>15</td>
<td>Transport</td>
<td>546.813</td>
<td>75.622</td>
<td>14%</td>
</tr>
<tr>
<td>16</td>
<td>Geothermal</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Solar thermal</td>
<td>-</td>
<td>524.922</td>
<td></td>
</tr>
</tbody>
</table>
Figure 26 showing energy consumption and waste heat recovery potential in the different sectors.

Figure 27 shows the waste heat recovery potential in the different sectors.
12.2 Assessment of waste heat potential

As some waste heat is already utilised and impossible to extract, therefore not all processes are considered to give out useful waste heat. For each sector and each process that are found to have waste heat potential, the typical temperature range of the heat is defined in this section.

Table 19 assessment of waste heat potential

<table>
<thead>
<tr>
<th>Reference No.</th>
<th>Sectors</th>
<th>Potential assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Households</td>
<td>Highest potential lies in refrigeration and boiler losses. Temperature ranges from 20 to 100°C.</td>
</tr>
<tr>
<td>2</td>
<td>Agriculture, forestry and fishing</td>
<td>Highest waste heat potential lies in refrigeration at 20-40°C.</td>
</tr>
<tr>
<td>3</td>
<td>Mining and quarrying</td>
<td>Highest waste heat potential lies in evaporation at 35-50°C.</td>
</tr>
<tr>
<td>4</td>
<td>Manufacturing</td>
<td>Manufacturing is one of the main sectors with a large potential of waste heat, mainly in evaporation and heating and boiling processes, food and chemical industry are one of subsectors with the largest waste heat potential at 40 - 60 °C due to industrial evaporation and drying.</td>
</tr>
<tr>
<td>5</td>
<td>Utility services</td>
<td>Large potential of waste heat in steam power plants, 2/5 of this waste heat lies in condenser at 20 -50°C and 3/5 of the waste heat lies in flue gas at 135 -180 °C.</td>
</tr>
<tr>
<td>6</td>
<td>Construction</td>
<td>No assessment.</td>
</tr>
<tr>
<td></td>
<td>Trade</td>
<td>Largest potential in refrigeration at 20 - 40 °C.</td>
</tr>
<tr>
<td>---</td>
<td>-------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>8</td>
<td>Information and communication</td>
<td>Due to large power consumption by computing and IT equipment, the greatest potential lies in cooling at 20 -40 °C.</td>
</tr>
<tr>
<td>9</td>
<td>Financial and insurance</td>
<td>The greatest potential lies in cooling at 20 -40 °C.</td>
</tr>
<tr>
<td>10</td>
<td>Real estate activities and renting of non-residential buildings</td>
<td>The greatest potential lies in cooling at 20 -40 °C.</td>
</tr>
<tr>
<td>11</td>
<td>Dwellings</td>
<td>The greatest potential lies in cooling at 20 -40 °C.</td>
</tr>
<tr>
<td>12</td>
<td>Other business services</td>
<td>The greatest potential lies in IT and electronic equipment at 20 - 85°C and cooling at 20 -40 °C.</td>
</tr>
<tr>
<td>13</td>
<td>Public administration, education and health</td>
<td>The greatest potential lies in cooling at 20 -40 °C.</td>
</tr>
<tr>
<td>14</td>
<td>Arts, entertainment and other services</td>
<td>The greatest potential lies in cooling at 20 -40 °C.</td>
</tr>
<tr>
<td>15</td>
<td>Transport</td>
<td>Preliminary assessment: transport sector has one of the largest potential of waste heat, mainly lies exhaust gas from both maritime and road transport by trucks. Other subsectors of transport have not been assessed.</td>
</tr>
<tr>
<td>16</td>
<td>Geothermal</td>
<td>The theoretically potential for utilizing geothermal energy in Denmark if large. The bottle neck in mapping the geothermal energy potential is the high costs of pre-investigations. The temperatures in deep geothermal energy can reach as high as 90 °C in Denmark. In the case of Shallow soil the temperature is 8-11°C.</td>
</tr>
<tr>
<td>17</td>
<td>Solar thermal</td>
<td>Significant amount of available solar thermal energy, twice as large as the total waste heat from all other sectors.</td>
</tr>
<tr>
<td>18</td>
<td>Air and Water</td>
<td>The averages air temperature in Denmark varies from 1.2 °C in February to 17.4 °C in July. The averages water temperature for Copenhagen varies from 2 °C in the winter months to 17°C in the summer months.</td>
</tr>
</tbody>
</table>

Figure 28 shows the total waste heat recovery potential at the different temperatures including solar energy. The solar given the big peak and therefore the decreasing the details of the other contributions.
Figure 28 total waste heat recovery potential including solar

Figure 29 shows the total waste heat recovery potential without the solar energy input. From the figure it can be seen that there are a large potential up to 60°C which are primarily all the energy that is covered today by different cooling systems. Then again from 70°C to 90°C there are a large potential which are to a large extent caused by refinery industry. The high potential from 133 °C to 181°C is primarily caused by boiler losses from a wide range of sectors.

Figure 29 total waste heat recovery potential (solar thermal excluded)

Figure 30 shows that approximately 85% of the total waste heat (including solar) are below 100°C.
Figure 30 cumulated waste heat recovery potential including solar thermal

Figure 31 shows that approximately 49% of the total waste heat (excluding solar thermal) are below 100°C.

Figure 31 cumulated waste heat recovery potential (solar thermal excluded)
Table 20 Summary table of waste heat sources of all business sectors (solar thermal excluded)

<table>
<thead>
<tr>
<th>Medium</th>
<th>Sources</th>
<th>Temperature</th>
<th>Energy</th>
<th>Exergy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low °C</td>
<td>High °C</td>
<td>GJ %</td>
</tr>
<tr>
<td>Flue gas</td>
<td>Boiler losses (industry/buildings)</td>
<td>160/40</td>
<td>250/100</td>
<td>11.404.812</td>
</tr>
<tr>
<td>Water</td>
<td>Heating/boiling</td>
<td>70</td>
<td>90</td>
<td>1.400.693</td>
</tr>
<tr>
<td>Air</td>
<td>Drying</td>
<td>80</td>
<td>100</td>
<td>4.271.120</td>
</tr>
<tr>
<td>Water</td>
<td>Evaporation</td>
<td>35</td>
<td>50</td>
<td>8.758.750</td>
</tr>
<tr>
<td>Water</td>
<td>Distillation</td>
<td>40</td>
<td>60</td>
<td>1.808.776</td>
</tr>
<tr>
<td>Flue gas</td>
<td>Furnace</td>
<td>200</td>
<td>250</td>
<td>344.776</td>
</tr>
<tr>
<td>Flue gas</td>
<td>Melting</td>
<td>300</td>
<td>400</td>
<td>90.290</td>
</tr>
<tr>
<td>Water</td>
<td>Other heat</td>
<td>150</td>
<td>200</td>
<td>353.979</td>
</tr>
<tr>
<td>Air</td>
<td>Compressed air</td>
<td>60</td>
<td>80</td>
<td>2.906.988</td>
</tr>
<tr>
<td>Water</td>
<td>Refrigeration/cooling</td>
<td>20</td>
<td>40</td>
<td>41.786.528</td>
</tr>
<tr>
<td>Water</td>
<td>Space heating</td>
<td>20</td>
<td>30</td>
<td>2.458.436</td>
</tr>
<tr>
<td>Air</td>
<td>IT, electronics and electrical</td>
<td>20</td>
<td>85</td>
<td>2.892.038</td>
</tr>
<tr>
<td>Water</td>
<td>Hot water</td>
<td>20</td>
<td>40</td>
<td>1.389.528</td>
</tr>
<tr>
<td>Water</td>
<td>Steam power plants (condenser)</td>
<td>5</td>
<td>20</td>
<td>16.075.201</td>
</tr>
<tr>
<td>Flue gas</td>
<td>Steam power plants (flue gas)</td>
<td>135</td>
<td>180</td>
<td>24.112.801</td>
</tr>
<tr>
<td>Water</td>
<td>Combined cycles (condenser)</td>
<td>5</td>
<td>20</td>
<td>2.179.696</td>
</tr>
<tr>
<td>Flue gas</td>
<td>Combined cycles (flue gas)</td>
<td>135</td>
<td>180</td>
<td>3.269.544</td>
</tr>
<tr>
<td>Flue gas</td>
<td>Gas turbines</td>
<td>120</td>
<td>140</td>
<td>1.271.673</td>
</tr>
<tr>
<td>Flue gas</td>
<td>Combustion engine</td>
<td>120</td>
<td>140</td>
<td>1.552.515</td>
</tr>
<tr>
<td>Water</td>
<td>Heating element</td>
<td>50</td>
<td>100</td>
<td>2.004</td>
</tr>
<tr>
<td>Water</td>
<td>Industrial processes</td>
<td>50</td>
<td>100</td>
<td>31.936</td>
</tr>
<tr>
<td>Water</td>
<td>Solar thermal</td>
<td>50</td>
<td>100</td>
<td>6.884</td>
</tr>
<tr>
<td>Water</td>
<td>Treated waste water</td>
<td>8</td>
<td>18</td>
<td>7.100.000</td>
</tr>
<tr>
<td>Flue gas</td>
<td>Surplus heat from biogas production</td>
<td>60</td>
<td>65</td>
<td>10.000</td>
</tr>
<tr>
<td>Water</td>
<td>Sludge for disposal</td>
<td>25</td>
<td>35</td>
<td>40.000</td>
</tr>
<tr>
<td>Air</td>
<td>Charge Air Cooling</td>
<td>90</td>
<td>170</td>
<td>12.990.611</td>
</tr>
<tr>
<td>Flue gas</td>
<td>Exhaust gas (maritime/truck)</td>
<td>200</td>
<td>400/330</td>
<td>54.319.639</td>
</tr>
<tr>
<td>Water</td>
<td>Engine coolant/Jacket water (maritime/truck)</td>
<td>85/80</td>
<td>130/85</td>
<td>8.270.709</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>211.189.927</td>
</tr>
</tbody>
</table>

13 Conclusions and recommendations

The energy mapping of the available waste heat energy in Denmark is based on the consumption in the 15 Danish sectors and from three natural energy sources. Some of the sectors are very much alike in terms of the way that energy is consumed and therefore also in the way that waste heat energy is available. Therefor the numbers of sectors were divided into groups from 15 to five, covering industry, buildings, utility, construction and transport. Besides looking at the waste heat energy from a sector perspective, the total waste heat energy is mapped from each unit operation from which the surplus energy originates from.

The large potential for waste heat is firstly within the transport sector, secondly utility, industry, building and finally construction where the potential is relatively small.

In the transport sector, the waste heat from maritime sector and road transport by trucks is estimated. The waste heat can be divided into one higher temperature interval and one lower. In the higher temperature interval, waste heat of around 200 °C up to 400 °C typically originates from the exhaust gas. In the lower temperature interval, waste heat of 80°C up to 160 °C typically originates from engine coolant and charge air cooling. Transport category is
the second highest waste heat source after industry category with a total of 75.600 TJ per year.

In the utility group the waste heat can be divided into two categories one low temperature category and one high temperature category. In the low temperature category, the temperature is typically below 20 °C and originates from condensate of steam power plants. 43 % of the waste heat is in that category. In the high temperature category, the temperature is typically 120°C up to 180°C, which covers 57% of the waste heat. The waste heat primarily originates from exhaust gas from the steam turbines, gas turbine, CHP plants combustion engines and boilers. The total amount of waste heat from the utility sector group is approximately 58.500 TJ per year.

In the industrial group there is a large potential for waste heat recovery in the temperature area up to 50°C. The waste heat originates from evaporation, distillation, cooling/refrigeration and space heating. 91 % of the waste heat from the industrial sector is below 100 °C. The temperature above 100 °C originates from primarily from boiler losses and secondarily from furnaces and melting processes. The waste heat temperatures from these processes can reach up to 400°C. The total heat recovery potential in the industrial group is approximately 47.800 TJ per year.

In the building group the majority of the waste heat is below 50 °C and comes from refrigeration and cooling. All the waste heat is below 100°C. Waste heat from boilers is estimated to reach temperatures up to 80°C. The total amount of waste heat from the building sector group is approximately 29.300 TJ per year.

In the construction sector it has not been possible to distinguish between temporary (construction sites) and permanent (office building) installations. Therefore the waste heat cannot be evaluated in the same way as the other sectors. From the distribution of the energy consumption it can be seen that there are only two possible waste heat sources, drying and space heating. It is evaluated that the potential for utilizing waste heat in this sector is very limited due to the large amount of temporary installations.

The three natural sources are geothermal, solar, air/water. An exact value of the potential for utilizing heat from natural sources has not been estimated during the framework of this project, but the temperature levels at which heat are accessible where determined. Geothermal heat in Denmark can be supplied at a temperature of up to 90°C, solar thermal energy can supply temperature up to 100°C and air/water can supply temperature up to 17°C in averages.

When looking at all the sectors and the accessible waste heat there are two major potential and this is low temperature waste heat in the form of water that originates from cooling/refrigeration, condensate and various industrial processes all below 60 °C and then there are the high temperature waste heat in the form of exhaust gas from various combustion and heating processes.
14 Prospective

The potential saving of 212 PJ corresponds to 13 % of the energy used by producers and end users. The total consumption of 1.650 PJ includes producers where an energy conversion takes places (production of heat and power) and therefore the Danish net energy input will is significant lower (791 PJ\textsuperscript{47}) than the baseline for this analysis.

\textsuperscript{47} Energistyrelsens, Energistatistik 2012

Viegand Maagøe | [THERMCYC]
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Vurdering af det geotermiske potentiale i Danmark, GEUS, 2009

The estimates are based on Muffler & Cataldi and Lavigne method. This method has also been used to establish a geothermal atlats in a study for the EU commission in 2002.

Geothermal reserves and sustainability in the Greater Copenhagen Area, Allan Mahler and Jesper Magtengaard, Dong Energy, April 2010

Interview of Allan Mahler and Søren Berg Lorenzen from Dansk Fjernvarmes Geotermisk skab, August 2014


Undergrunden som geotermisk resource, GEUS, May 2011
Annex I
All graphs and data – see attached excel files
Annex II – Geothermal

In terms of mapping the geothermal potential in Denmark a number of different studies have been conducted. The studies has been initiated both by the Danish department of energy and EU. The studies has been conducted mainly by DONG Energy, Hovedstadsområdets Geotermiske Samarbejde (HGS), De Nationale Geologiske Undersøgelser for Danmark og Grønland (GEUS) og Dansk Fjernvarmes Geotermiselskab.

At this stage only detailed studies has been conducted locally and therefore an exact overview of the geothermal energy potential in Denmark is not possible to give. In the following sections the conditions for the utilisation of geothermal energy in Denmark is described.

It should also be mentioned that EA energianalyse, COWI, GEUS and Dansk Fjernvarmes Geotermiselskab is conductions a resource assessment of geothermal potential in Denmark. The assessment is expected to be completed during the summer 2015. Furthermore then GEUS is making an update of the geological map of Denmark.

14.1 Background

The Danish underground contains very large geothermal resources in the form of deep or shallow soil geothermal energy. All geothermal energy in Denmark is in a global context categorized as low temperature, due to the nature of the Danish underground. The geothermal temperature can vary from 8°C up until 90°C, depending on a number of local conditions. At this stage with the present temperatures and technical capability the utilisation of geothermal heat is only suited for heat production. In order to evaluate the geothermal potential in Denmark it is important to distinguish between the two kinds of resources.

Deep geothermal energy: This is characterized by relatively high temperature and deep wells. In Denmark the geothermal gradient is approximately 30 °C/km calculated form the surface, but can have large local variations. Due to the nature of the Danish reservoirs geothermal heat can be extracted from depth up to 3 km, resulting in a production temperature of up to 90 °C. Energy in the deep geothermal reservoirs is primarily generated by radioactive decay from a number isotopes and the heat conducted from the core of the earth.

Shallow soil geothermal energy: This is characterized by low temperature and shallow installations. The temperature is in the range of 8-11 °C and the installation depth is in the range of 0-100 m. The energy is primarily generated from the radiation from the sun and only to a minor extent from the heat flux from the ground.

14.2 Deep geothermal energy:

According to GEUS\textsuperscript{48}, there is developed an estimate of the regional possibilities of finding sandstone layers of adequate quality with regards to porosity, permeability and temperatures. Based on this GEUS has developed geological maps showing sandstone layers with a minimum thickness of 25 m and located in the interval of 800-3,000 m, which is the depth where there is a technical and financial potential of producing geothermal hot water in Denmark. The calculations that GEUS has performed with regards to the potential resources is conservative because it doesn’t take the energy content from poor water conducting sand/clay stone layer that are located under, above and in between the reservoirs or sand

\textsuperscript{48}Vurdering af det geotermiske potentiale i Danmark, GEUS, 2009
stone layers that are less than 25 m thick into account. Furthermore it is assumed that the heat production is stopped after 30 years of production due to a decline in the production temperature. Therefore the estimated resources must be considered as a minimum accessible energy content in a certain area.

In Figure 32 a map of the geothermal sandstone reservoirs is shown. Of the sandstone layers shown in the figure the Haldager, Gassum and Bunter has the largest potential for exploitation of geothermal heat production. In the interval from 800 m to 3,000 m then more than one sandstone layer can be utilized from the same location (shaded areas) – see also Figure 33 as a cross section example. The cross section is taken from the Skagen in Jutland to Ullerslev at Fyn – see the small map in Figure 35.

Areas not suited for geothermal exploration are the main part of Fyn, the south eastern part of Zealand, the mid-western part of Jutland and parts of Bornholm.

![Figure 32 location of potential geothermal sandstone reservoirs](image_url)
In the left side of Figure 34 a sum of the estimated geothermal resources from the different reservoirs that has an economical and financial potential to be exploited in the future can be seen. The resources are given in GJ/m² of ground surface (the resources is/can be a sum of several reservoirs). The resource is direct proportional to the potential cooling of the geothermal water and the actual reservoir volume\textsuperscript{49}. From the map it can be seen that the heat flux varies from zero GJ/m² (light yellow) to 20 GJ/m² (dark green). On the right of Figure 34 a map showing the depth of the different geothermal reservoirs can be seen.

\textsuperscript{49} The estimates are based on Muffler & Cataldi and Lavigne method. This method has also been used to establish a geothermal atlas in a study for the EU commission in 2002.
The maps in Figure 34 are a sum of a number of maps. In Figure 35 is given an example of a map from the Skagerak/Bunder formation. From the maps it shall be noticed that energy content is reduced to a maximum of 18 GJ/m² in very limited areas. The majority of the resources is in the area of 1-5 GJ/m². The depths of the formations are up to 3,000 m, but the majority is in the area around of up to 1,600 m.

Example of a detailed study of the Greater Copenhagen area and a part of north Zealand: In the report for Dong Energy, 50 a detailed analysis has been made by the partners in the Greater Copenhagen area. The analyses where based on the identification of the main sandstone reservoirs in an area divided into 462 blocks each of 4 m² covering the greater Copenhagen area and a part of north Zealand. In the analyses the production temperature has been modelled over a period of 500 years with a moderate and commercial production. The result from the analyses showed that the production temperature decreased relatively slowly, due to a significant flow of heat from the surrounding layers. Based on the chosen commercial cut off price in the analysis, then the producible amount of heat is 60,000 PJ. If this is compared to the present district heat consumption in the areas of 40 PJ/year then the underground is seen to have a capacity to cover the district heating consumption for thousands of years.

The temperature will increase with increasing depth, but regional and local temperature variation will occur. The variations are caused by the reservoirs heat conducting ability, the geothermal heat flux and the groundwater movement. Over time the heat production will also affect the production temperature locally.

50 Geothermal reserves and sustainability in the Greater Copenhagen Area, Allan Mahler and Jesper Magtengaard, Dong Energy, April 2010
Due to the lack of information of the thermal properties and lateral variations it is not possible to make a map of the thermal gradients. By using generalised regional temperature-depth relations for Denmark based on all available, adjusted temperature data in the interval 0-3,000 m a temperature-depth relation has been made – see Figure 36.48

The black line shows the temperature-depth relation of 30 °C/km and the green line shows the generalized temperature-depth relation of ~28 °C/km (assumed a surface temperature of 8°C). It is worth noticing the one of the latest investigations (Magretheholmen) has a gradient that is lower than the two temperature-depth relations. Not shown on the figure is that Sønderborg has a gradient of 40 °C/km (48°C at a depth of 1.20 km) and Thisted has a gradient of 34 °C/km (43°C at a depth of 1.25 km).

As shown the geothermal heat potential is relatively large and temperatures up to 90 °C can be produced. Both the heat flux and temperature gradients will vary from region to region. One of the main reasons that the potential is connected with large uncertainties is the lack of good data. In order to determine if an areas is worth exploring then first a pre-investigation needs to be made. If this turns out positive then an exploratory drilling needs to be done. The pre-investigation costs are in the order of 15 mio. DKK and the exploratory drilling will costs in the area of 50 mio. DKK.51, which can turn out to be wasted if the final results are negative (the costs are very affected by local conditions). The local heating supply companies in Denmark are relatively small companies and they are not able to spread the risk of the investments on to other activities, which makes it difficult for them to in exploration. In Denmark it is not possible to get insurance, because no companies will cover the uncertainties51.

If geothermal heat is seen in connection with district heating then due to the temperature gradient, widespread geothermal aquifers and a district heating network that covers 60 % of the

51 Interview of Allan Mahler and Søren Berg Lorenzen from Dansk Fjernvarmes Ge-otermiselskab, august 2014
heating supply for Danish housing, then it is estimated that geothermal heat can cover 20-50% of the present heating demand for several hundreds of years\textsuperscript{52}.

14.3 Shallow soil geothermal energy:
Shallow soil geothermal energy is characterised by the utilisation of the energy content in the Shallow soil of groundwater and it relatively low temperature area of around 8-11°C. The energy is mainly related to radiation from the sun and to a lesser extent the heat flux from the ground\textsuperscript{53}—see Figure 37.

![Figure 37 illustration of solar radiation and heat flux\textsuperscript{53}](image)

The utilisation of shallow soil geothermal heat is done in relation with single households or single building complexes. There are mainly three methods to extracting the heat:

A. Closed horizontal systems, with hoses buried 1 m below ground

B. Closed vertical systems, with hoses in geothermal wells (10-20 m below ground)

C. Open system with a production well and an injection well

In Figure 38 the three different systems are illustrated.
The closed systems circulate a frost-protected fluid and the heat is transferred by a heat pump.

**The horizontal system** requires a relatively large amount of space. The horizontal systems are very much affected by seasonal temperature variations. The low temperature during the winter decreases the efficiency but on the other hand then during the summer the soil is heated up relatively fast.

**The vertical systems** do almost not require any space. The installation is a bit more expensive compared to the horizontal systems, but on the other hand then the efficiency is higher because of more constant temperatures throughout the year. With this system it is important that the systems are dimensioned correct, because the regeneration process is somewhat slower because it is less affected by the temperature variations during the year.

**The Open systems** are circulating groundwater between an production well and an injection well. Heat in these systems is also extracted by a heat pump. There are a lot of requirements to fulfil with these systems in order to secure a minimum effect on the ground water aquifers in terms of chemical and temperature pollution.

### 14.4 Geothermal summery

Based on the evaluation of the different studies it is clear that there is a huge energy potential for utilizing geothermal energy. In the case of deep geothermal energy there is a potential of reaching temperatures up to 90 °C, with a thermal gradient of 30 °C/km. The energy that can be extracted and the temperatures that can be reached are very much depending on regional and local reservoir conditions. Based on the summation of resources over the Danish area, then resources as high as 20 GJ/m² can be found. The summarized map of resources is the sum of several sub maps of different geological formations.

The big challenges that deep geothermal energy exploration is facing is the gathering sufficient and reliable data. Geothermal pre-investigations and exploration drilling are very costly, in the area of 65 mio. DDK. The relatively high pre-investigations costs acts as a bottleneck in order to determine the deep geothermal potential in Denmark. Deep geothermal energy is with the present technologies only suited for large users or user networks such as district heating.

With regards to the shallow soil geothermal energy then the temperature levels is in the area of 8-11 °C. The heat content is also in this context very large. The potential is here depending on local thermal conditions, local legislation, type of extraction technology, equipment
prices and development and local energy prices. The utilisation of shallow soil geothermal energy is with the current technical systems most suited for smaller consumers.