1. Spreadsheets instructions for simple heat pump calculations

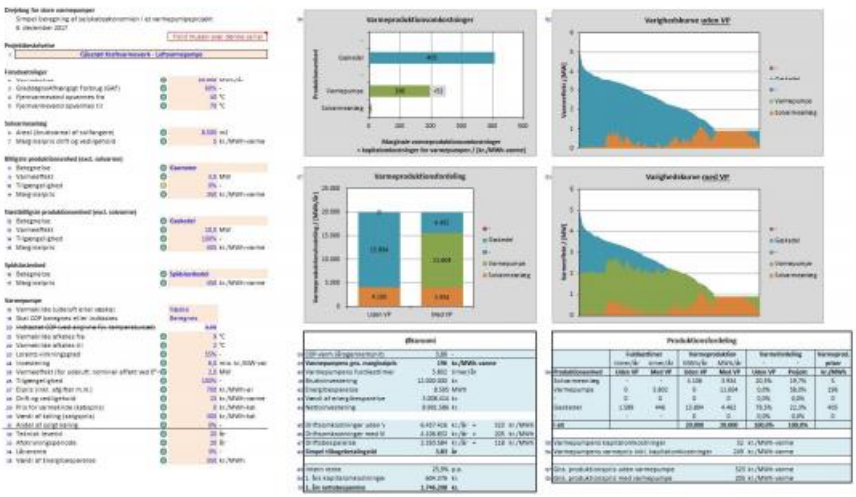
In connection with the preparation of the "Guide to large heat pump projects in district heating", a spreadsheet-based tool has been developed, which can be used to make initial, simple calculations of the economics of electrically driven heat pump projects in district heating. It should be stressed that the actual economics of a project may differ significantly in compared to what is calculated in this tool. The tool should therefore only be used at an initial stage of a project and the calculated results should always be validated through other studies before being used for decisive decisions.

The spreadsheet, called "Simple heat pump calculation.xlsx", can be downloaded from the Danish Energy Agency's website. The spreadsheet, developed in Microsoft Excel, consists of one tab. It is recommended to zoom the spreadsheet so that the whole tab can be seen on the screen. Figure 1 shows the spreadsheet user interface. A larger version of the figure can be found in Annex E.

The purpose of the spreadsheet is to calculate the cost-effectiveness of a heat pump project at an existing heating plant. The calculation therefore takes is based on an existing heating plant that is supplemented with a heat pump. The existing heating plant may consist of up to four different production units, one of which is a solar heating plant.

The calculation is based on user-based inputs in the 35 sand-colored cells on the left side of the user interface. The results of the calculation are shown in the four figures on the right-hand side of the interface, as well as the light blue tables the figures.

Figure 1 - Spreadsheet user interface. A larger version of the figure can be found in Annex A.



1.1 Input

The spreadsheet is completed with example values in all the sand-colored input cells. These may serve as inspiration, but it is recommended that you relate to them all.

The spreadsheet makes a simple check of the values entered and to the left of the values marks them with a , or , depending on whether the current value is judged to be "acceptable", "doubtful" or "unrealistic". However, this assessment is indicative only and does not affect the calculations in the spreadsheet. However, it is recommended that all values are marked with .

To the left of all the sand-colored input cells, is a small blue number, which refers to the notes below.

1. In this cell you can enter a short description of the current calculation. This is particularly useful if you are saving several versions or printing the spreadsheet.

2. In this cell, enter the annual heat production/heat demand delivered to the grid, corresponding to heat sold including conduction losses in a normal year. If the heat demand evolves, a projected average over the next 10 years or so can be used.
3. In this cell, enter the proportion of the heat demand in cell (2) that is degree day dependent, i.e. that depends on outside temperature. If you do not know this figure, you can use 60 %.
4. Enter the average return temperature of the district heating system. This is used to calculate the performance of the collectors and COP value of the heat pump.
5. The average flow temperature of the district heating system is entered here. This is used to calculate the performance of the solar collectors and COP value of the heat pump.

If the plant has a solar heating system, or is considering installing one, the data for a solar thermal system is entered in cells (6) and (7).

6. The total area of the solar thermal installation is entered here. You can adjust the area if you want to hit a known output for the solar thermal system being calculated. If there is no solar collectors in the system enter '0' in the cell.
7. In this cell you can enter the variable heat price of the solar thermal system, which is typically around 5 Euro/MWh. The solar thermal system has 1st priority in the calculation and the solar collectors variable heat price has no influence on the profitability of a heat pump.

In cells 8-11 data are entered for the current cheapest production unit, disregarding a possible solar thermal system. This unit will normally be the base load unit.

8. In this cell the name of the production unit is entered.
9. In this cell, enter the heat output of the production unit. If there are several comparable units, you can enter the total heat output of these. For example, if there are three identical natural gas engines with 2,0 MW heat each, enter '6,0' in the cell.
10. In this cell the average availability of the production unit on an annual basis is entered. Boilers will normally have a high availability (close to 100 %). Natural gas CHP will normally be limited by spot prices, which corresponds to a low availability. You can adjust the figure in the cell if you want to hit a certain annual production in cell Y41, for example last year's heat production.
11. In this cell the average variable heat price of the production unit on an annual basis is entered. The variable heat price of a natural gas engine will usually be (slightly) lower than the variable price of a natural gas boiler.

In the calculation of the annual energy conversion, the experienced heat effect of the production unit, is assumed to be equal to the heat effect of the unit, cf. note (9), multiplied by its availability, see note (10). In cells (12) - (15), data for the current second cheapest production unit, are entered, excluding any solar thermal installation. This unit will normally be the intermediate load unit.

12. See note (8).
13. See note (9).
14. See note (10).
15. See note (11).

In cells (16) - (17) enter the data for the current peak load unit. It is assumed that the heat output of the peak load unit is always sufficient, and its availability is 100 %.

16. See note (8).
17. See note (11).

If the heating plant has fewer than three production units (excluding a possible solar heating plant), you can turn of the cheapest and/or the second cheapest production unit, by setting the heat output in cell (9) and/or cell (13) to '0.0'. On the other hand, the peak load unit cannot be switched off, so if the

heating plant has only one production unit, e.g., a chip boiler, this must be inserted as the peak load unit in cells (16) and (17).

In cells (18) - (35) the data for the heat pump project is entered.

18. In this cell it is selected whether the heat source is outside air or whether the heat pump cools a liquid (for example groundwater, wastewater, cooling water from a process etc.).
19. Here you select whether the COP value of the heat pump is to be calculated or a fixed COP is used throughout the calculation. I case, select 'Enter' in cell 19 and the entered value is used. If the value is calculated, annual variations in outdoor temperature are corrected for when air is used as the heat source. For liquid-based heat sources, the COP is calculated based on the source temperatures entered in the following cells, and a defined efficiency in cell 23. For both air and liquid, the COP is calculated based on the selected district heating temperatures in cell 4 and 5. At the same time, the COP is increased when there is co-generation with boilers or other units apart from solar heating. This should be emphasized, that the calculated COP should only be interpreted as a starting point and that COP for an actual system could differ significantly from that calculated in the sheet.
20. In this cell a fixed COP value is entered if this is selected in Alternatively, this cell is omitted.
21. Enter the temperature of the heat source if 'Liquid' is selected in cell 18 and 'Calculate' is selected in cell 19. If 'Outdoor' is selected in cell 18 and/or 'To be entered' in cell 19, this cell is omitted.
22. Enter the outlet temperature of the liquid from the heat pump (after cooling) if 'Liquid' is selected in cell 18 and 'Calculated' is selected in cell 19. If 'Outside air' is selected in cell 18 and/or 'To be entered' is selected in cell 19, this cell is omitted.
23. In this cell the Lorentz efficiency of the system is entered. The Lorentz efficiency is typically between 35 % and 60 %. The COP of the heat pump in cell (38) is calculated from the entered temperatures for district heating water and heat source, and this efficiency. In most cases, a starting point efficiency of at least 50 % could be used. However, in cases where the temperature rise from the heat source to the district heating system is low, the efficiency will be lower. Therefore, if the temperature difference between the heat source and the flow temperature of the district heating system is less than about 40°C, the efficiency should be set to around 40 %. It should be stressed that the calculated COP is only should be interpreted as a starting point and that the COP of an actual system could differ significantly from that calculated in the sheet.
24. Entered in this cell the total specific investment of the heat pump project, including heat sources, hot side connections, as well as electrical connection etc. In some projects the specific investment has been around 1 million EURO /MW heat (of which the heat pump itself represents about half), but there can be large differences from project to project. If the project receives a capital grant, this must be deducted from the amount. The value of the energy saving (Danish scheme) is automatically included and therefore not deducted here.
25. In this cell, the heat output of the heat pump is entered. For air source heat pumps, the output is stated at an outdoor temperature of 0 °C. From this point the heat pump's power is calculated at other temperature levels. It must be emphasized that this temperature correction may deviate depending on the heat pump type and technical design.
26. In this cell enter the annual availability of the heat pump. It will typically be high for the heat pump itself but can be limited by the heat source. For example, is the heat source only available in 5000 hours per year, enter 5000/8760 = “57%” in the cell.
27. In this cell, enter the expected average electricity price over the next approx. 10 years, including electricity spot price, transport costs.
28. In this cell, enter the expected variable costs for operation and maintenance, including expected overhauls, renovations, and reinvestments over the life of the project. For most projects, there may be budgeted with 2 Euro MWh/heating (Danish experience).

29. If the heating plant pays for the energy in the heat source, for example in the form of surplus heat from a company, enter the MWh price for this in the cell. If the heating plant does not pay for the energy in the heat source, for example where it is used air or groundwater, enter “0” in the cell.
30. If a part of the produced refrigeration is sold, for example as district cooling or for industrial cooling, enter the expected sales price here. If the cooling is not sold, for example in connection with an air or groundwater heat pump, enter “0” in the cell.
31. In this cell, enter the percentage of cooling that is sold. If as an example, cooling is only sold during the summer, for example, enter “50%” in the cell. If the cooling is not sold, enter “0%” in the cell. It is noted that at least one of the cells (29), (30) and (31) will usually be “0”, although this is not a requirement.
32. In this cell, the expected technical lifetime of the heat pump is entered, typically 15-20 years. In the spreadsheet, the lifetime is used exclusively to calculate the project's internal interest rate, cf. note (51).
33. In this cell, the project depreciation period is entered, as typical will be 10-15 years. The depreciation period should not exceed the technical life, cf. note (32).
34. In this cell, the loan interest rate is entered, including a possible guarantee commission. Cells (33) and (34) are used exclusively to calculate the values in cells (51), (52), (57) and (58).
35. Enter the value of the Energy Saving (Danish scheme) generated by the heat pump system. The value is entered as Euro / MWh.

It must be noted that the spreadsheet does not include any revenue in connection with system services for the electricity system.

1.2 Calculation results

The results of the calculation are shown in the four figures on the right of the user interface and the light blue tables below the figures. To the left of these are some small, blue numbers, which refer to the notes below.

36 This figure shows the variable heat production costs / marginal heat prices on the various heat production units there. The heat pump's variable costs are calculated in the spreadsheet, cf. note (39), and the costs of the other production units is entered by the user, see notes (7), (11), (15) and (17).
37 This figure shows how the annual heat production is distributed between the different heat production units respectively without and with the heat pump (VP).
38 This cell shows the heat pump annual system COP, which is calculated or entered. It must be emphasized that the actual COP can deviate from the calculated and that the results of this calculation should be seen solely as a starting point.
39 This cell shows the variable heat production cost of the heat pump.
40 In this cell, the heat pump's calculated number of full load hours is showed.
41 In this cell, the total gross investment is shown before the value of the energy savings are deducted. The gross investment is calculated as the specific investment per MW heat (cell 42) multiplied by the system's heat output (cell 43).
42 This cell shows the total size of the energy savings (Danish scheme) which the project generates.
43 The total amount for the project's energy savings (Danish scheme) is shown here background in the value selected in cell 35.
44 In this cell, the net investment is displayed when the total value of the energy savings (Danish scheme) is deducted from the gross investment (cell 41 and 43).
45 In this cell, the annual variable operating costs are shown without the heat pump, calculated as the annual heat production, cf. ta bel (55), multiplied by the variable production costs, cf. ta bel (55),

summed up for all production units. In addition, is displayed the average operating costs per MWh_{heat}.

46 This cell shows the annual, variable operating costs with the heat pump, calculated as the annual heat production, cf. table (55), multiplied by the variable production costs, cf. table (55), summed for all production units. In addition, they are displayed average operating costs per $MWh_{heat.}$

47 This cell shows the annual operating savings of the heat pump project. In addition, the average operating savings per $MWh_{heat.}$

48 In this cell, the simple payback time of the project is showed.

49 This cell shows the project's internal interest rates, calculated based on the investment in cell (44), the annual operating saving in cell (48) and the technical life of the project in cell (32).

50 This cell shows the first year's cost of capital on an annuity loan, calculated from cells (33), (34) and (55).

51 This cell shows the 1st year net savings, calculated as operating savings (47) minus the 1st year capital costs.

52 This figure shows a 24-hour duration curve for heat production without the heat pump. Solar heat production is distributed after a standardized reference year, and the actual solar heat production may therefore be distributed significantly differently.

53 This figure shows a 24-hour duration curve for the heat production with the heat pump. Solar heat production is distributed after a standardized reference year, and the actual solar heat production may therefore be distributed significantly differently.

54 This table shows the number of full load hours, the annual heat production distribution for the various heat production units without and with the heat pump, respectively. Furthest to the right see production-dependent heat production price for the different units.

55 This cell shows the heat pump's capital costs per produced heating unit.

56 This cell shows the total heat price from the heat pump, where both production-dependent and capital costs are included.

57 This cell shows, the average heat production price for the complete system without the heat pump.

58 This cell shows, the average heat production price for the complete system with the heat pump.

Script for large heat pumps

Simple calculation of the company economy in a heat pump project
6. December 2017

Hold the mouse over this cell!

Project description

1

Prerequisites

2	Heat demand	60.000	MWh/year
3	Degree Dependent Consumption	60%	-
4	District heating water heatet from	30	°C
5	District heating water heatet to	60	°C

Solar plant

6	Area (gross area of solar collectors)	5.000	m2
7	Marginal price operation and maintenance	5	l/MWh-heat

Cheapest production unit (excl. Solar heating)

8	Designation	Gas engine	
9	Heat output	1,0	MW
10	Avaliability	50%	-
11	Marginal Price	85	l/MWh-heat

Second cheapest production unit (excl. Solar heating)

12	Designation	Gas engine	
13	Heat output	1,0	MW
14	Avaliability	100%	-
15	Marginal Price	85	l/MWh-heat

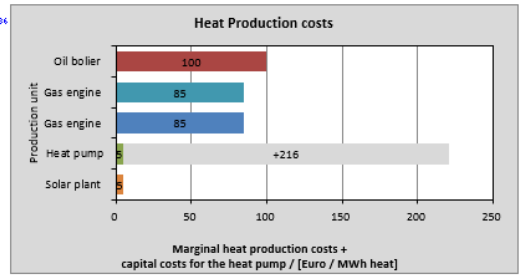
Peak load unit

16	Designation	Oil bolier	
17	Marginal Price	100	l/MWh-heat

Heat pump

18	Heat source (air or liquid)	Udeluft	
19	Should the COP value be calculated or entered	Beregnes	
20	~~Entered COP value (at the specified District heating te~~	~~2,50~~	
21	~~Heat source is cooled from~~	~~9~~	~~°C~~
22	~~Heat source is cooled to~~	~~2~~	~~°C~~
23	~~Lorentz - efficiency~~	~~55%~~	~~-~~
24	Investment	6,0	mio. l/MW-heat
25	Heat output (outdoor air: nominal power at 0 °C)	14,0	MW
26	Availability	100%	-
27	Electricity price (incl. Taxes, etc.)	10	l/MWh-electricity
28	Operation and maintenance	2	l/MWh-heat
29	Price for heat source (purchase price)	0	l/MWh-cooling
30	Refrigeration - expected sales price.	15	l/MWh-colling
31	Percentage of cooling that is sold.	0%	-
32	Expected technical lifetime	25	year
33	Project depreciation period	12	year
34	Loan interest rate	10%	-
35	Værdi af Energibesparelse	0	l/MWh

34



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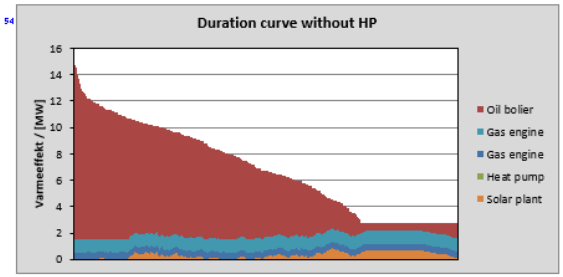

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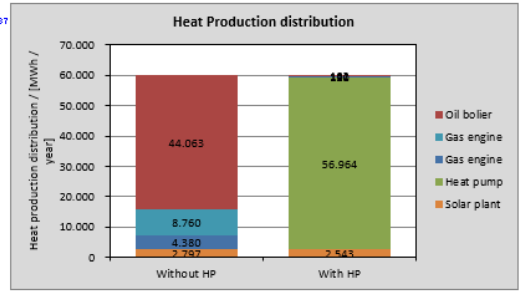

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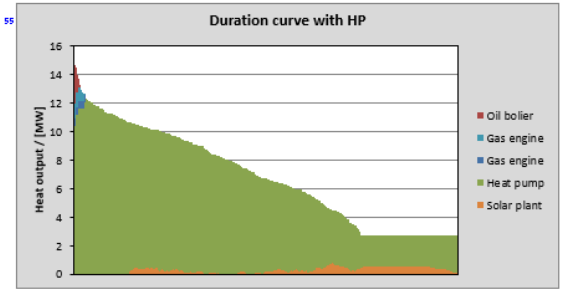

Economy

38	COP - hot (year average)	3,92	-	
39	**Varmepumpens gns. marginalpris**	**5**	**l/MWh-heat**	
40	Heat pump	4.069	hour/year	
41	Gross investment	84.000.000	l	
42	Energy saving	42.421	MWh	
43	Value of energy saving	0	l	
44	Net investment	84.000.000	l	
45	1. years capital costs	12.328.118	l	
46	Total net investment	##########	l	
47	Operating costs without projec	5.537.142	l/year =	92 l/MWh
48	Operating costs with project	316.688	l/year =	5 l/MWh
49	Operational savings	5.220.455	l/year =	87 l/MWh
50	**Simple payback time**	**16,09**	**year**	
51	Internal rate of interest	3,7%	p.a.	
52	1. years capital costs	12.328.118	l =	
53	**1st year net savings**	**-7.107.664**	**l**	

Production distribution

		Full load hours		Heat production		Heat distribution		Heat
		hour/year	hour/year	MWh/year	MWh/year	-	-	production
54	**Produktionsenh**	**Without HP**	**With HP**	**Without HI**	**With HP**	**Without HI**	**Project**	**l/MWh**
	Solar plant	-	-	2.797	2.543	4,7%	4,2%	5
	Heat pump	0	4.069	0	56.964	0,0%	94,9%	5
	Gas engine	4.380	120	4.380	120	7,3%	0,2%	85
	Gas engine	8.760	191	8.760	191	14,6%	0,3%	85
	Oil bolier	-	-	44.063	182	73,4%	0,3%	100
	I alt			**60.000**	**60.000**	**100,0%**	**100,0%**	

57	Heat pump CAPEX	216	l/MWh-heat
58	Heat pump heat price incl. capital cost.	221	l/MWh-heat
59	Avg. production price without heat pump	92	l/MWh-heat
60	Avg. production price with heat pump	5	l/MWh-heat