Multiconsult

Balancing hot and cold.

How to find the optimum delivery temperature for an industrial high temperature ammonia heat pump.

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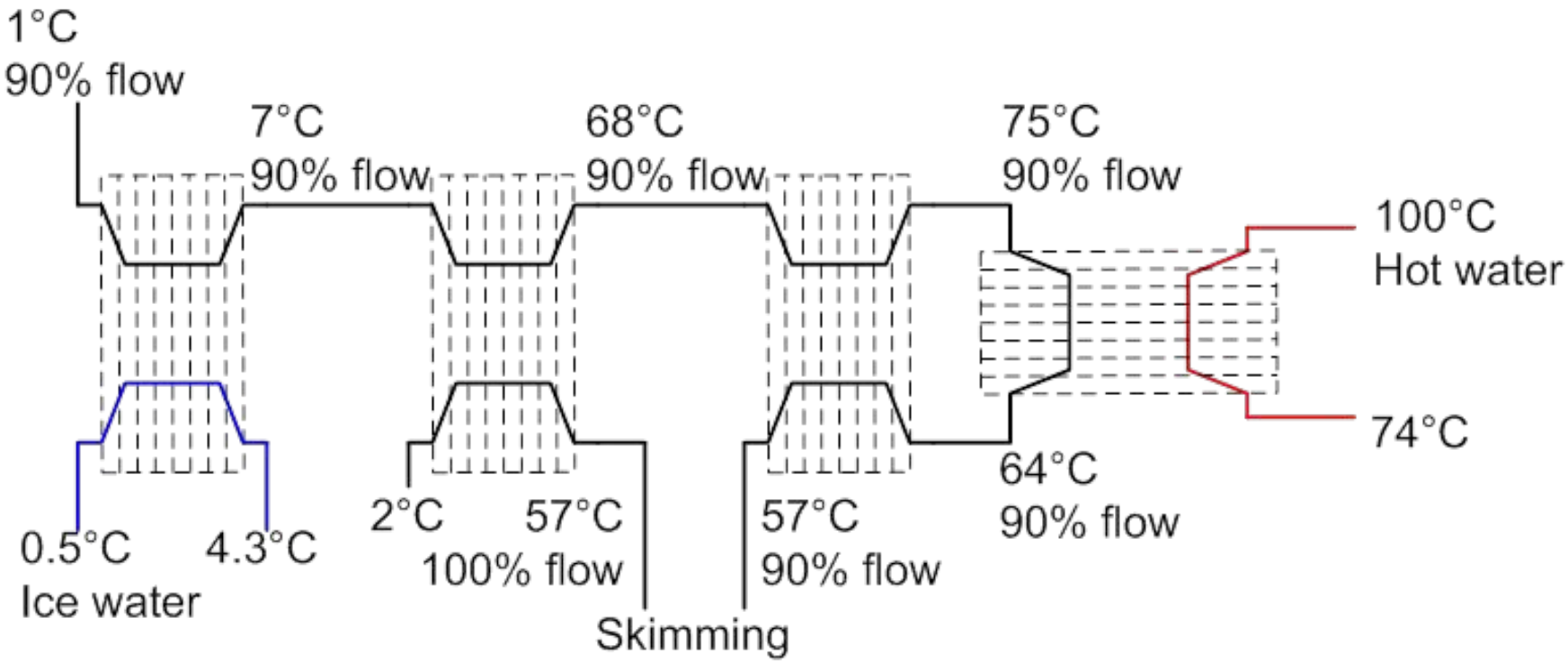
CO2 emission reduction

- When picking fruit you take the low hanging ones first.
- When reducing the carbon footprint do the same.
- Many ripe fruits are hanging within easy reach, ready to be picked.
- Food industry has a huge carbon footprint, as it is usually applying both high temperature processing and low temperature storage
- In a dairy the production process is characterized by heating (pasteurizing) and subsequent cooling. Balancing the load and harvesting and recycling the surplus heat can reduse the carbon footprint significantly.

Dairy process. Pasteurizing

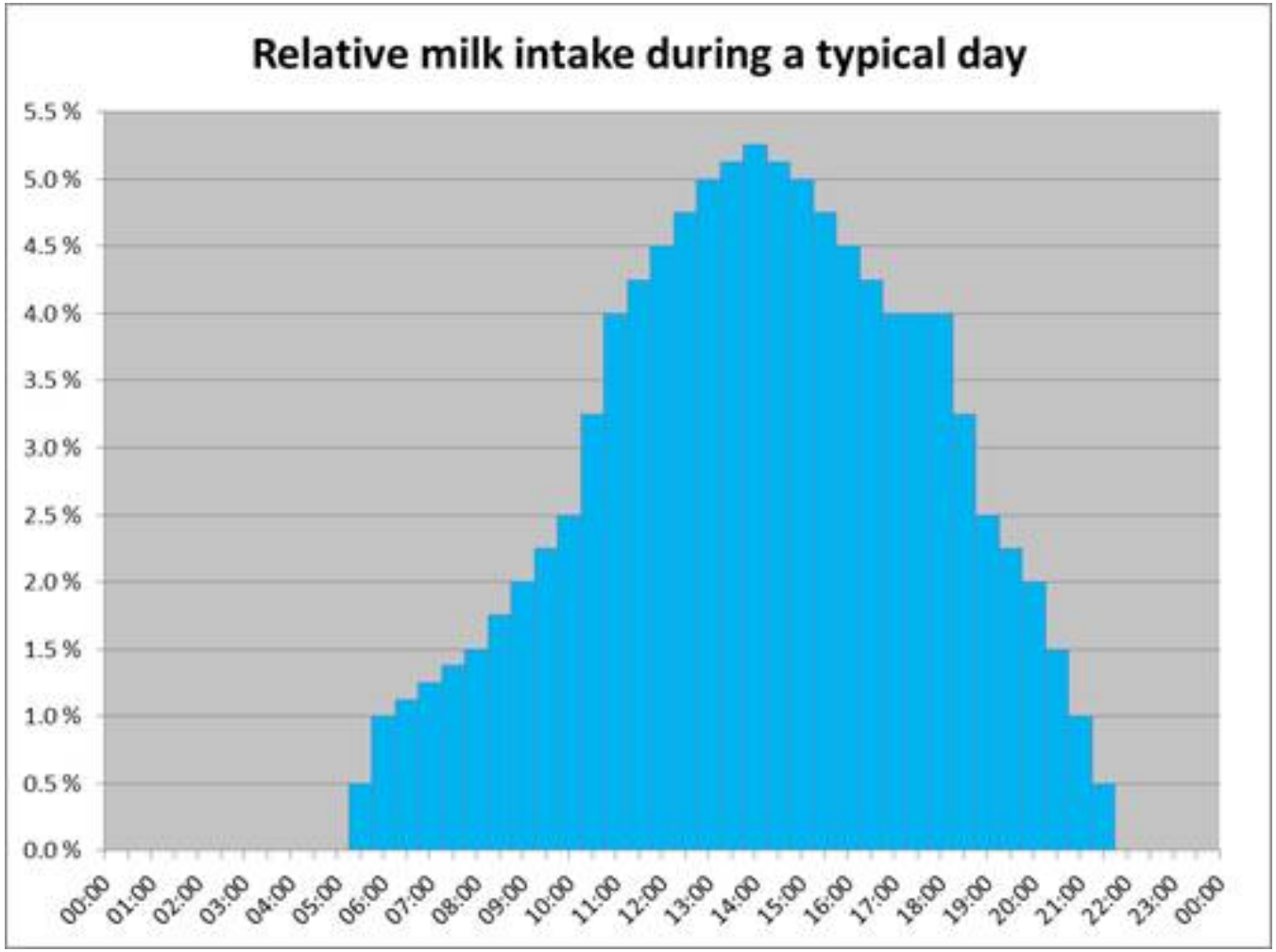


Dairy example. Basic facts

- Typical comsumption dairy, handling 155 000 000 litres of milk per year.
- Production flow is 600 000 litres/production day, 5 days per week
- The daily influx of milk is 425 000 litres/day 7 days a week.
- The cows can’t bottle up during weekends.
- Milk delivery starts at 0500 and continues until 2200.

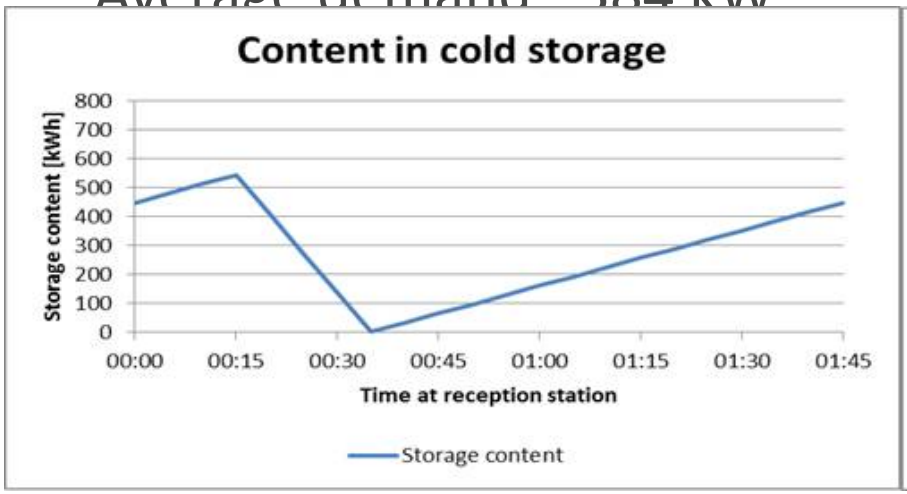
Milk reception

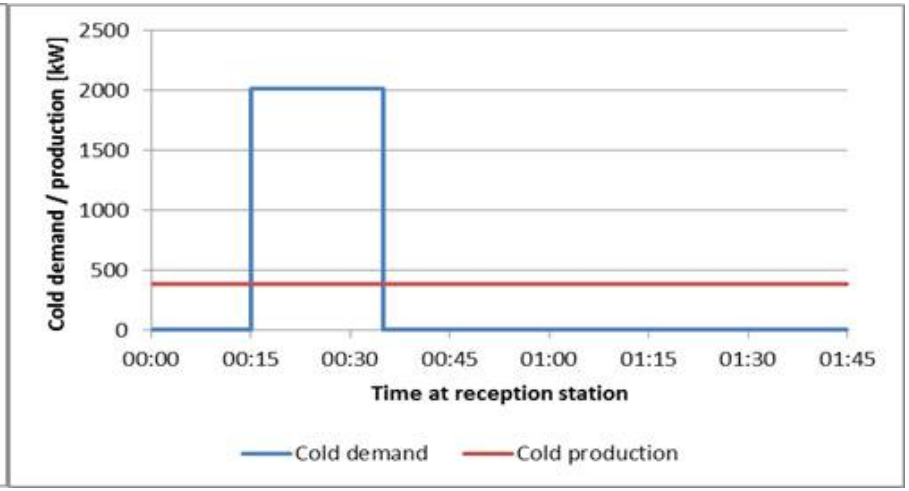
- Design delivery temperature 8°C.
- Storage temperature 2°C.
- Design cooling energy 2 855 kWh.



Milk reception

- Each reception station can handle 60 000 litres/h
- Worst case. 5 lorries emptying simultaneously.
- Each lorry holds 20 000 litres at 8^{o}C which is to be cooled to 2^{o}C.
- Total cold demand : 2 014 kW.
- The emptying process lasts 105 minutes.
- Average demand : 384 kW

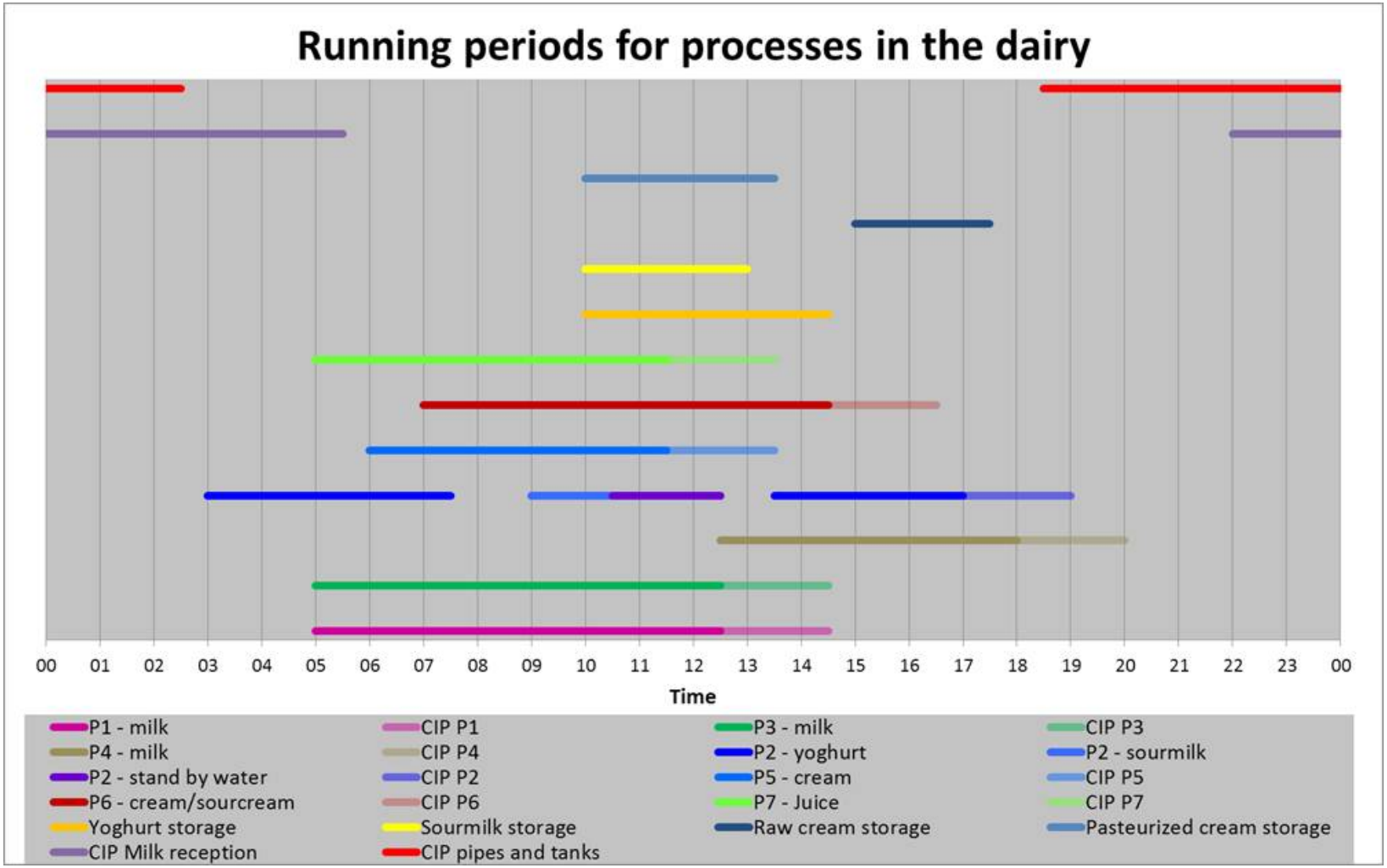




Dairy process

	Density	Heat capacity	Flow			Run time	Start	Stop
	kg/litre	kJ/kgK	l/h	kg/s	kg/24h	h		
Milk reception	1.033	3.90			433 860		06.00	22.00
Pasteurizer 1 – milk (P1)	1.036	4.00	23 750	6.83	196 840	8h 00’	05.00	13.00
Pasteurizer 3 – milk (P3)	1.036	4.00	28 100	8.09	232 893	8h 00’	05.00	13.00
Pasteurizer 4 – milk (P4)	1.036	4.00	28 100	8.09	154 291	5h 18’	13.00	18.18
Pasteurizer 2 – standby water (P2)	1	4.20	15 000	4.17	25 099	1h 40’	11.00	12.40
Pasteurizer 2 – sour milk (P2)	1.062	3.90	15 000	4.43	31 860	2h 00’	09.00	11.00
Pasteurizer 2 – yoghurt. Part 1 (P2)	1.062	3.90	8 900	2.63	44 500	5h 00’	03.00	08.00
Pasteurizer 2 – yoghurt. Part 2 (P2)	1.062	3.90	8 900	2.63	35 600	4h 00’	13.30	17.30
Pasteurizer 5 – cream (P5)	0.996	3.30	4 200	1.16	25 099	6h 00’	06.00	12.00
Pasteurizer 6 – cream/Sour cream (P6)	0.996	3.90	4 700	1.30	37 450	8h 00’	07.00	15.00
Pasteurizer 7 – Juice (P7)	1	4.20	17 000	4.72	119 000	7h 00’	05.00	12.00
Yoghurt storage	1.062	3.90	16 992	5.01	81 774	4h 32’	10.00	14.32
Sour milk Storage	1.033	3.90	14 462	4.15	51 629	3h 27’	10.00	13.27
Raw cream storage	0.996	3.30	6 000	1.66	17 928	3h 00’	15.00	18.00
Pasteurized cream storage	0.996	3.30	4 000	1.11	15 936	4h 00’	10.00	14.00
CIP Milk reception	1	4.20	12 000	3.33	90 000	7h 30’	22.00	05.30
CIP P1	1	4.20	10 000	2.78	20 000	2h 00	13.00	15.00
CIP P3	1	4.20	10 000	2.78	20 000	2h 00	13.00	15.00
CIP P4	1	4.20	10 000	2.78	20 000	2h 00	18.30	20.30
CIP P2	1	4.20	10 000	2.78	20 000	2h 00	17.30	19.30
CIP P5	1	4.20	10 000	2.78	20 000	2h 00	12.00	14.00
CIP P6	1	4.20	10 000	2.78	20 000	2h 00	15.00	17.00
CIP P7	1	4.20	10 000	2.78	20 000	2h 00	12.00	14.00
CIP pipes and tanks	1	4.20	10 000	2.78	90 000	9h 00	18.30	03.30

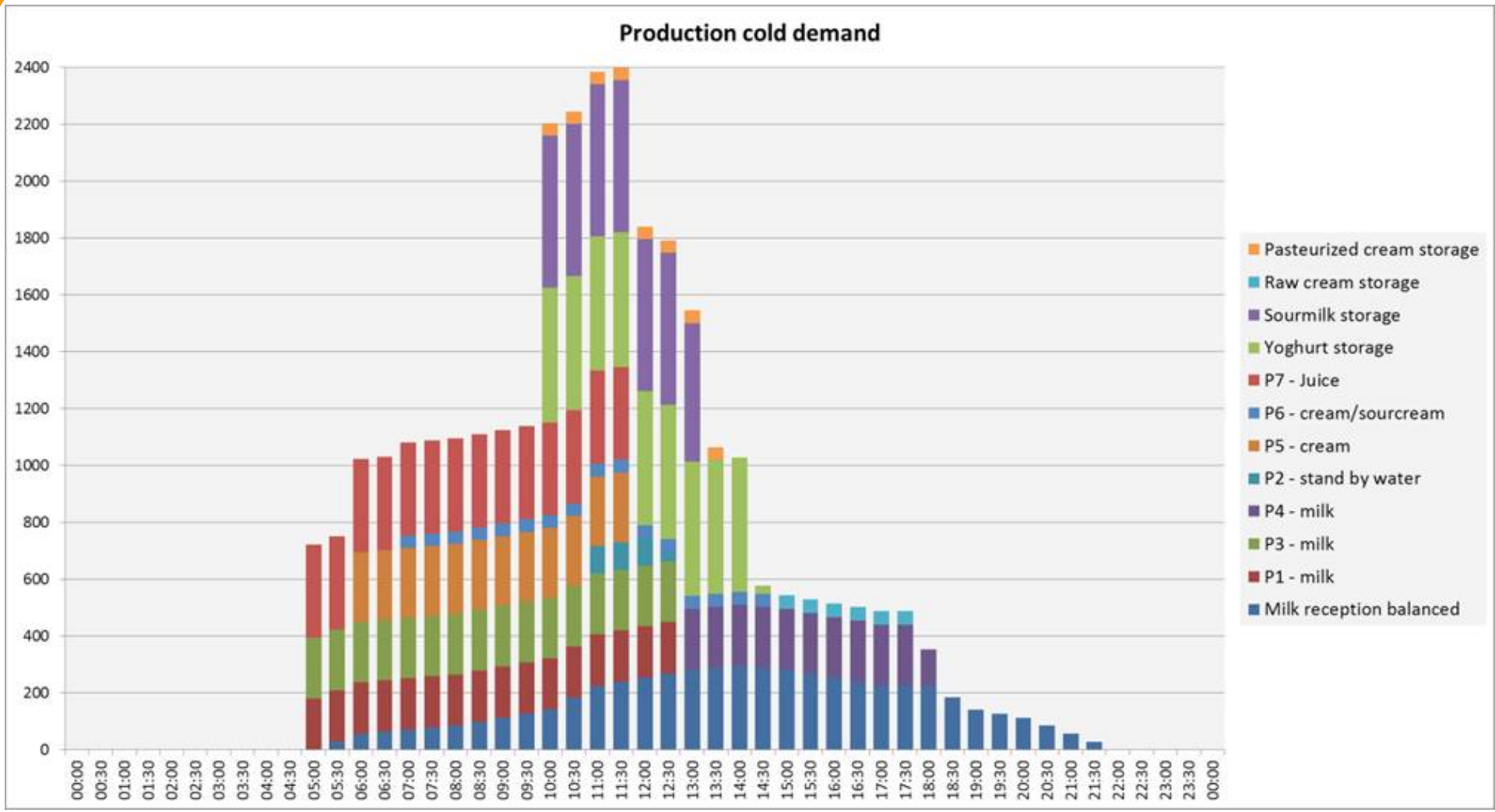
Dairy process



Dairy process. Cold demand. Temperature

Ice water	Tin [°C]	Tout [°C]	Margin	Cold demand [kW]	Cold energy. [kWh]		T return, ice water [°C]
Milk reception balanced	8	2		384	2 855		5.6
Pasteurizer 1 – milk (P1)	7	1	10 %	180	1 443		4.3
Pasteurizer 3 – milk (P3)	7	1	10 %	214	1 708		4.3
Pasteurizer 4 – milk (P4)	7	1	10 %	214	1 131		4.3
Pasteurizer 2 – standby water (P2)	7	2	10 %	96	161		3.6
Pasteurizer 5 – cream (P5)	68	10	10 %	245	1 468		39.0
Pasteurizer 6 – cream/Sour cream (P6)	32	24	10 %	45	357		5.6
Pasteurizer 7 – Juice (P7)	20	5	10 %	327	2 291		10.3
Yoghurt storage	43	21	10 %	473	2 144		15.0
Sour milk Storage	40	10	10 %	534	1 846		20.3
Raw cream storage	10	2	10 %	48	145		5.6
Pasteurized cream storage	13	2	10 %	44	177		7.6
Total				2 804	15 726		

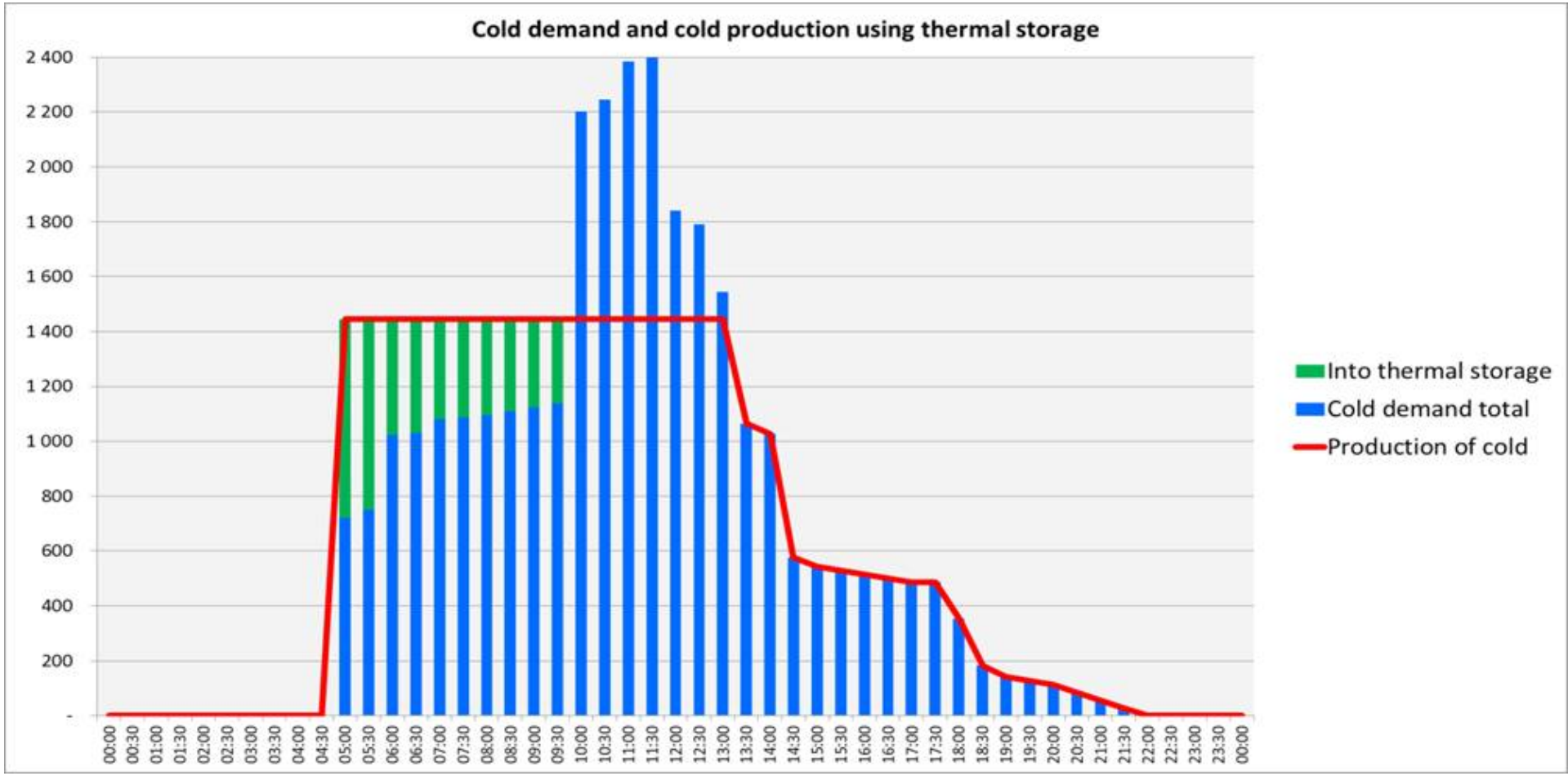
Dairy process. Cold demands



Dairy process. Cold demand, production and storage

- Design demand : 2 400 kW
- Design pretext:
  - One redundant chiller to ensure production during down time, maintenance etc.
  - Two chillers, 1/3 and 2/3 capacity to ensure good capacity control.
  - Thermal storage to shave the peak demand.
  - Performance of the smallest chiller 2400/5 = 480 kW.
  - Performance of the larger chiller 2 * 480 = 960 kW.
  - Peak shaved 960 kW.
  - Storage 2 150 kWh + 545 kWh = 2 700 kWh

Dairy process. Cold demand and production



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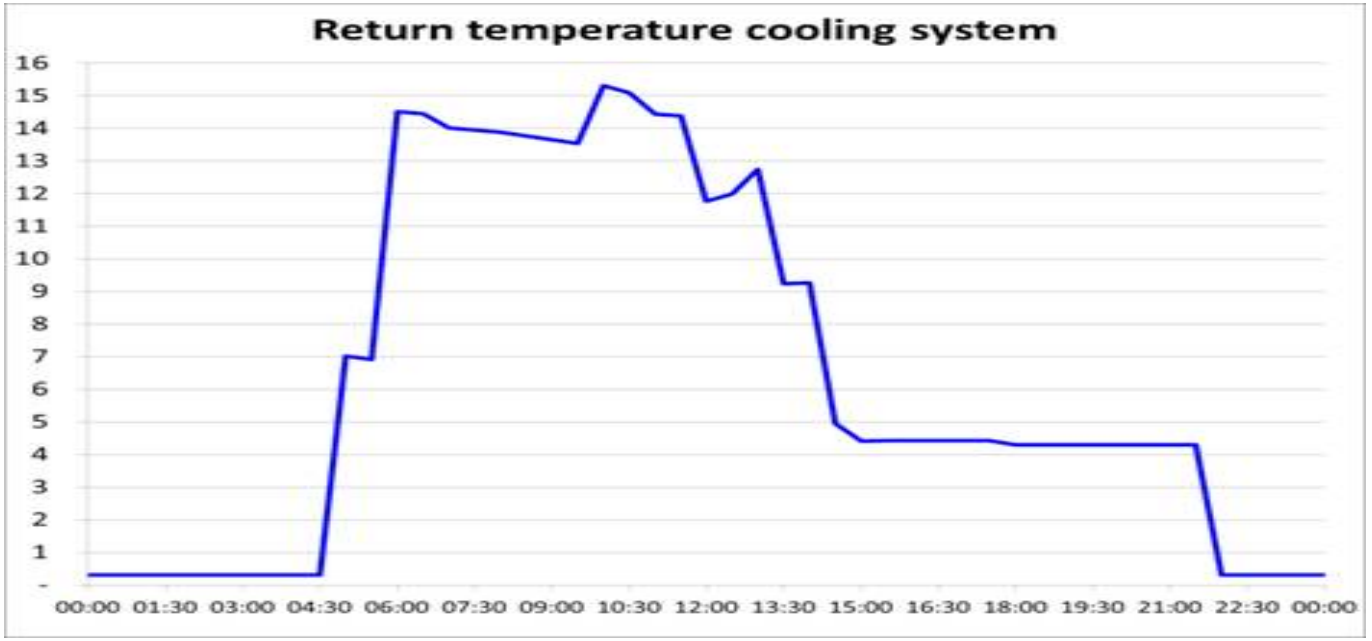
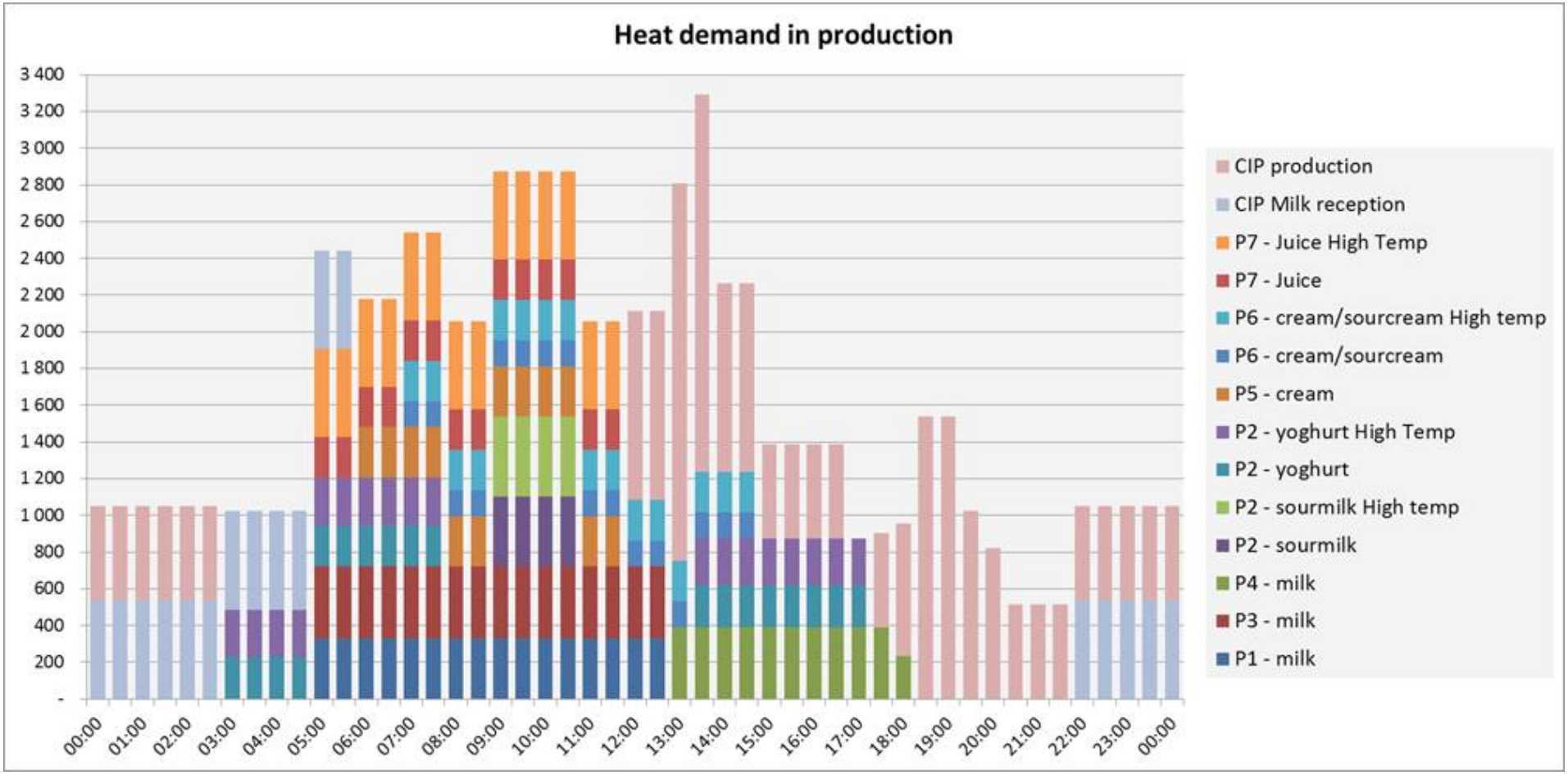
Dairy process. Cold demand. Temperature and storage

- Stratification tank vs. Ice storage.
- Ice storage will need precooling of the return water.
- Ice storage will need TEVAP = -8^{o}C. Stratification will need -3^{o}C
- Ice storage is smaller, but not as responsive.



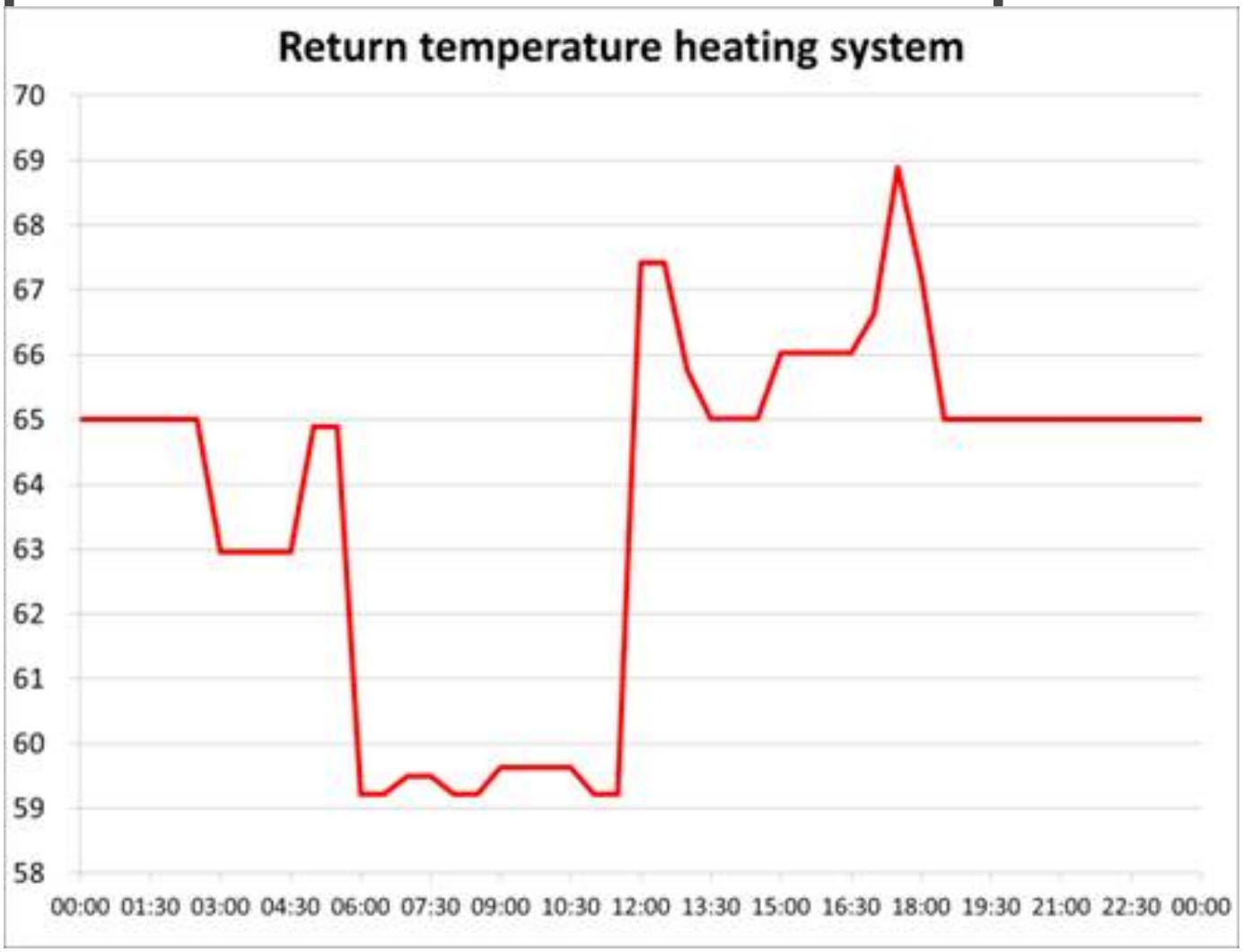
Dairy process. Heat demand



Dairy process. Heat demand and temperature levels

	Tin [°C]	Tout [°C]	Margin	10 % Heat [kW]	Energy [kWh]		T return hot water [°C]
Pasteur 1 – milk	75	64	10 %	330.8	2 646		74
Pasteur 3 – milk	75	64	10 %	391.4	3 131		74
Pasteur 4 – milk	75	64	10 %	391.4	2 074		74
Pasteur 2 – sour milk	45	25	10 %	379.7	759		35
Pasteur 2 – sour milk (HT)	96	73	10 %	436.6	873		83
Pasteur 2 – yoghurt	45	25	10 %	225.3	2 027		35
Pasteur 2 – yoghurt (HT)	96	73		259.1	2 332		83
Pasteur 5 – cream	75	10	10 %	274.2	1 645		20
Pasteur 6 – cream/sour cream	70	45	10 %	139.5	1 116		55
Pasteur 6 – cream/sour cream (HT)	95	55	10 %	223.1	1 785		65
Pasteur 7 – Juice	15	5	10 %	218.2	1 527		15
Pasteur 7 – Juice (HT)	90	68	10 %	480.0	3 360		78
CIP Milk reception	90	55	10 %	539.0	4 312		65
CIP production	95	55	10 %	2 053.3	11 550		65
Total					39 139		

Dairy process. Heat demand and temperature levels



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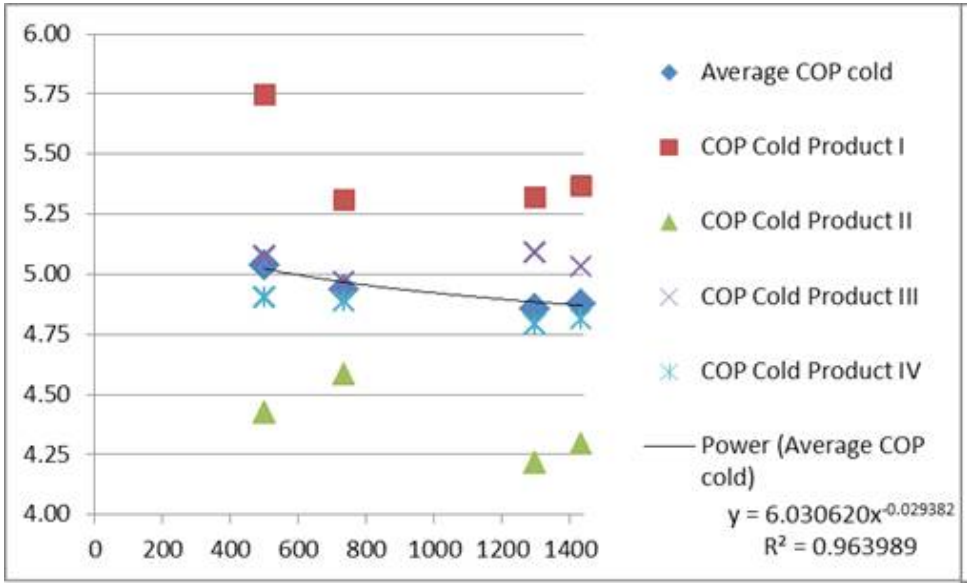
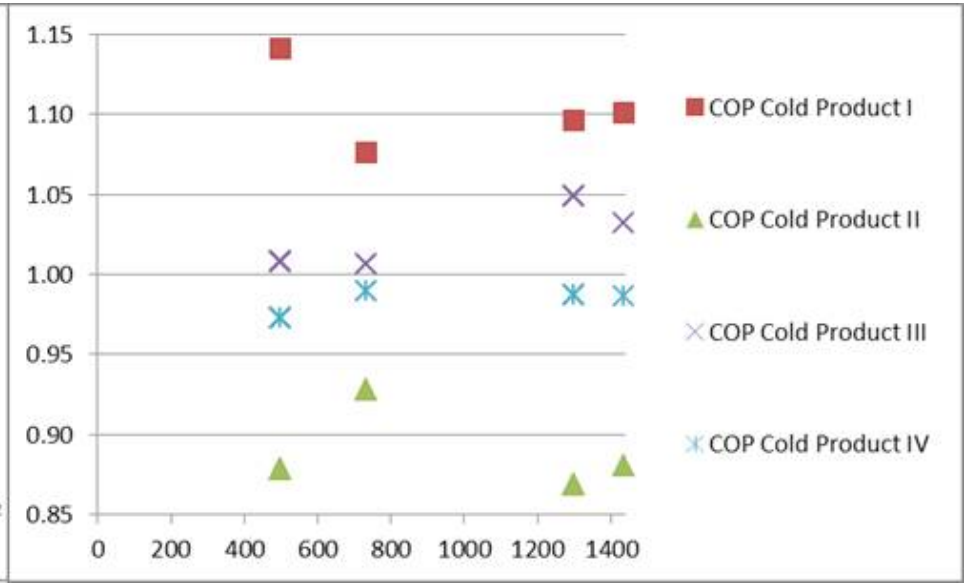
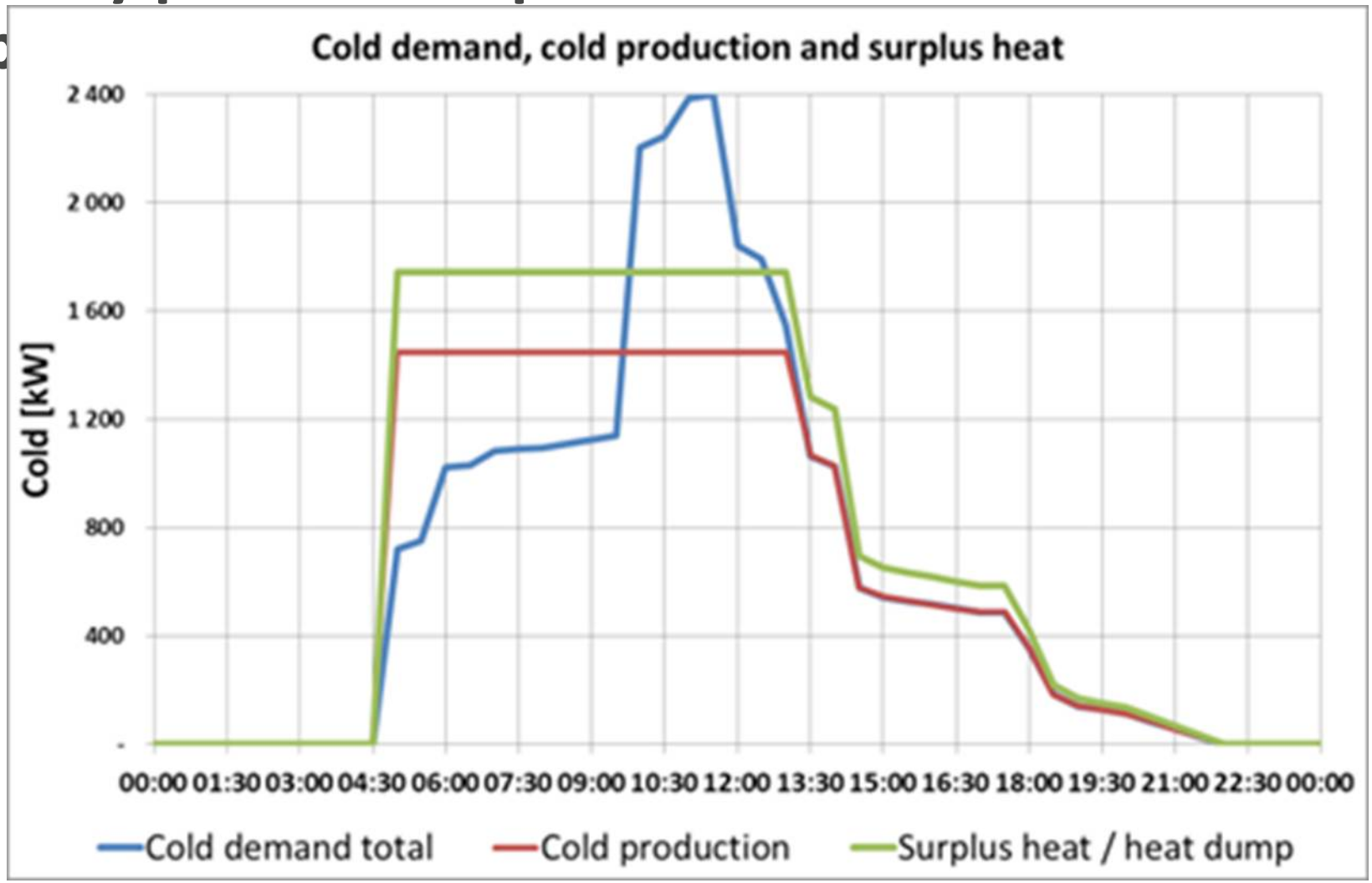
Refrigeration machinery. Efficiency





Dairy process. Surplus heat from cold p



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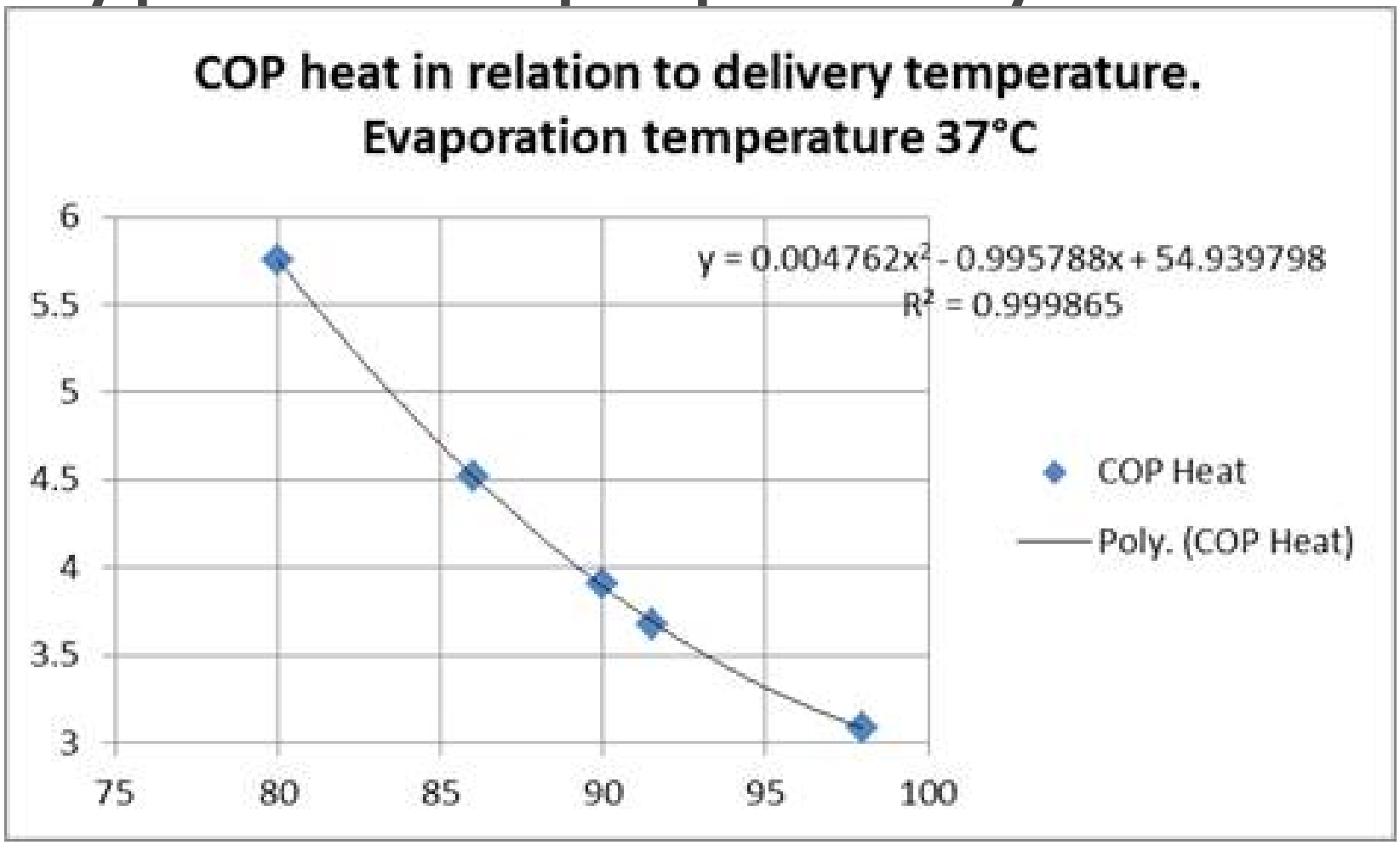
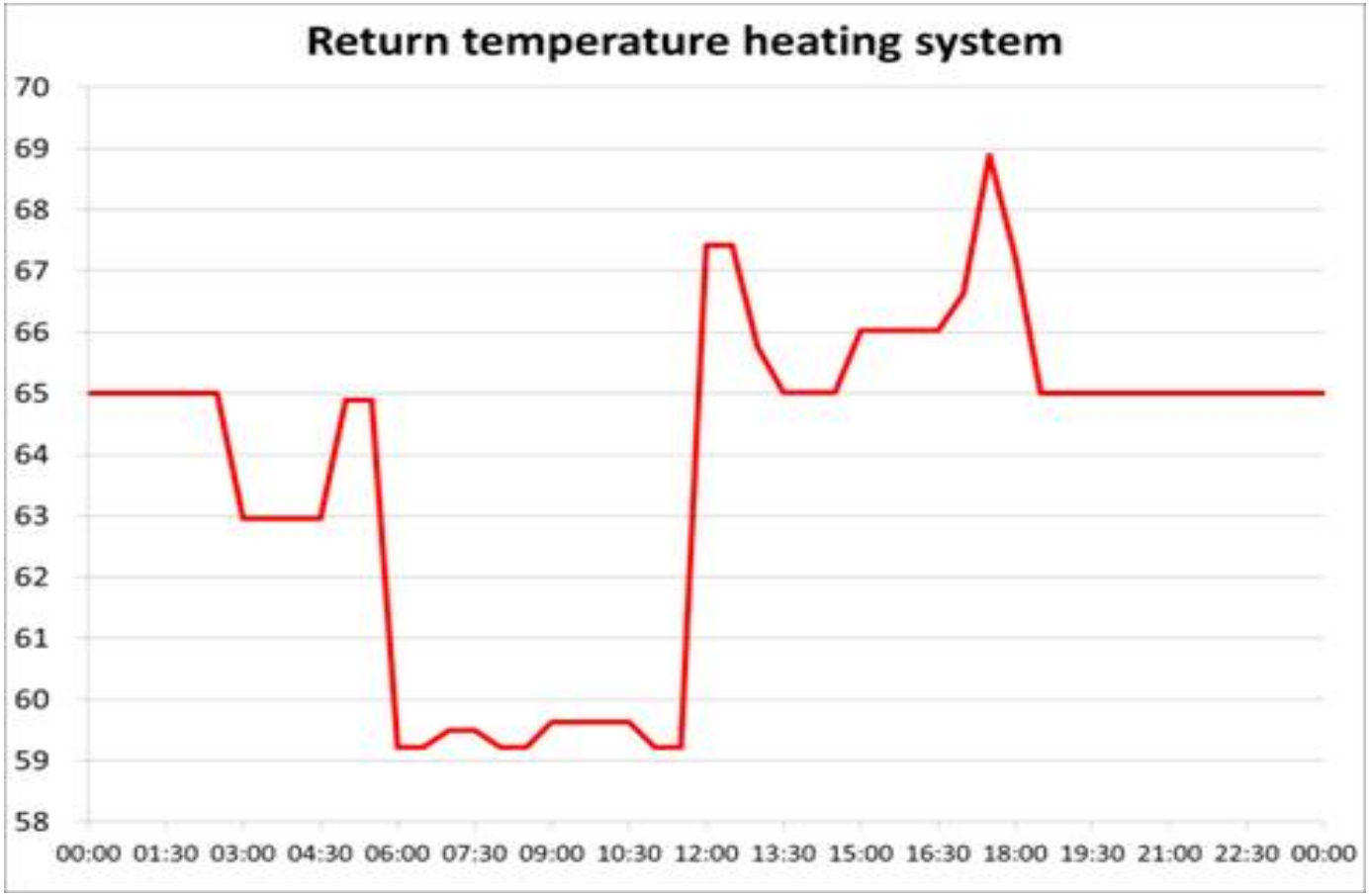
Dairy process. Heat pump efficiency



Dairy process. Heat pump production potential

Delivery temp. [°C]	COP	Potential heat production [kWh]
86.0	4.52	24 260
90.0	3.91	25 420
91.5	3.68	25 900
98.0	3.09	27 940

Dairy process. Heat pump production potential, temperature variations



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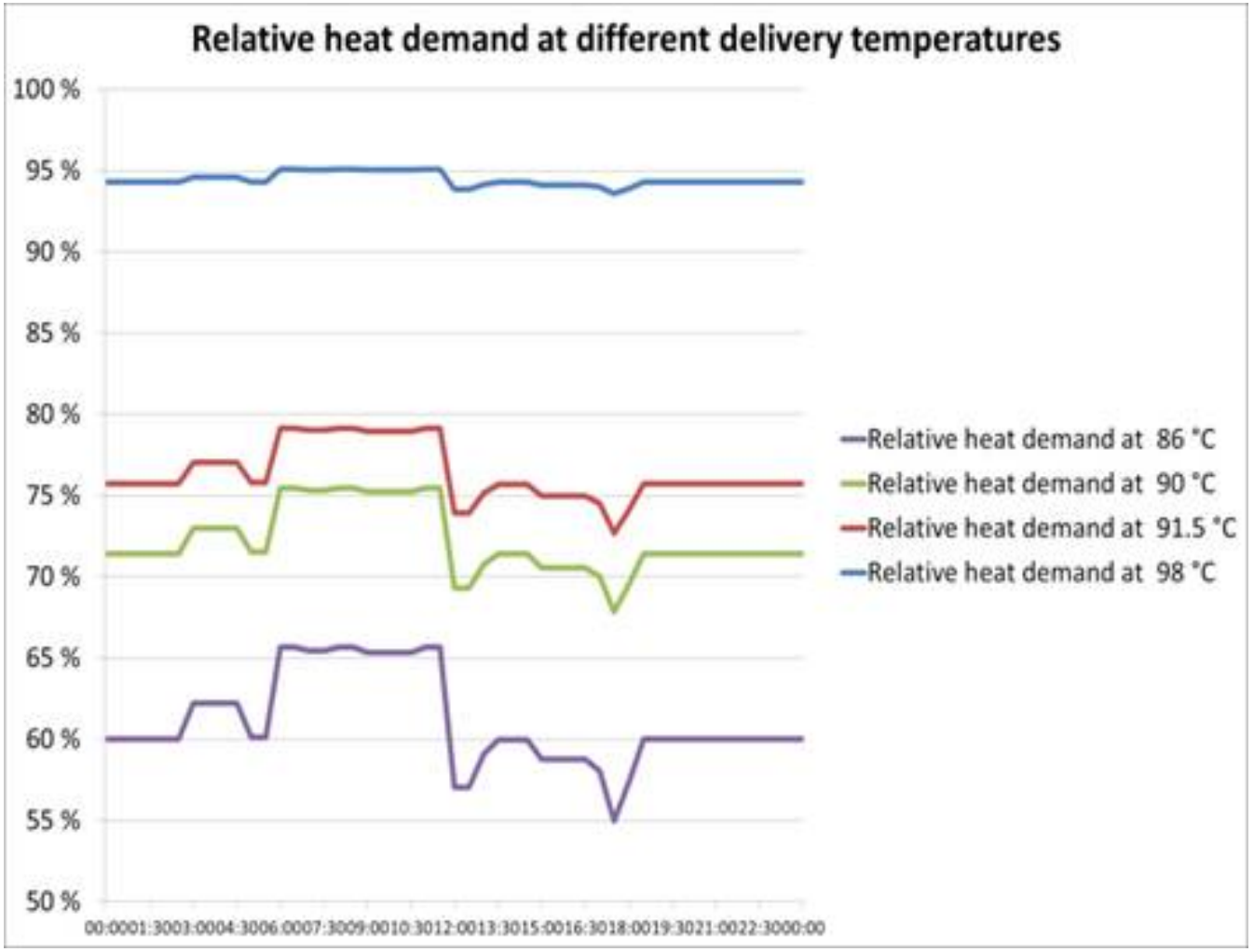
Dairy process. Heat demand and temperature variations



Dairy process. Heat pump production potential, heat demand coverage

Delivery temp. [°C]	COP	Potential heat production [kWh]	Potential heat demand [kWh]	Relation available heat and heat demand
86.0	4.52	24 260	24 180	100%
90.0	3.91	25 420	28 450	89%
91.5	3.68	25 900	30 050	86%
98.0	3.09	27 940	37 000	76%

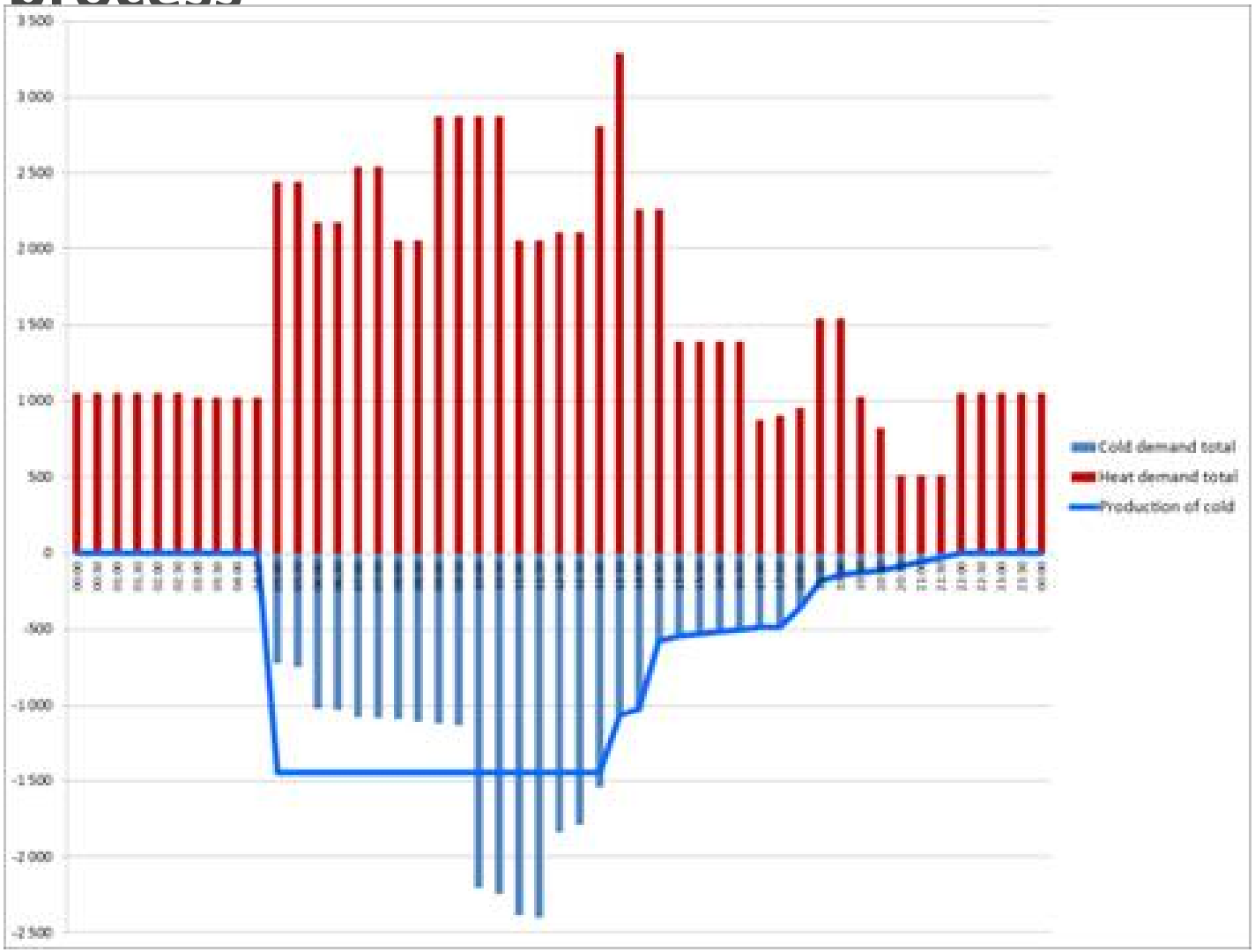
Dairy process. Energy efficiency and CO2

		Today	90°C	91.5°C	98°C
Heat demand	kWh	39 140	39 140	39 140	39 140
Heat delivery from heat pump	kWh		25 420	25 900	27 940
Heat delivery from steam boiler		39 140	13 720	13 240	11 200
Boiler efficiency	85 %				
Energy supplied to boiler	kWh	46 047	16 141	15 576	13 176
Heat pump process COP			3.91	3.68	3.09
Power train efficiency	93 %				
Actual COP			3.64	3.42	2.87
Energy supplied to heat pump	kWh		6 991	7 568	9 723
Total energy demand per day	kWh	46 047	23 132	23 144	22 899
Total energy saved per day	kWh		22 915	22 903	23 148
Emission reduction	tons CO2		2 360	2 359	2 384

Dairy process. Heat pump economic efficiency

	Energy savings		Invest HP	Pay back HP	Invest chillers	Equipment total	Payback equipment
	kWh	Euro	Euro	Years	Euro	Euro	Years
II	5 974 336	477 947	1 042 076	2,2	1 112 114	2 154 190	4,5
III	5 971 087	477 687	1 371 198	2,9	996 488	2 367 686	5,0
IV	6 034 996	482 800	2 709 190	5,6	1 009 811	3 719 001	7,7

Dairy process



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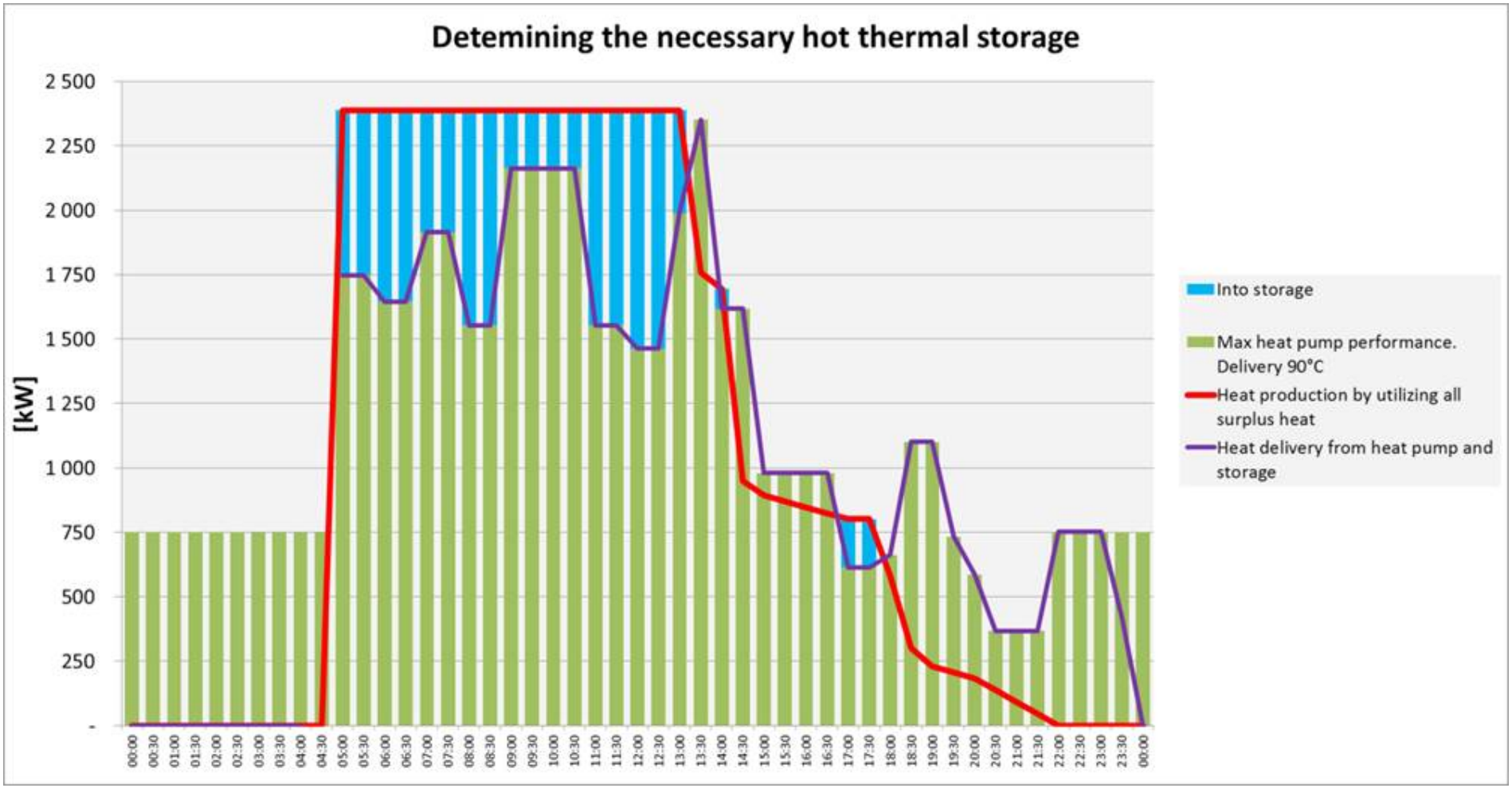

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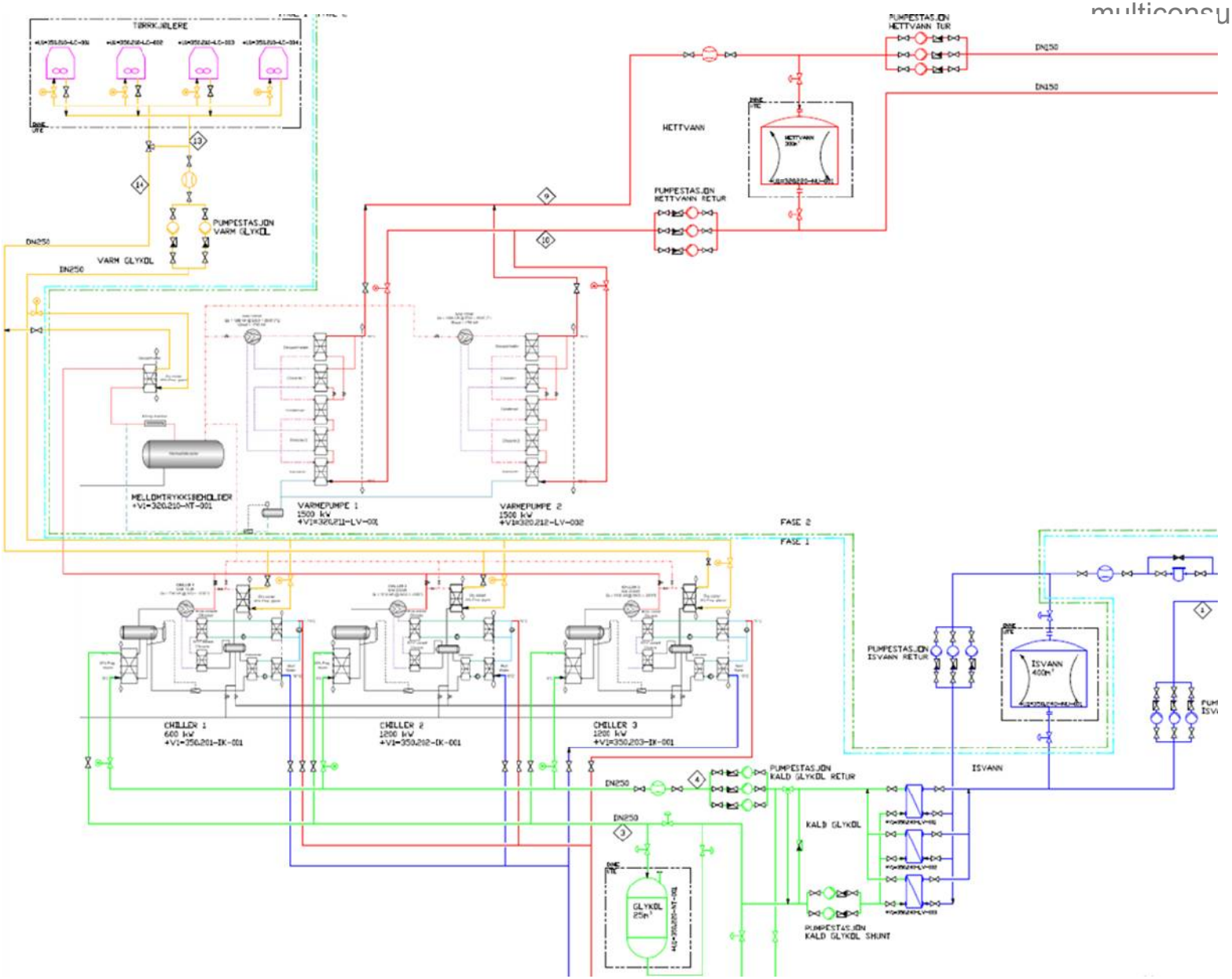

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