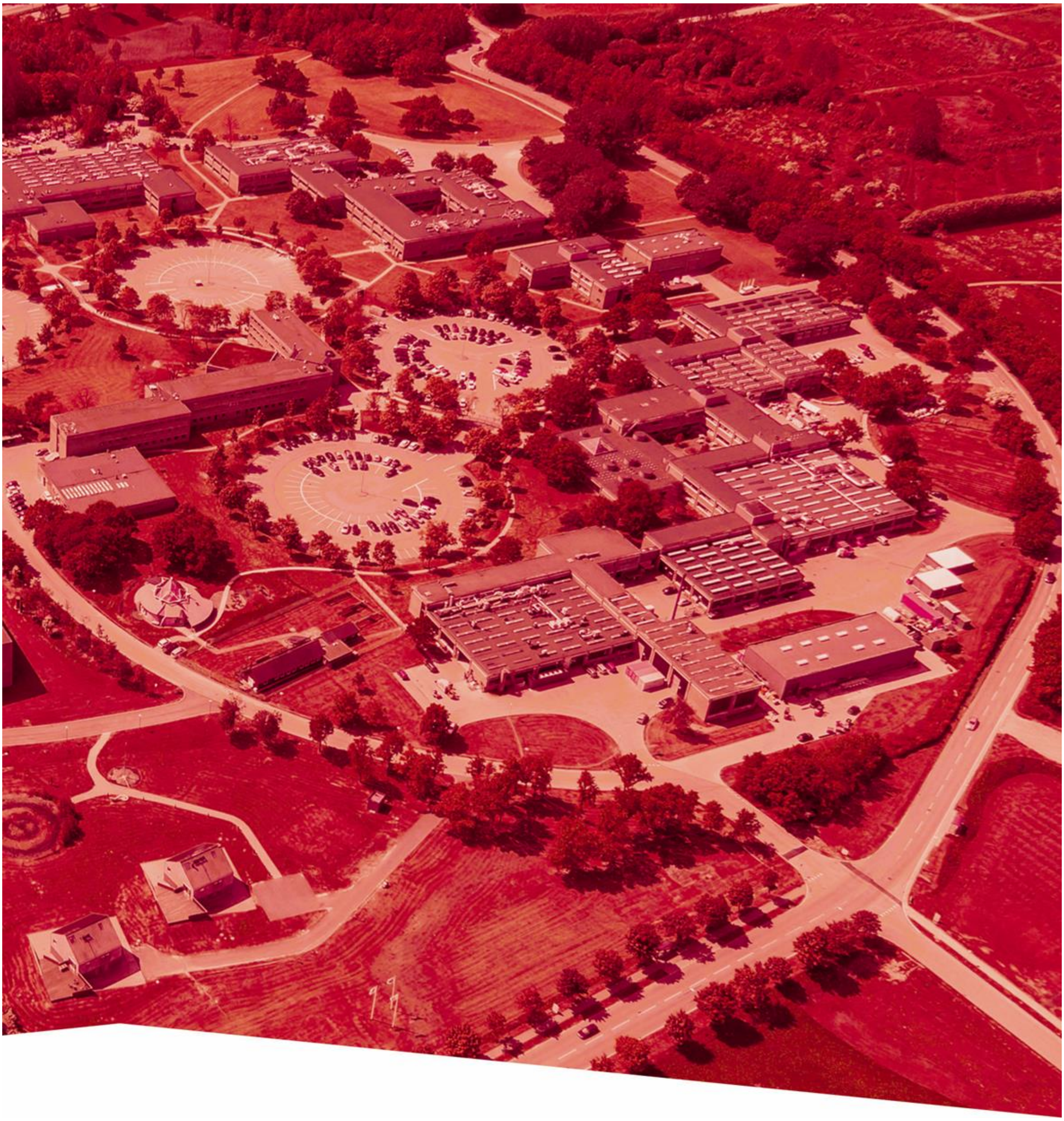

Evaluation of pump energy consumption for two principles for hydraulic balancing and control of cooling systems

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Evaluation of pump energy consumption for two principles for hydraulic balancing and control of cooling systems

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1. Contents

2. Introduction

FRESE A/S has asked DTI to evaluate two strategies for larger hydraulic cooling systems – in terms of pump energy consumption.

Two examples have been chosen, both using water as cooling fluid:

1. A server room including battery pack and several cooled racks
2. A comfort cooling system with cooled ceiling panels

The strategies considered are:

- Hydraulic balancing using "static" valves + one differential pressure controller for the network. In order to measure and adjust the flow, some pressure drop is needed in the static valves.
- Hydraulic balancing using "dynamic" valves mounted at each cooling device. The dynamic valve is a combined differential pressure controller and control valve. This system is in a wide range independent of the flow and pressure conditions in the network and further valves in the network are not needed.

To quantify the energy consumption some operation profiles are needed. At part load the water flow rapidly decreases. To take this into account the figure 1 is used. The relation between flow and cooling load is calculated based on traditional heat exchanger theory.

The Grundfos product center dimensioning is used for the calculation of annual savings. The Grundfos system allows for user defined load profiles.

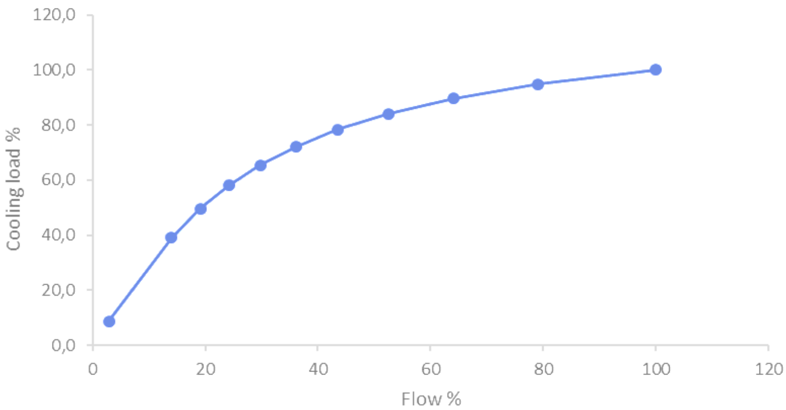


Figure 1 Simplified relation between flow of cooling fluid and cooling load for a server-room-cooler. 50% load needs 20% flow. The calculation of the relation is based on heating up the cooling water by 5 K at max. load and 20 °C in the room. The curve is also assumed to be valid for comfort cooling.

The assumption is that the load differs from day to night, due to the load on server capacity. At 50 % cooling load in the night, the flow is calculated to 20%.

3. Server room

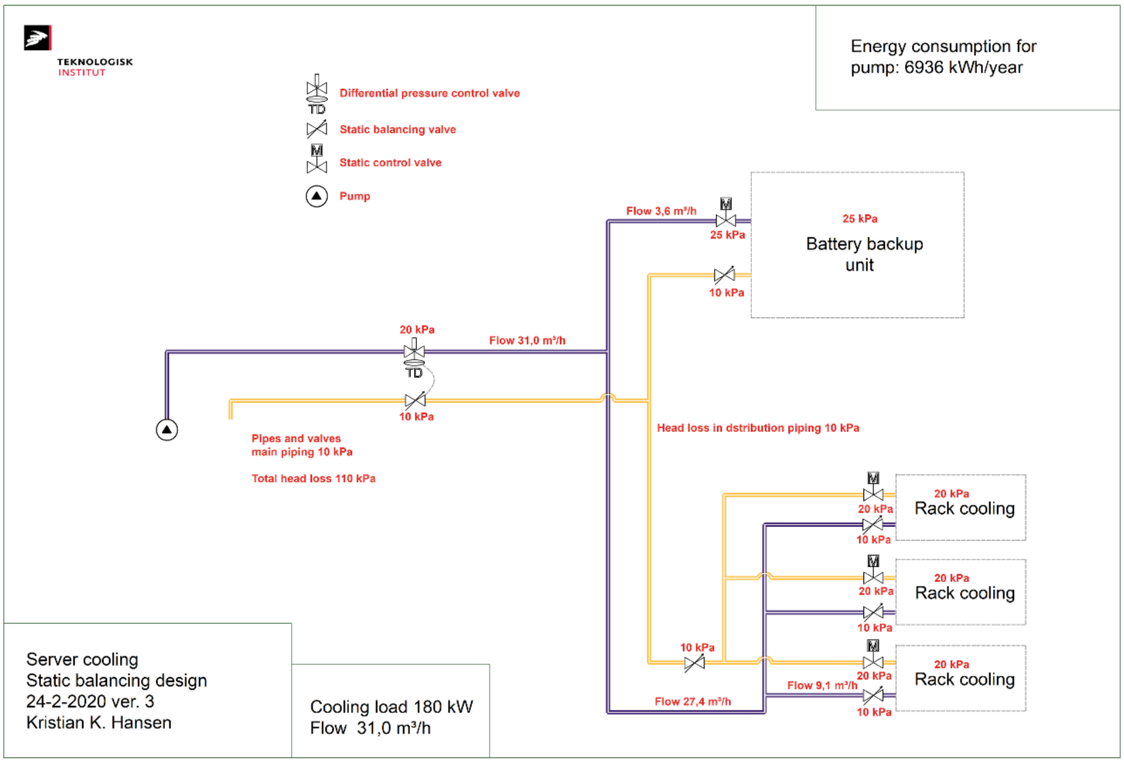


Figure 2 Server room static valves

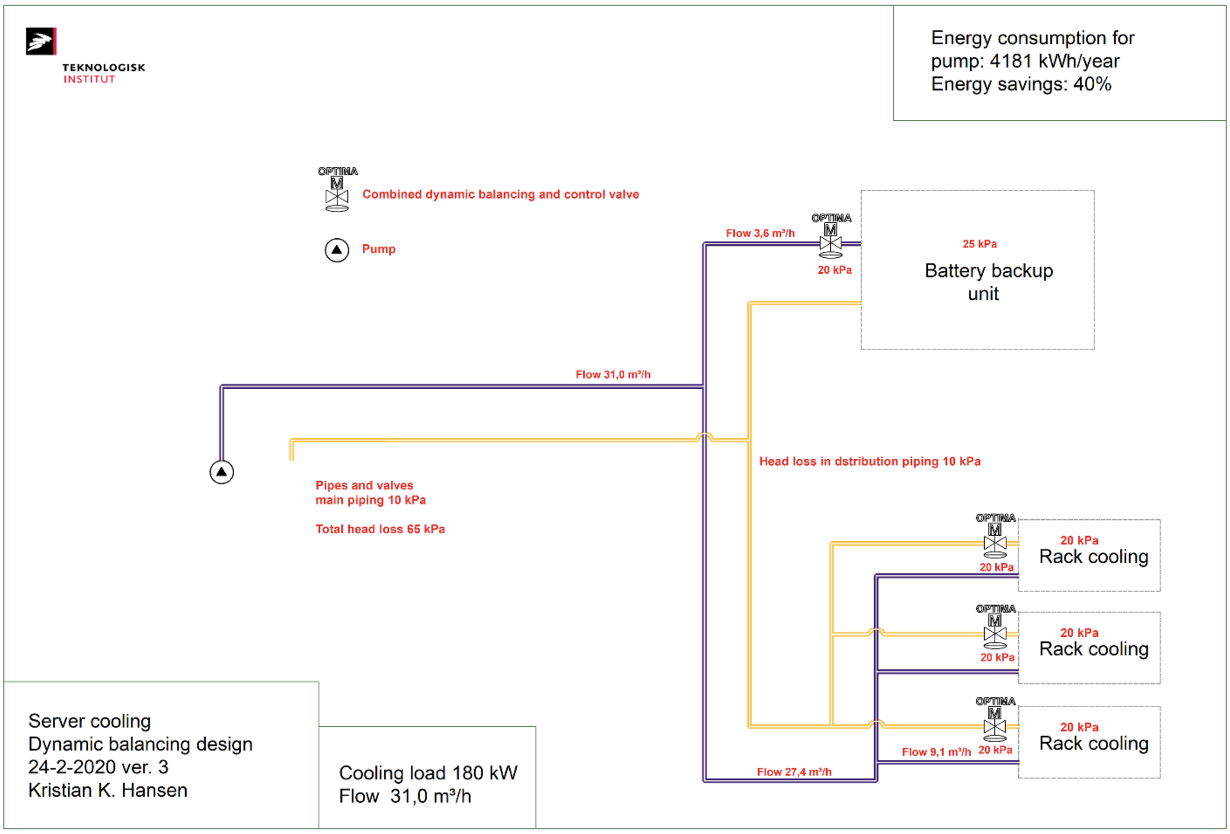


Figure 3 Server room dynamic valves

Sizing result							
Type	MAGNA3 65-150F			Load profile			
Quantity	1				1	2	
Motor				Flow	100	20	%
				Head	100	43	%
Flow	31	m³/h		P1	1.372	0.211	kW
Head	110	kPa		Eta total	69.0	38.6	%
Power P1	1.373	kW		Time	4380	4380	h/a
Eta pump+motor	69.0	%=Eta pump * Eta motor		Energy consumption	6012	925	kWh/Year
Eta total	69.0	%=Eta relative to the duty point		Quantity	1	1	
Energy consumption	6936	kWh/Year					
CO2 emission	3950	kg/Year					
Price	28.635,00	DKK					
Life cycle cost	320617	DKK/15Years					

Table 1 Pump selection for the static balanced and controlled system. The part load head is estimated, based on the assumption that the total pressure drop at 20% flow in the pipes and the static valves is negligible, while the pressure drop across the control valve is maintained.

Sizing result

Type	MAGNA3 80-100F	
Quantity	1	
Motor		
Flow	31	m³/h
Head	65	kPa
Power P1	0.859	kW
Eta pump+motor	65.2	%=Eta pump * Eta motor
Eta total	65.2	%=Eta relative to the duty point
Energy consumption	4181	kWh/Year
CO2 emission	2380	kg/Year
Price	28.810,00	DKK
Life cycle cost	204826	DKK/15Years

Load profile

	1	2	
Flow	100	20	%
Head	100	34	%
P1	0.859	0.096	kW
Eta total	65.2	39.5	%
Time	4380	4380	h/a
Energy consumption	3761	420	kWh/Year
Quantity	1	1	

Table 2 Pump selection for the dynamic balanced and controlled system. The part load head is estimated, based on the assumption that the total pressure drop at 20% flow in the pipes is negligible, while the pressure drop across the control valve is maintained.

Static balanced and controlled	**Day**	**Night**
Load %	100	50
Flow m³/h	31	6,2
Head kPa	110	47
Operation hours	4380	4380
kWh/year	6936	

The calculation shows a pump energy consumption of app. 7000 kWh per year in a static balanced and controlled system for an evenly distributed day and night-time operating cycle.

Dynamic balanced and controlled	**Day**	**Night**
Load %	100	50
Flow m³/h	31	6,2
Head kPa	65	22
Operation hours	4380	4380
kWh/year	4181	

The calculation shows a pump energy consumption of app. 4200 kWh per year in a dynamic balanced and controlled system for an evenly distributed day and night-time operating cycle.

Table 3 Results for the server room. The pump energy savings are 40 % when changing from static to dynamic balanced and controlled system.

4. Comfort cooling – cooling ceiling

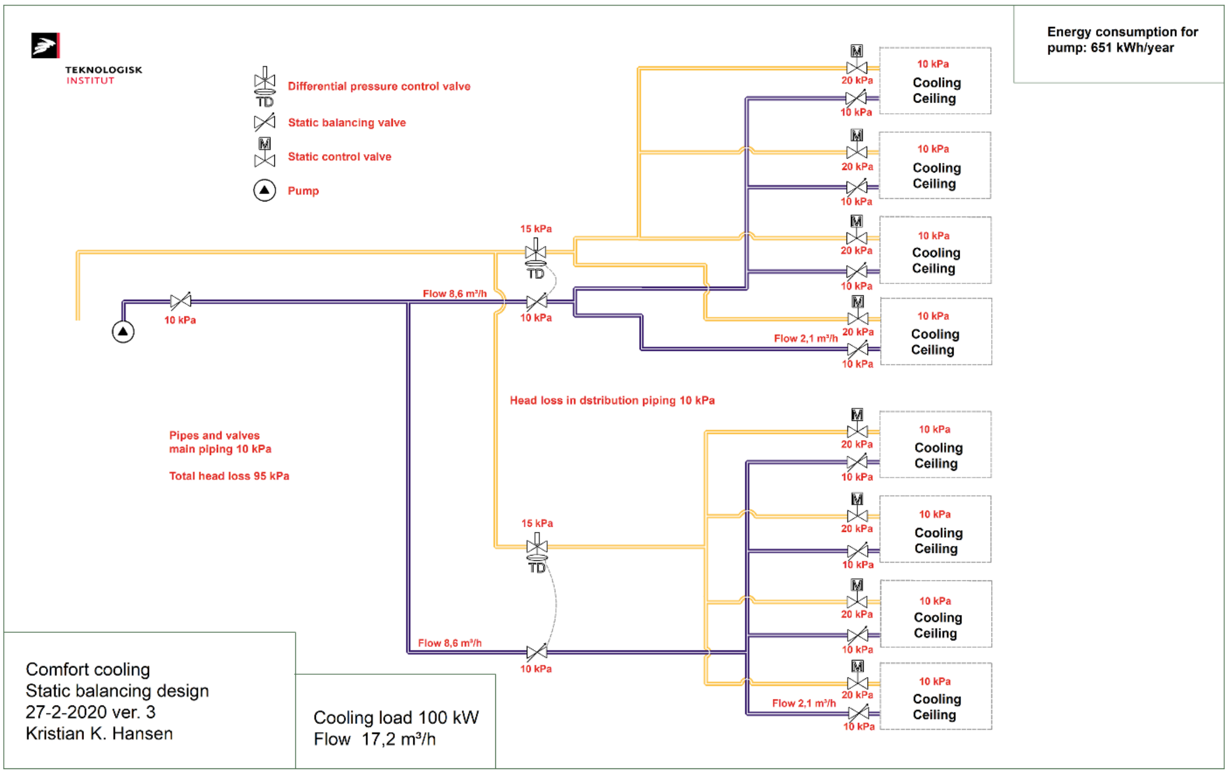


Figure 4 Comfort cooling static valves

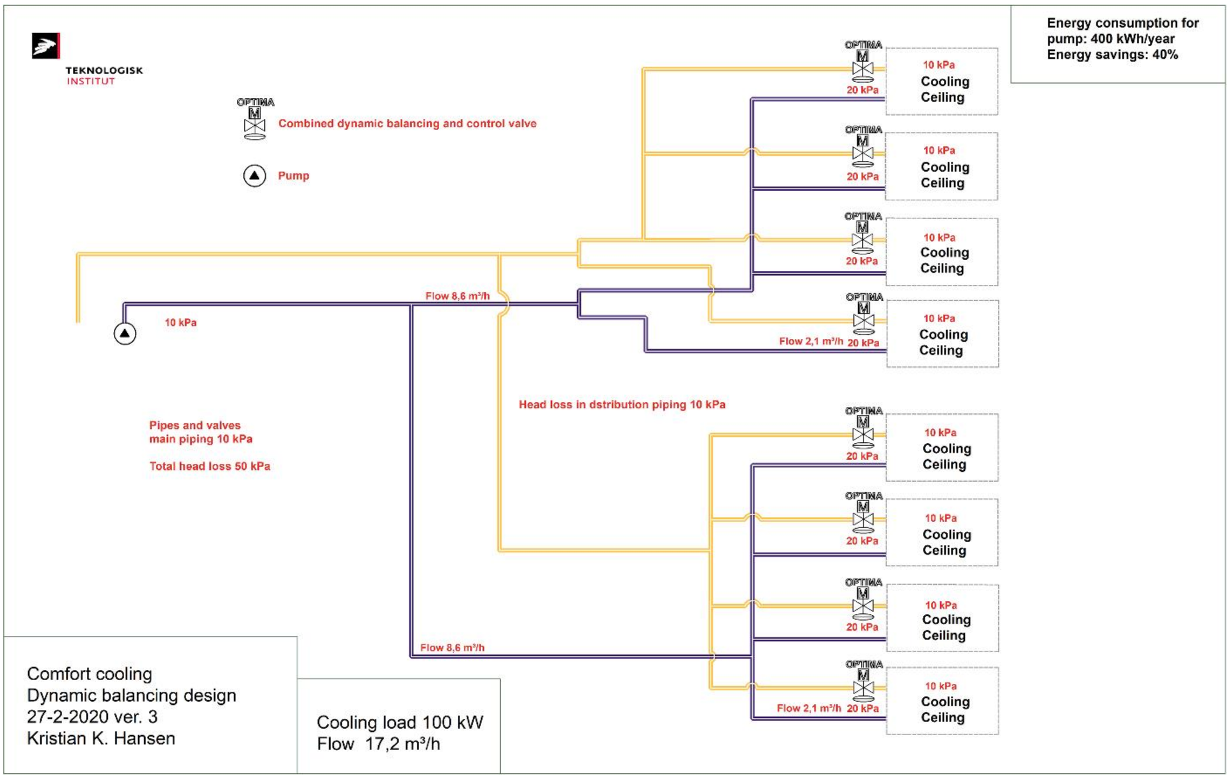


Figure 5 Comfort cooling dynamic valves

The cooling load is controlled by changing the flow, assuming a constant cooling water temperature. The load is taken from a cooling degree-days distribution from southern Europe, see figure 6.
Source: https://www.degreedays.net

The load uses 10-degree daily average as base. Danish Technological Institute assume that many buildings will need some cooling, due to internal and passive solar load from a 10-degree daily average.

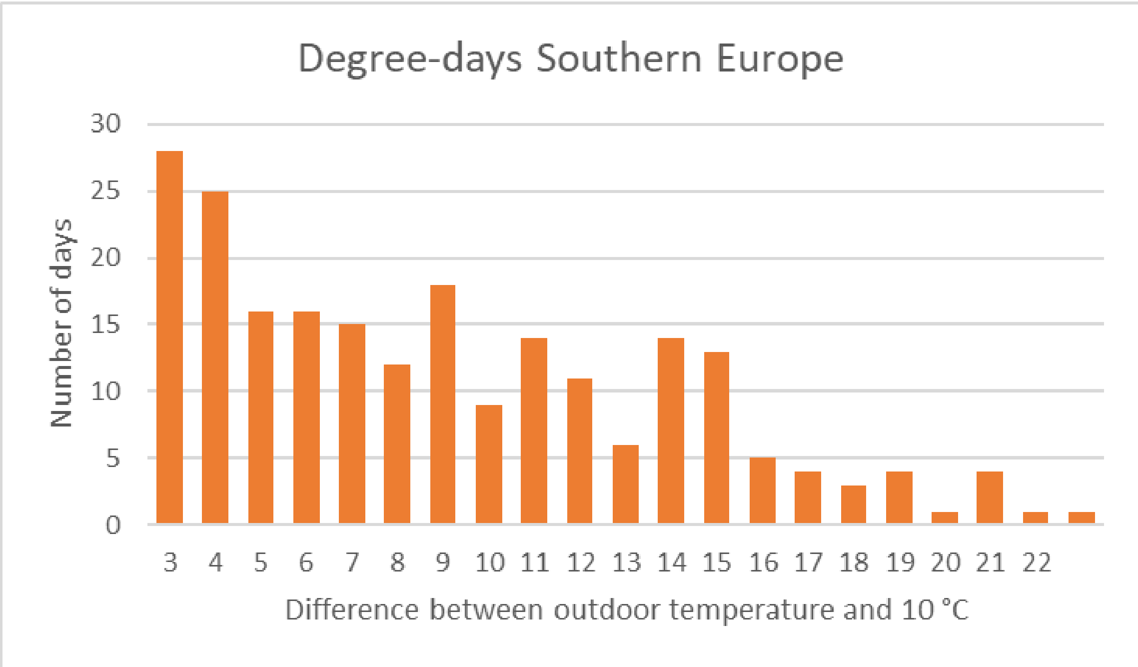


Figure 6 The load distribution is assumed to follow the cooling degree days for Lyon, basis 10 °C, 221 days

	Bin 1					Bin 2							Bin 3								Bin 4
Degrees	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Days	**28**	**25**	**16**	**16**	**15**	**12**	**18**	**9**	**14**	**11**	**6**	**14**	**13**	**5**	**4**	**3**	**4**	**1**	**4**	**2**	**1**

Table 4 Load distribution divided in 4 bins, 5, 11, 19 and max 23 K temperature difference to a chosen basic temperature of 10 °C

							Static Bal.	Dynamic Bal.
Bin	Delta T	Days	Hours	% load	% Flow	Flow m^3/h	Delta P kPa	
1	5	100	2400	21,7	9	1,5	35,5	30,2
2	11	84	2016	47,8	20	3,4	37,4	30,8
3	19	36	864	82,6	50	8,6	50,0	35,0
4 (max)	23	1	24	100,0	100	17,2	95,0	50,0
Min = pressure drop control valves							35,0	30,0
Total		221	5304					

Table 5 Load distribution for the pump, static and dynamic balancing. The flow needed is taken from figure 1.

Sizing result		
Type	MAGNA3 50-180F	
Quantity	1	
Motor		
Flow	17.2	m³/h
Head	95	kPa
Power P1	0.712	kW
Eta pump+motor	63.8	%=Eta pump * Eta motor
Eta total	63.8	%=Eta relative to the duty point
Energy consumption	651	kWh/Year
CO2 emission	371	kg/Year
Price	27.265,00	DKK
Life cycle cost	54675	DKK/15Years

Load profile	1	2	3	4	
Flow	9	20	50	100	%
Head	37	39	53	100	%
P1	0.09	0.112	0.223	0.711	kW
Eta total	16.4	31.6	53.5	63.8	%
Time	2400	2016	864	24	h/a
Energy consumption	216	225	193	17	kWh/Year
Quantity	1	1	1	1	

Table 6 Sizing. This pump in a static balanced and controlled system has an annual consumption of 651 kWh/ year.

Sizing result		
Type	MAGNA3 40-120F	
Quantity	1	
Motor		
Flow	17.2	m³/h
Head	50	kPa
Power P1	0.391	kW
Eta pump+motor	61.1	%=Eta pump * Eta motor
Eta total	61.1	%=Eta relative to the duty point
Energy consumption	400	kWh/Year
CO2 emission	228	kg/Year
Price	15.935,00	DKK
Life cycle cost	32765	DKK/15Years

Load profile	1	2	3	4	
Flow	9	20	50	100	%
Head	60	62	70	100	%
P1	0.054	0.071	0.138	0.391	kW
Eta total	23.4	41.2	60.5	61.1	%
Time	2400	2016	864	24	h/a
Energy consumption	129	142	119	9	kWh/Year
Quantity	1	1	1	1	

Table 7 Sizing. This pump in a dynamic balanced and controlled system has an annual consumption of 400 kWh/ year

The conclusion for the cooling ceiling is a reduction in annual consumption for the pump from 651 to 400 kWh, or 39% when changing from a static to a dynamic balanced and controlled system. The gross price of the pump is 41% lower in a dynamic system.

Cooling load controlled by cooling water temperature, assuming a constant flow. This is the other extreme, with no individual control of the ceiling panels.

Sizing result		
Type	MAGNA3 50-180F	
Quantity	1	
Motor		
Flow	17.2	m³/h
Head	95	kPa
Power P1	0.712	kW
Eta pump+motor	63.8	%=Eta pump * Eta motor
Eta total	63.8	%=Eta relative to the duty point
Energy consumption	3757	kWh/Year
CO2 emission	2140	kg/Year
Price	27.265,00	DKK
Life cycle cost	185396	DKK/15Years

Load profile	1	
Flow	100	%
Head	100	%
P1	0.711	kW
Eta total	63.8	%
Time	5280	h/a
Energy consumption	3757	kWh/Year
Quantity	1	

Table 8 Pump sizing using static balancing in a temperature-controlled cooling system

Sizing result					
Type	MAGNA3 40-120F		Load profile		
Quantity	1			1	
Motor			Flow	100	%
			Head	100	%
Flow	17.2	m^3/h	P1	0.391	kW
Head	50	kPa	Eta total	61.1	%
Power P1	0.391	kW	Time	5280	h/a
Eta pump+motor	61.1	%=Eta pump * Eta motor	Energy consumption	2065	kWh/Year
Eta total	61.1	%=Eta relative to the duty point	Quantity	1	
Energy consumption	2065	kWh/Year			
CO2 emission	1180	kg/Year			
Price	15.935,00	DKK			
Life cycle cost	102862	DKK/15Years			

Table 9 Pump sizing using dynamic balancing in a temperature-controlled cooling system

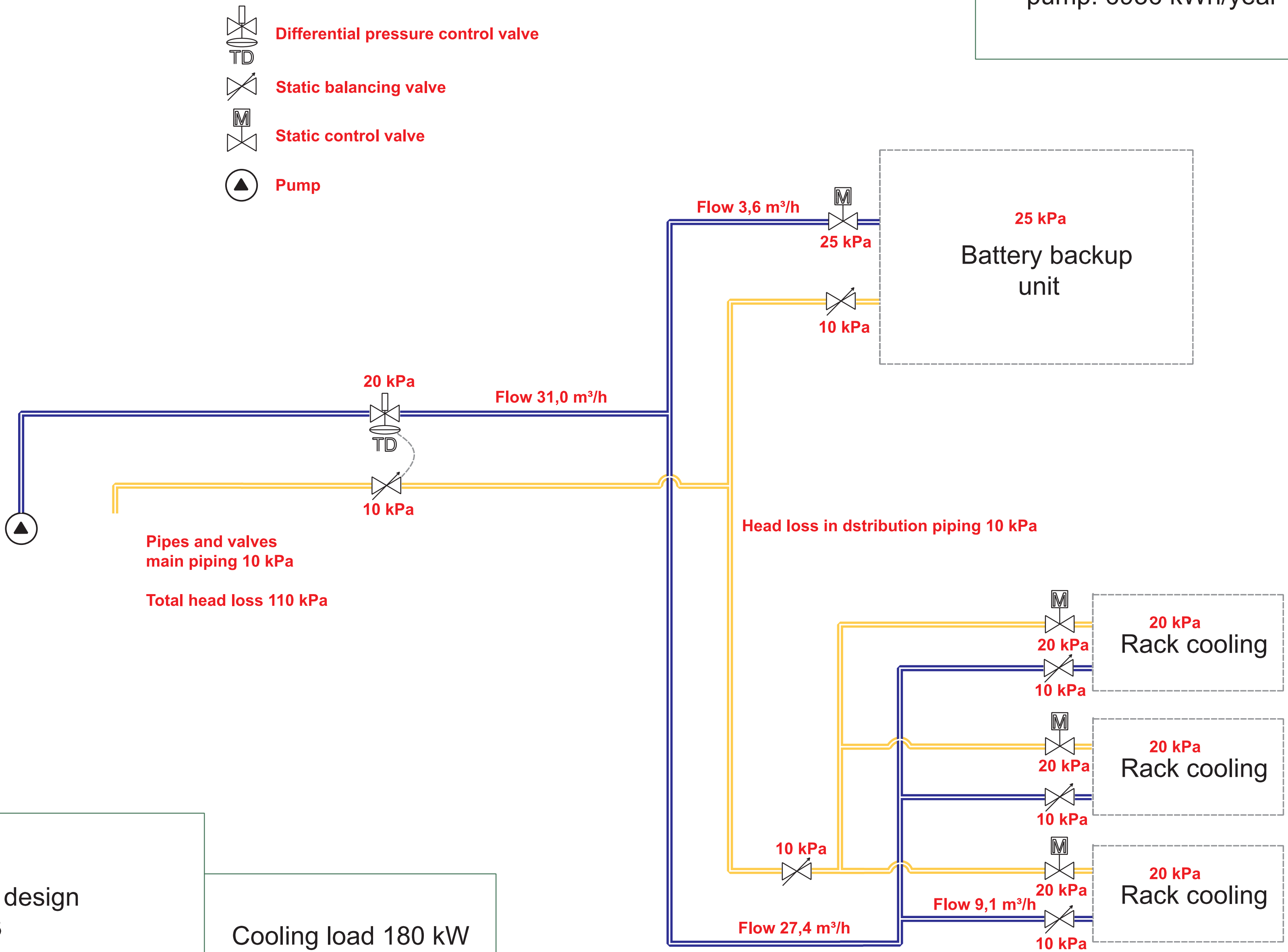
In the above example the pump energy saving is 45 % when changing from a static to a dynamic balanced and controlled system. The gross price of the pump is 41% lower in a dynamic system.

In the practical situation the control of the load will be a combination of flow and temperature control. The pump energy savings will be 40–45%. Flow control of the cooling load reduces the electricity consumption, but for the cooling ceiling there will be considerations concerning minimum flow for some types of panels in order to ensure a correct flow distribution inside the cooling panels.

5. Conclusion

Based on a simple analysis, a pump energy saving at 40–45% will be achieved by using dynamic balancing and control valves for each device. The saving is due to a reduced number of static balancing and control valves and therefore in general a reduced head loss in the system. Reduced head loss means reduced pump energy consumption and a reduced pump size.

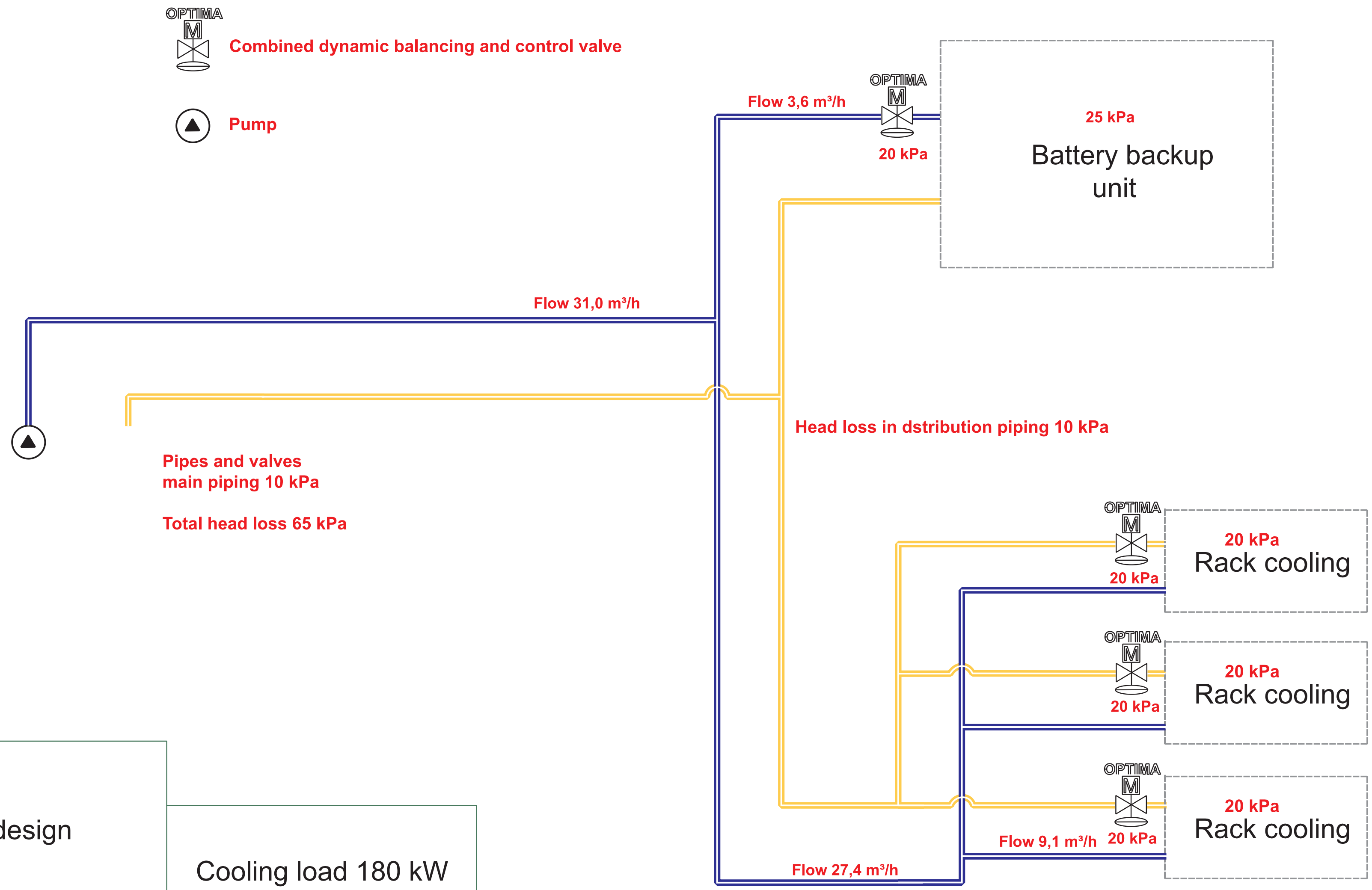
Energy consumption for
pump: 6936 kWh/year



Server cooling
Static balancing design
24-2-2020 ver. 3
Kristian K. Hansen

Cooling load 180 kW
Flow 31,0 m³/h

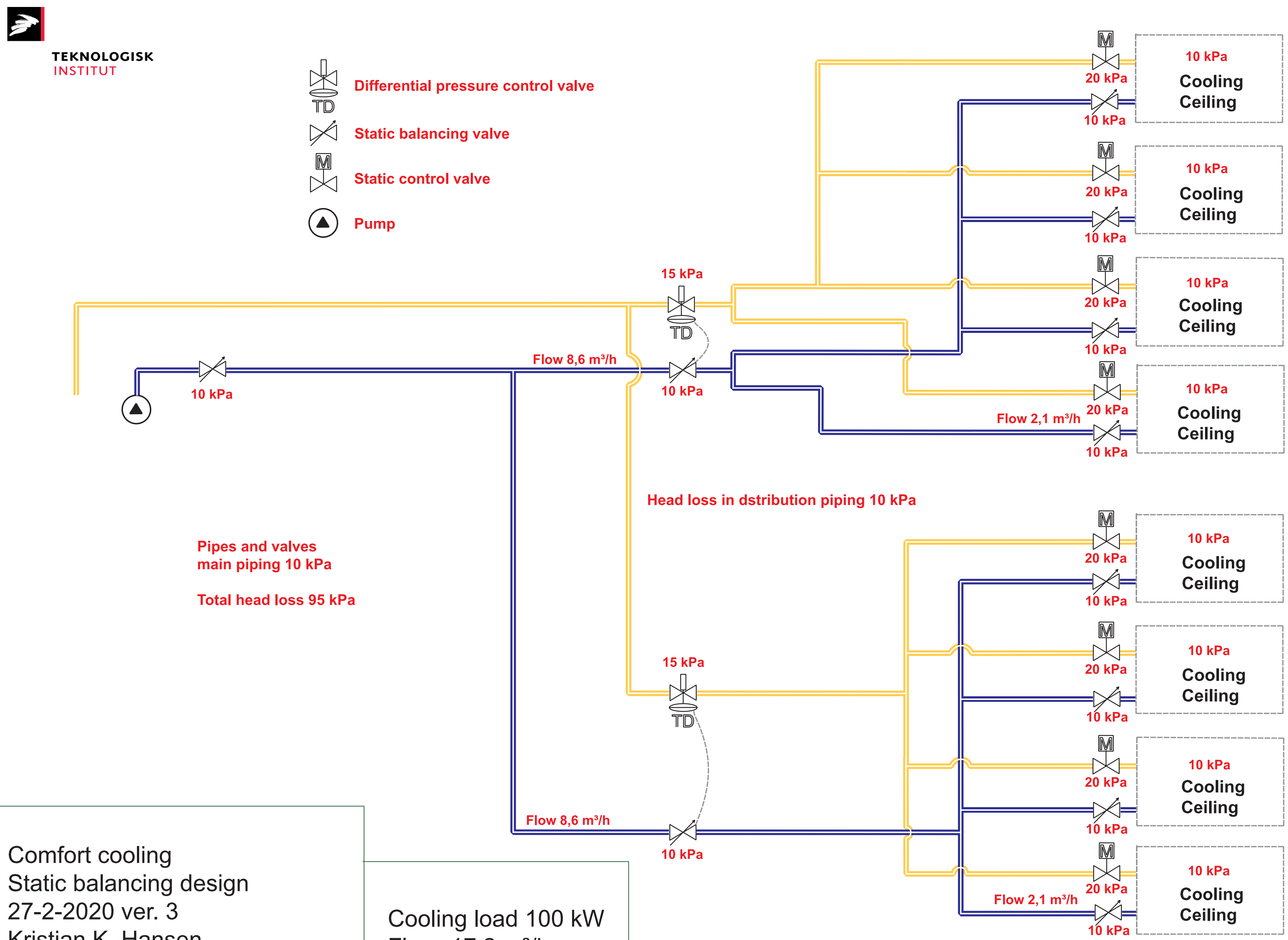
Energy consumption for
pump: 4181 kWh/year
Energy savings: 40%



Server cooling
Dynamic balancing design
24-2-2020 ver. 3
Kristian K. Hansen

Cooling load 180 kW
Flow 31,0 m³/h

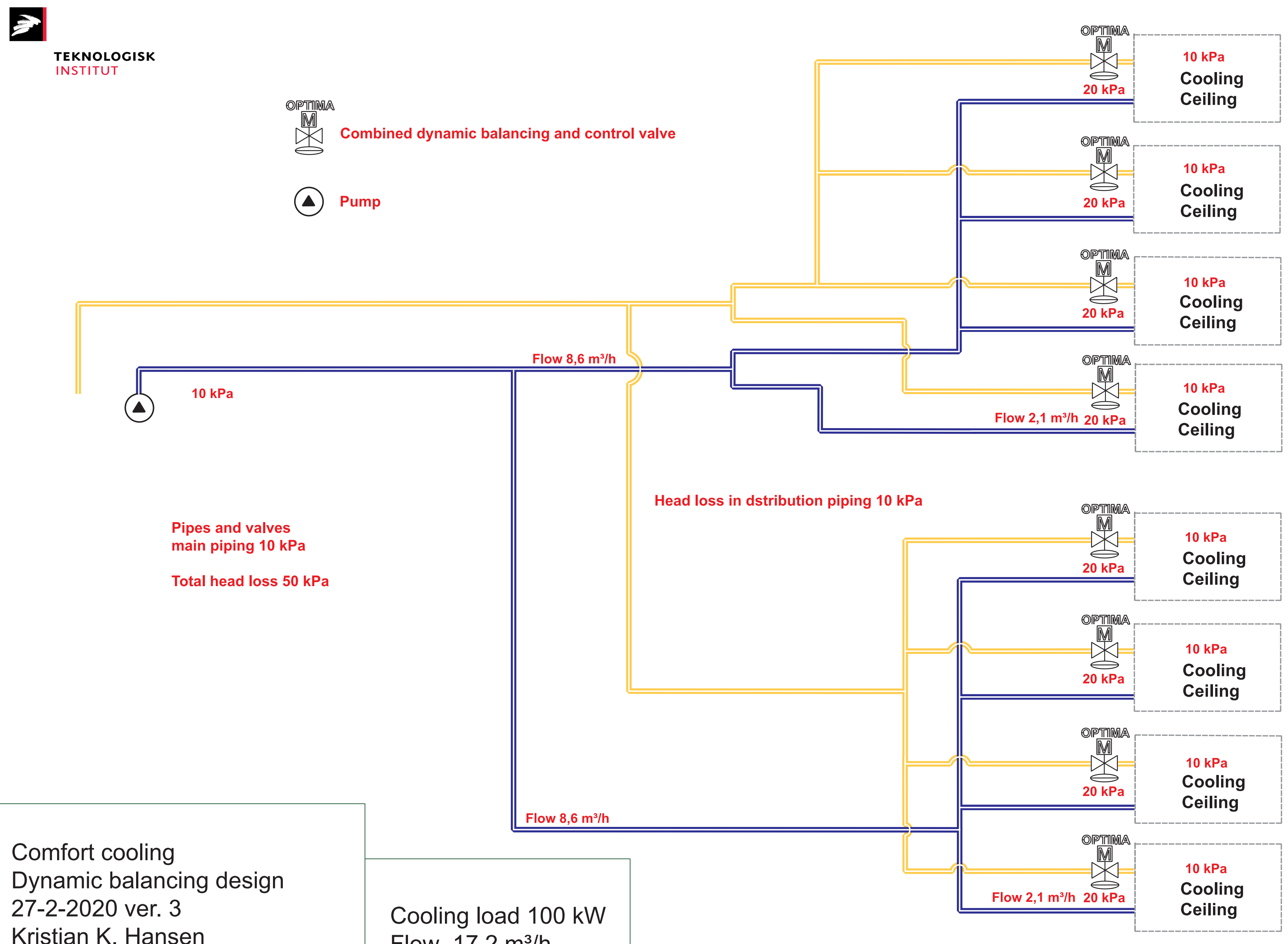
Energy consumption for pump: 651 kWh/year



Comfort cooling
Static balancing design
27-2-2020 ver. 3
Kristian K. Hansen

Cooling load 100 kW
Flow 17,2 m³/h

Energy consumption for pump: 400 kWh/year
Energy savings: 40%



Comfort cooling
Dynamic balancing design
27-2-2020 ver. 3
Kristian K. Hansen

Cooling load 100 kW
Flow 17,2 m³/h

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