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ENERGY EFFICIENCY IN HVAC HYDRAULIC SYSTEMS

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LEARNING OBJECTIVES

1. Understand the relevance of pump energy use in existing buildings.
2. Knowledge of theoretical energy use in pumps.
3. Knowledge of typical pump energy use in existing operating buildings.
4. Knowledge of typical causes of excessive pump energy use.
5. Knowledge of remediation of typical causes of excessive pump energy use.

INTRODUCTION

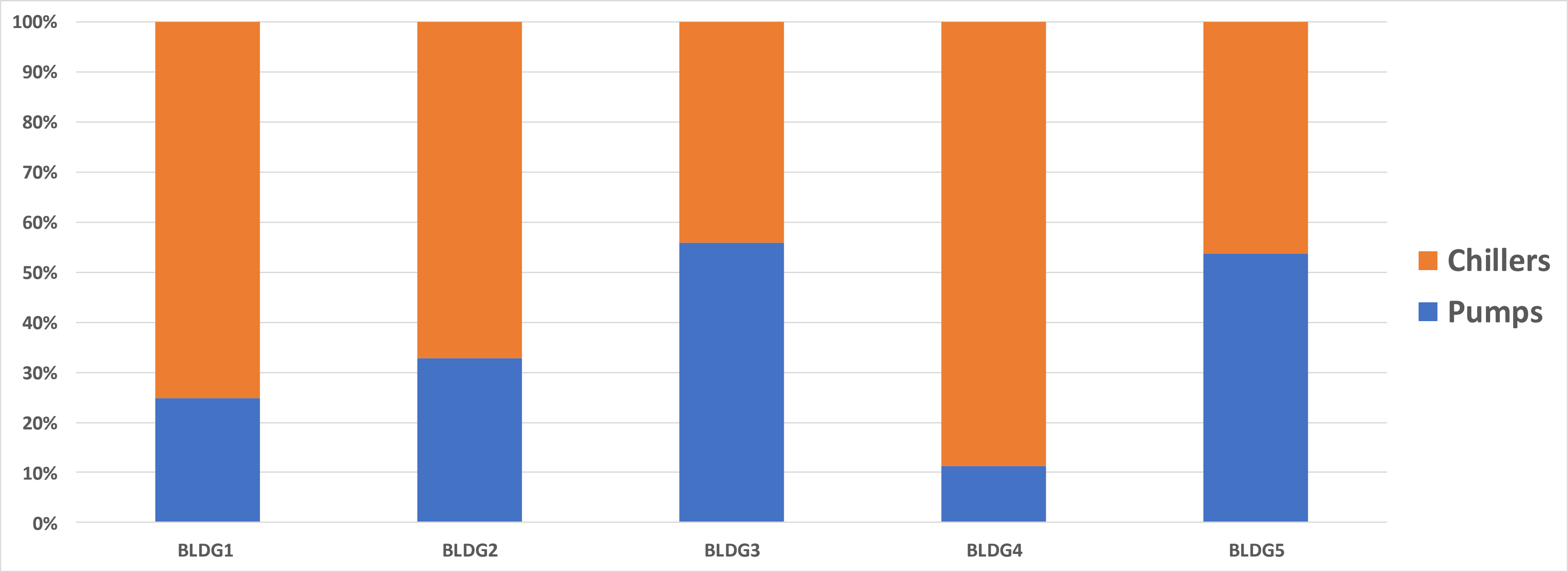
The ambitious objective of decarbonizing the economy, which includes the objective of constructing and operating buildings with a net zero energy balance (NZEB), requires a focus on the details of the systems, without this effort, the fulfillment of those objectives is compromised.

When things don't work out as expected, it is said that "the devil is in the details", to be effective we need to "**put God in the details**".

ENERGY SIMULATION MODELS VERSUS REAL BUILDINGS

In detailed dynamic building energy simulation **models**, energy use in HVAC system pumps is typically well below **10%** of the energy used in chillers.

Energy monitoring of **existing buildings** shows a **very different reality**.



THEORETICAL ENERGY USE IN HVAC PUMPS

Energy use in pumps should never exceed **10%** of the energy used in chillers, as is showed in the following simplified, conservative, calculation.

description	symbol	value	units	formula/source
utilized cooling power capacity	U_c	1.000	W	
piping system losses (pump heat + pipe gain + leakage)	L_c	7,5%	%	admitted (1)
chiller cooling power capacity	CH_c	1.075	W	U_c x (1 + L_c)
water density	ρ	1.000	$kg.m^{-3}$	at typical HVAC temperatures
water specific heat	c_p	4,2	$kJ.kg^{-1}.K^{-1}$	at typical HVAC temperatures
water delta T	ΔT	5,0	K	current value
cooling per (l/s)	cap	21,0	kW	ρ . c_p . ΔT / 1.000
flow per kW cooling	q	0,048	$l.s^{-1}$	1 / cap
pump pressure	P	375	kPa	typical value (primary + secondary)
pump efficiency (global)	η	0,60	-	typical value
pump power per kW cooling	**P_e**	**30**	**W**	q . P / η
average yearly EER	EER_{avg}	3,50	-	typival value
chiller power per kW cooling	CH_e	307	W	CH_c / EER_{avg}
pump power relative to chiller power	**p_p**	**9,7%**	**%**	P_e / CH_e

(1) Investigation of maximum cooling loss uncertainty in piping network using Bayesian Markov Chain Monte Carlo method, Pei HUANG, Gongsheng HUANG

THEORETICAL ENERGY USE IN HVAC PUMPS

In **variable flow systems**, since required pump pressure is much lower than design in most of the operating hours, energy use in pumps should be much **less** than the 10% calculated value.

In **constant flow systems**, since energy use in pumps will be constant throughout the year, while energy use in chillers will be variable, energy use in pumps will significantly **exceed** the 10% calculated value. This excessive energy use is further enhanced because of the normal oversizing of the secondary pumps in constant water flow systems.

CAUSES AND REMEDIATION

Low ΔT operation

Often, systems are designed for a **5K ΔT** but operate with a lower than **2K ΔT**.

Low ΔT operation leads to a higher than predicted water flow.

Higher than predicted water flow operation leads to:

- Increase of energy use in pumps.
- Increase of energy use in chillers, since pump heat will also increase, adding to the chiller load.

Energy use in chillers also increases because they will operate at lower evaporating temperatures, reducing their energy efficiency.

CAUSES AND REMEDIATION

Three-way control valves.

Inexplicably, still a relevant number of existing systems operate with three-way control valves. Often in these type of systems annual pump energy use exceeds annual chiller energy use. The simple low-cost remedy is to convert the valves to two-way operation by shutting off the coil bypass, whenever possible. The best performing remedy is to replace three-way control valves with state-of-the-art electronic, addressable, pressure independent two-way control valves. In more important energy users, namely AHUs, valves with ΔT control should be applied.

CAUSES AND REMEDIATION

Operation with fully open control valves.

When the temperature setpoint is unattainable by the HVAC equipment, the temperature controller will command the control valve to the 100%, fully open, position, keeping the valve in this fixed position until the setpoint is reset.

Note that beyond a certain limit, the increase in water flow does not have relevant consequences in the coil thermal power and constitutes a pure loss without any positive effect.

Following, we will describe usual causes for the operation with fully opened control valves in existing systems.

CAUSES AND REMEDIATION

Operation with fully open control valves.

Perhaps the most frequent cause of operation with low ΔT is the choice by users of **unattainable setpoints**, i.e., excessively low in cooling or high in heating.

The remedy for this problem is to **limit the action of users** in the indoor temperature setpoint reset, for example using +/- 1,5 K commands.

CAUSES AND REMEDIATION

Operation with fully open control valves.

Anomalies that reduce HVAC equipment thermal capacity cause the operation with fully open control valves and, consequently, low ΔT, for example:

- Clogged air filters.
- Dirty coils (inside and outside).
- Coils with deformed fins.
- Poorly tensioned fan belts.
- Obstructions in the ductworks.
- Plant schematics that result in higher than design water temperatures

CAUSES AND REMEDIATION

Oversized end-of-line bypasses.

End-of-line bypasses are often used to maintain the design water temperature in all parts of the piping network even during periods of time when control valves are closed. End-of-line bypasses must be equipped with flow limiting valves selected for the minimum water flow necessary to compensate for piping thermal losses. In many existing installations end-of-line bypasses do not have correctly sized flow limiting valves, or even no flow limiting valves at all, leading to a very high bypass flow and a low operating ΔT.

CAUSES AND REMEDIATION

Oversized end-of-line bypasses.

The image to the right shows an end-of-line bypass of an existing HVAC system, where it can be seen that, in addition to the absence of any flow limiting device, the bypass was installed with an excessively large diameter.

CAUSES AND REMEDIATION

Oversized end-of-line bypasses.

Systems that have permanent use of chilled water do not need end-of-line bypasses, in these cases, end-of-line bypasses must be eliminated or shut-off.

When end-of-line bypasses are needed, correctly sized flow limiters must be installed.

CAUSES AND REMEDIATION

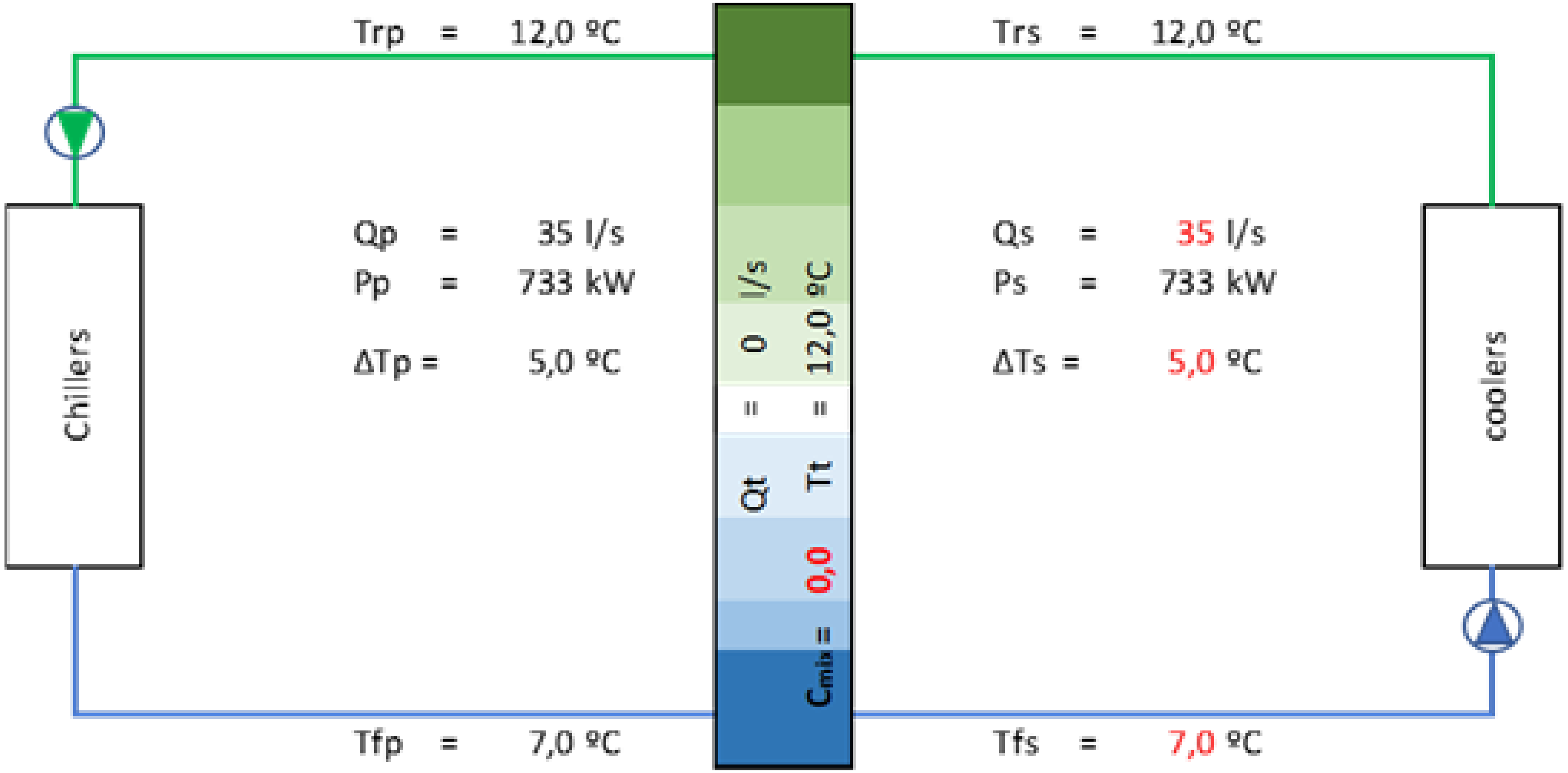
Inadequate hydraulic plant schematic.

Anomalies in the design of the chilled water plant schematics can lead to operation with low ΔT. A design anomaly often found in existing HVAC systems is the use of a water tank functioning as a hydraulic decoupler between primary and secondary circuits.

CAUSES AND REMEDIATION

Inadequate hydraulic plant schematic.

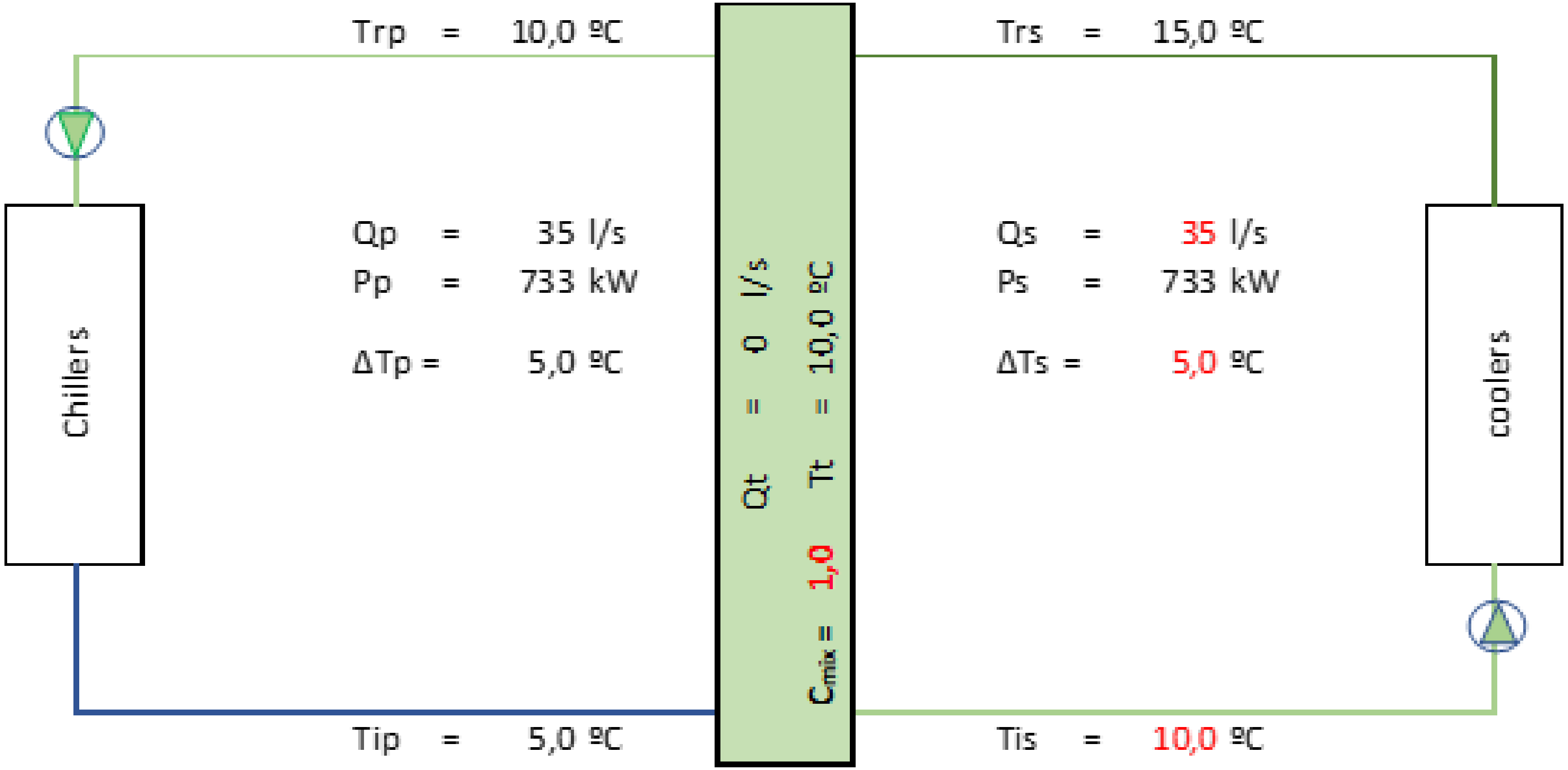
For a tank installed as a decoupler not to impair system effectiveness and energy efficiency, it would have to operate with a perfect thermal stratification and no mixing.



CAUSES AND REMEDIATION

Inadequate hydraulic plant schematic.

In real life the tank operates perfectly mixed, resulting that the temperature of water supply to the secondary equals the temperature of the return water to the chillers.



CAUSES AND REMEDIATION

Inadequate hydraulic plant schematic.

When the decoupling tank operates in a perfectly mixed configuration:

- Plant effectiveness is compromised since it is not possible to deliver the design water flow temperature for the secondary.
- Chiller efficiency is very low, since chillers must produce chilled water at a much lower temperature than the one required in the secondary system.
- Energy use in pumps is very high since the delivery of chilled water at a higher than design temperature reduces equipment thermal capacities and drives two-way control valves fully open to try to reach setpoints.

CAUSES AND REMEDIATION

Inadequate hydraulic plant schematic.

Remedies:

- Preferably implement solutions with variable primary flow (VPF).
- In primary/secondary systems use a simple bypass pipe as decoupler.
- If needed add thermal inertia by increasing manifold’s diameter.
- Never install a tank as an hydraulic decoupler.
- Where this solution is implemented, install a bypass line to the tank.
- Select water temperatures and ΔT higher than the traditional ones.
- Convert “U” type manifolds to “H” type manifolds.

CAUSES AND REMEDIATION

Inadequate sizing and control of pumps.

Often, pumps are oversized and a static balancing valve downstream of the pump, dissipates the excess pressure.

Pumps equipped with a variable speed drive often operate at constant speed, normally at 50Hz. An effective control algorithm to readjust the pump rotation speed according to the needs of each moment is often not implemented.

Often there is a very high number of pumps, sometimes including tertiary pumps, making it difficult to effectively monitor and optimize their operation.

CAUSES AND REMEDIATION

Inadequate sizing and control of pumps.

Remedies:

- Ensure that the hydraulic network pressure loss is correctly calculated.
- Ensure that pumps are correctly selected.
- Apply ePIV control valves and implement critical zone pressure setpoint reset algorithm.
- Ensure that an adequate pump speed reset algorithm is implemented.
- When no balancing is required, replace static balancing valves with low pressure drop shut-off valves.

CAUSES AND REMEDIATION

Incorrectly balanced systems

Often existing systems are not balanced leading to a capacity deficit in some terminals and an excess in others, causing the latter to operate with low ΔT.

Many variable flow systems have static balancing valves, thus, the balance of the network in partial load situations is not ensured.

Recommended solutions:

- Install ePIV control valves.
- In systems that require static balancing valves, ensure that the balancing procedure is in accordance with ANSI/ASHRAE 111.

CAUSES AND REMEDIATION

Not water-tight control valves

Most installed control valves are not water-tight in the closed position.

Often control valves have a maximum close-off pressure lower than the pump pressure, not being able to close the valve in many operating conditions, this anomaly is especially harmful in four pipe systems.

Recommended solutions:

- Ensure that all control valves have a close-off pressure greater than the pressure of the pump.
- Preferably apply control valves with Class A leakage.

CAUSES AND REMEDIATION

Constant water flow in chillers

Often chillers operate with a constant water flow not taking advantage of the possibilities of current chiller technology.

Recommended solutions:

- Preferential implementation of solutions with variable primary flow (VPF), without manifolds and equipped with a single pumping group for the primary and the secondary.
- In systems with decoupled primary and secondary, implement variable water flow in the primary, within the limits indicated by the chiller manufacturer.

CAUSES AND REMEDIATION

Constant water flow in cooling towers

Open cooling towers often operate with constant water flow, not varying even in cases where all towers operate continuously and in parallel. It should be noted that most open cooling towers allow water flow turndown up to 50% of its nominal value, in accordance with the requirements ANSI/ASHRAE 90.1.

Recommended solutions:

- Select cooling towers that allow 50% water flow turndown.
- Always operate with all available towers and vary the water flow in the towers up to the lower limit of 50% of the nominal flow.

CONCLUSION

Designing, installing and operating HVAC systems with attention to the details described it is possible to approximate the performance of real systems in operation to the predicted theoretical performance.