Università
degli Studi
di Padova

DEPARTMENT OF INDUSTRIAL ENGINEERING
UNIVERSITY OF PADOVA

BETALAB

SIZING OF DOMESTIC HOT WATER PRODUCTION SYSTEMS

Eng. Marco Marigo

marco.marigo@unipd.it

HOW DO WE USE WATER IN BUILDINGS?

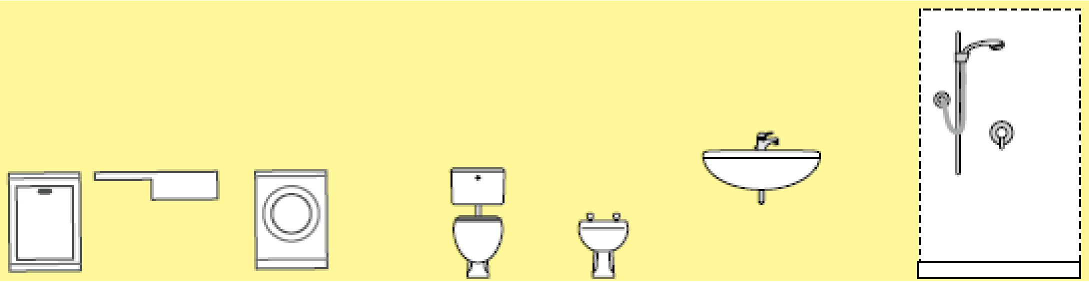
Water can be used in many different ways inside buildings!

Shower

Dishwasher

Washing machine

Water for the fire suppression system



WC

Bath tub

Sink

Bidet

Potable water?

Non-potable water?

Hot water?

Cold water?

THE DOMESTIC HOT WATER

All sanitary fixtures must be supplied with potable water except from the WC

- Some fixture only need cold water (DCW)
  - Dishwasher, washing machine
- Almost all the others, need both hot (DHW) and cold water (DCW)
  - Sinks, showers, bidet, bath tub

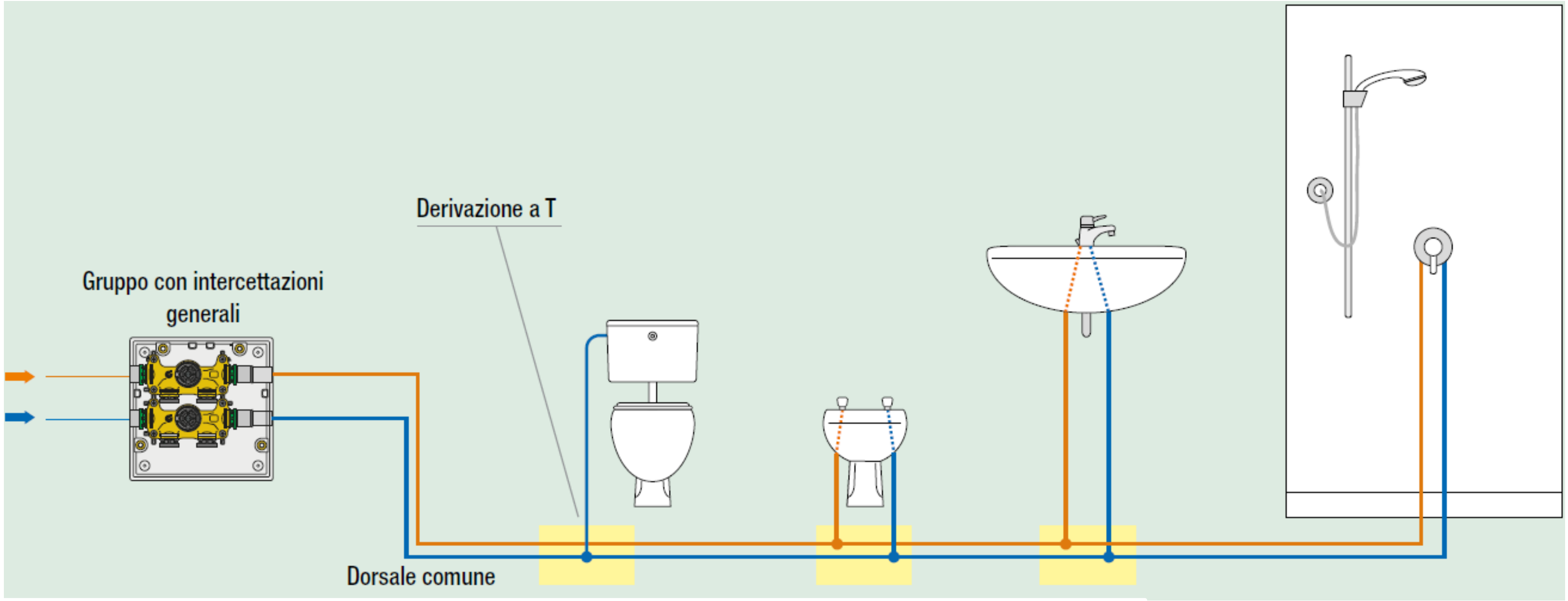
FOUR ISSUES

Water waste	*Stagnation*
Energy waste	*Too low supply temperature*

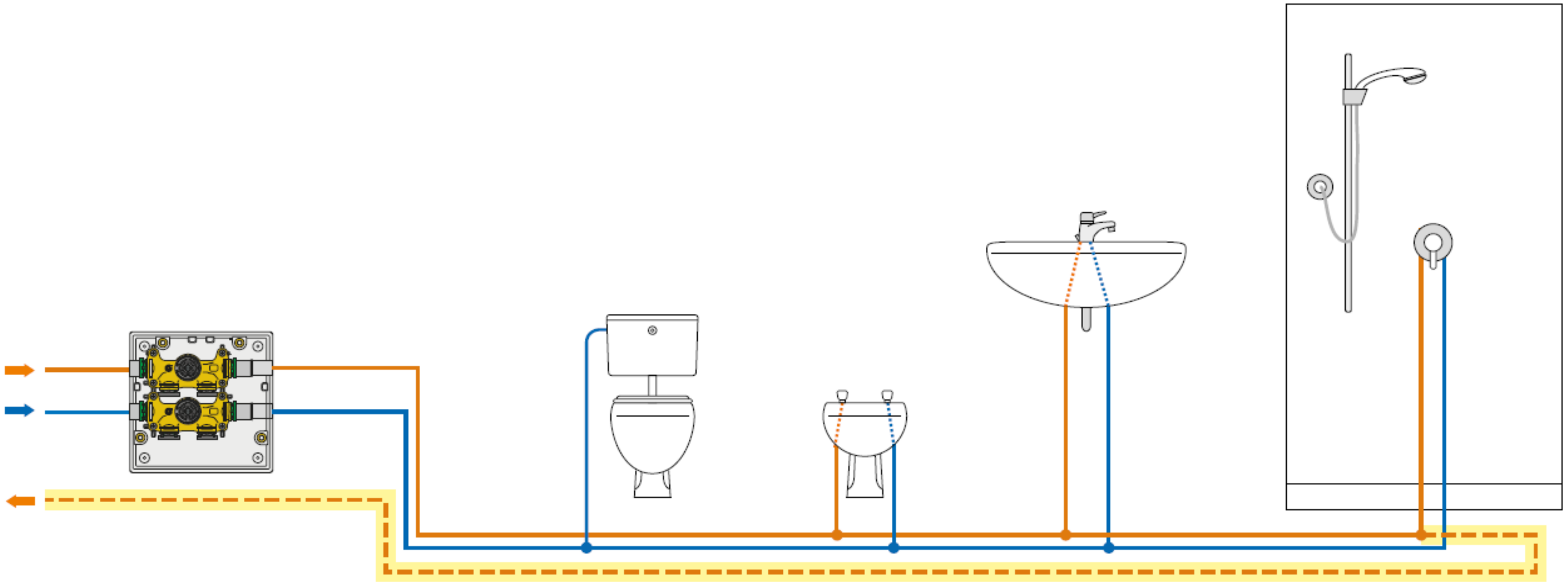
The purpose of this lectures is **the hot water preparation**!

SOME EXAMPLES OF DISTRIBUTION

Without recirculation

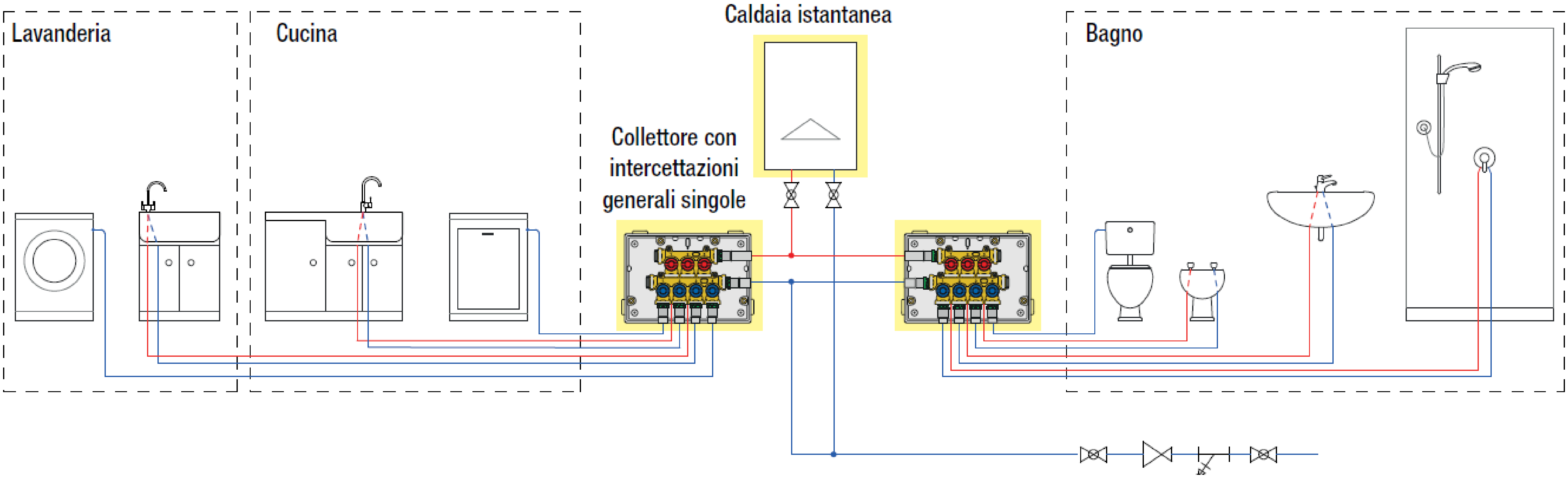


With recirculation



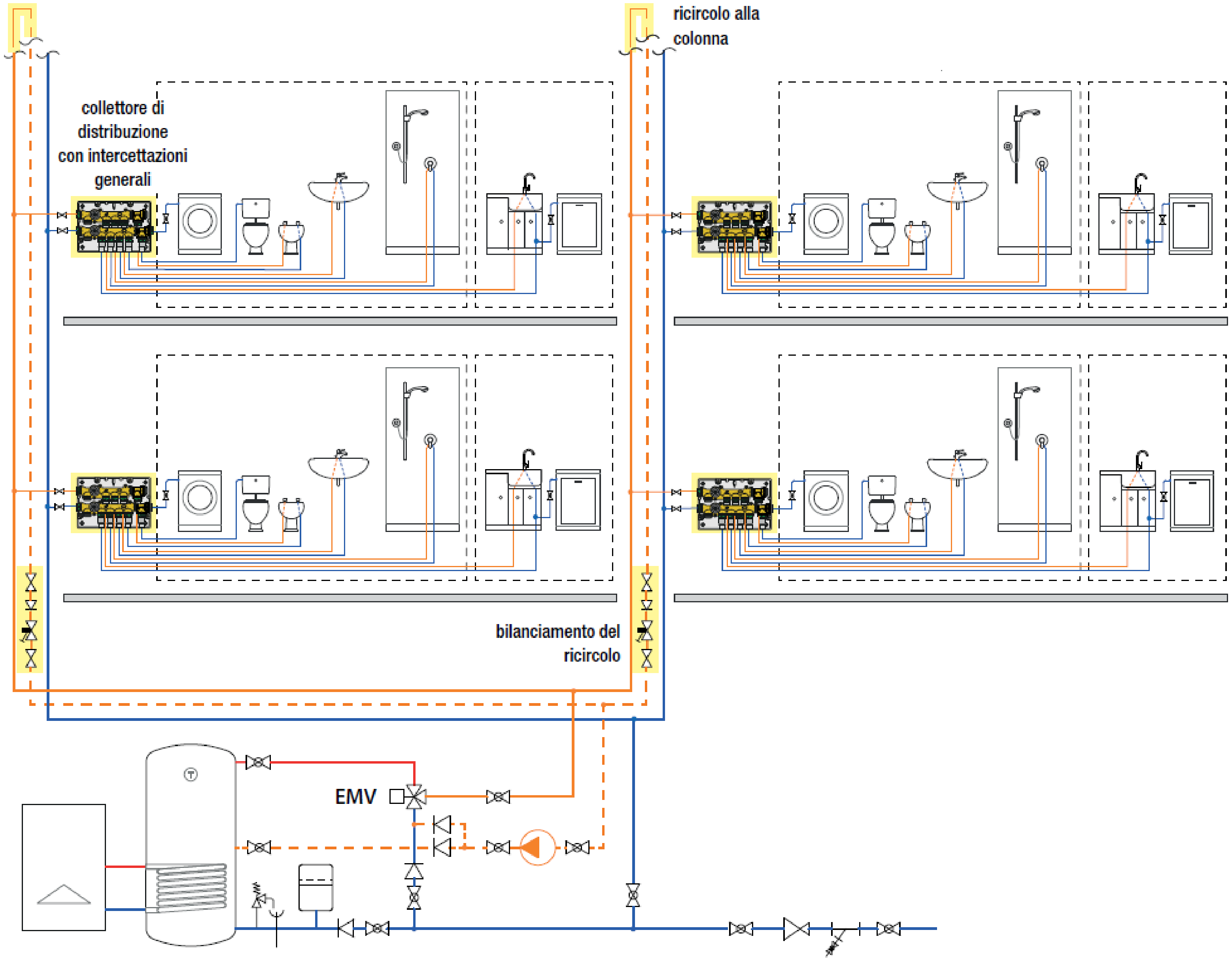
SOME EXAMPLES OF DISTRIBUTION

With manifolds
No recirculation



SOME EXAMPLES OF DISTRIBUTION

With manifolds
and recirculation

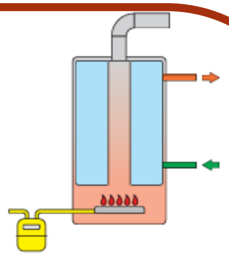
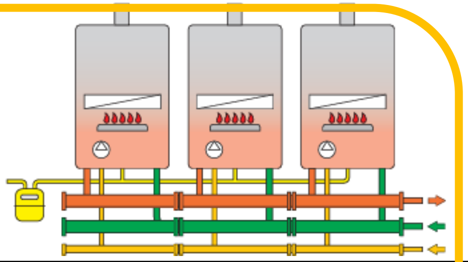
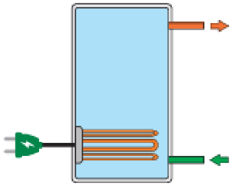
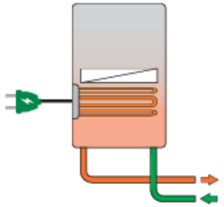
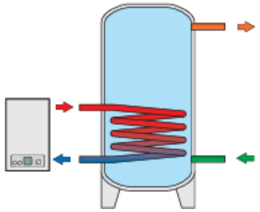
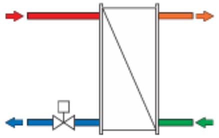
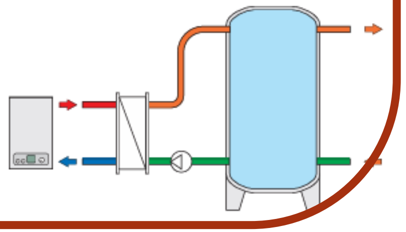
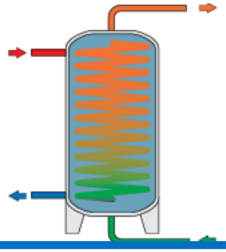


SOME DEFINITIONS…

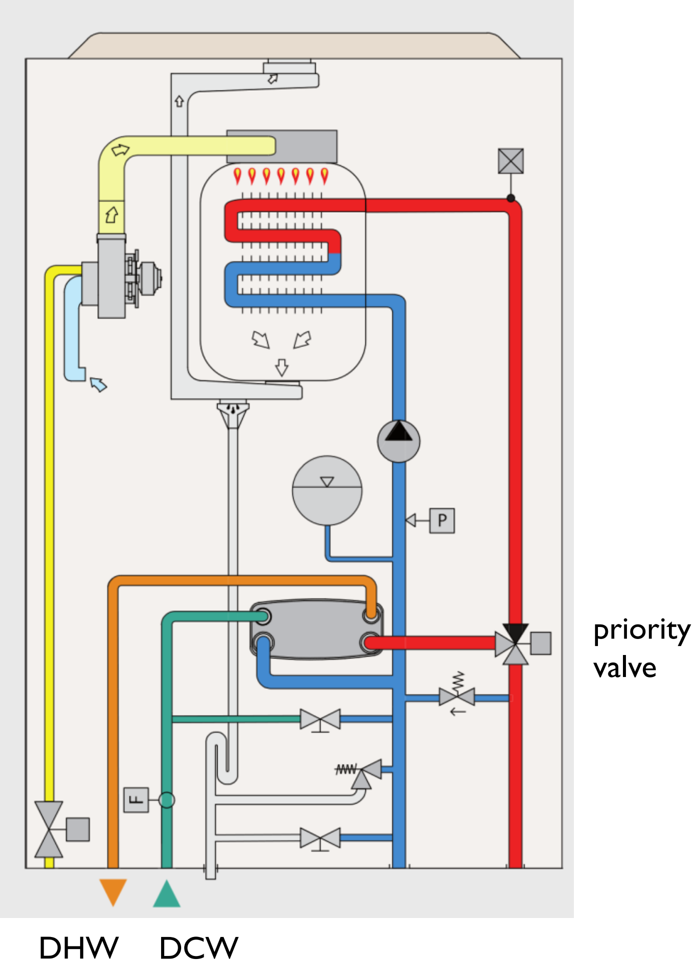
Different concepts for DHW preparation:

- INSTANTANEOUS PRODUCTION: DHW is instantaneously heated when required
- PRODUCTION WITH STORAGE: The storage helps in reducing thermal power required
- DIRECT PRODUCTION: DHW is heated directly by the heat source
- INDIRECT PRODUCTION: An operative fluid is used as medium to heat up DHW

DHW PRODUCTION

	WITH STORAGE	INSTANTANEOUS
DIRECT (using directly the heat flux from combustion or electrical resistances)	gas 	gas 
	electricity 	electricity 
INDIRECT (using a working fluid previously heated)	Immersed heat exchanger 	Plate heat exchanger 
	External heat exchanger 	Immersed heat exchanger 

INSTANTANEOUS GAS BOILER



Instantaneous combined gas boilers:

- Instantaneous indirect DHW production through plate HE
- The priority valve switches between space heating and DHW
- These systems are already optimized by constructors.

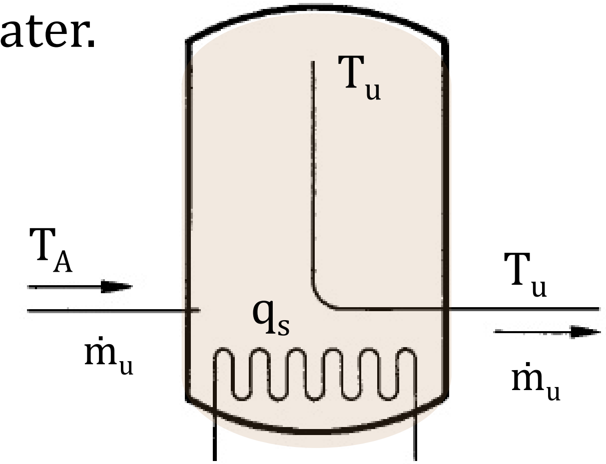
→ **You don't need to design, just choose!**

INSTANTANEOUS PRODUCTION WITH ELECTRICITY

SPECIFICHE TECNICHE	**Andris Elite EU 10/5**	**Andris Elite EU 15/5**	**Andris Elite EU 30/5**
DATI TECNICI			
Capacità	10 l	15 l	30 l
Installazione	Sopralavello	Sopralavello	Sopralavello
Potenza	1,2 kW	1,2 kW	1,5 kW
Tensione	220/240 V	220/240 V	220/240 V
Tempo di riscald. (ΔT= 45°C)	0,30 h, min.	0,45 h, min.	1,10 h, min.
Temp. max d'esercizio	80 °C	80 °C	80 °C
Dispersione termica a 65°C	0,71 kWh/24h	0,61 kWh/24h	0,77 kWh/24h
Pressione max d'esercizio	8 bar	8 bar	8 bar
Peso netto	6,6 kg	7,4 kg	12,8 kg
Protezione	X4 IP	X4 IP	X4 IP

THE MIXED HOT WATER STORAGE SYSTEMS

The mass flow rate $\dot{m}_u$ flows within the water tank increasing its temperature from the inlet temperature T_A to the outlet temperature T_u; the power q_s is released to the water.



During the hot water supply a certain mass flow rate $\dot{m}_u$ is required (equal to m_d/τ_d) at a constant temperature T_u.

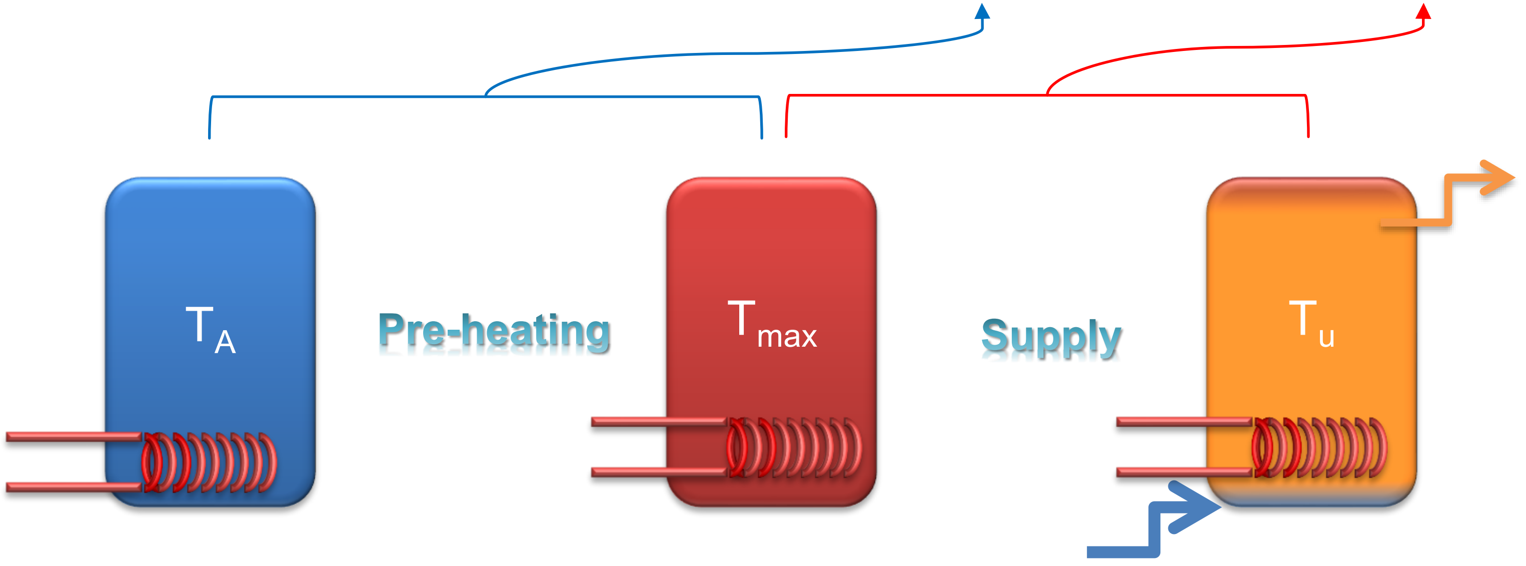
Assuming that the whole volume V_s is at a uniform temperature T_u (neglecting the stratification within the tank) the thermal behaviour of the system can be written by the following equation:

$$\boxed{\rho \cdot V_s \cdot c\,(dT_u / d\tau)} = \boxed{q_s} \boxed{- \dot{m}_u \cdot c \cdot T_u + \dot{m}_u \cdot c \cdot T_A} \boxed{- K_i \cdot S_i\,(T_u - T_{amb})}$$

Internal energy of the system variation	**Heat released by the heating fluid**	**Heat exchange due to the heat up of the water flow rate**	**Heat losses through the envelope**

PRE-HEATING AND SUPPLY TIME

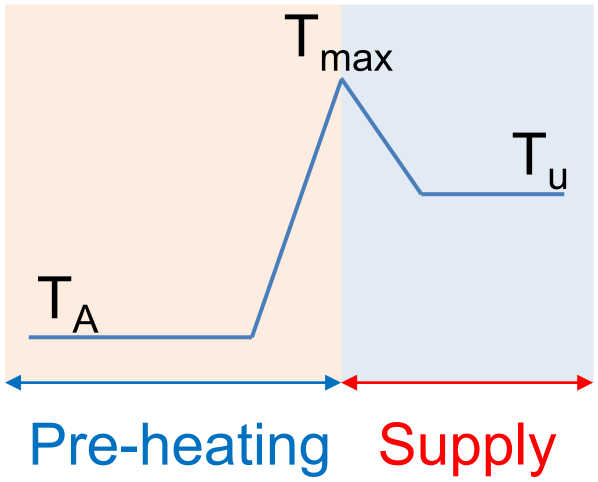
It can be useful to split between the **pre-heating** and the **supply** time.



Heat losses during pre-heating phase

$$q_{dp} \cdot \tau_p + q_{dd} \cdot \tau_d$$

Heat losses during the supply phase



Pre-heating:

$$q_{dp} = K_i \; S_i \; (T_{mp} - T_{amb})$$

$$T_{mp} = (T_A + T_{max}) / 2$$

Supply:

$$q_{dd} = K_i \; S_i \; (T_{me} - T_{amb})$$

$$T_{md} = (T_{max} + T_u) / 2$$

THE MIXED HOT WATER STORAGE SYSTEMS – SIMPLIFIED METHOD

$$\boxed{\rho \cdot V_s \cdot c\,(dT_u / d\tau)} = \boxed{q_s}\ \boxed{- \dot{m}_u \cdot c \cdot T_u + \dot{m}_u \cdot c \cdot T_A}\ \boxed{- K_i \cdot S_i\,(T_u - T_{amb})}$$

It can be useful to split between the pre-heating and the supply time. **Integrating the general thermal balance equation in the tank** in the whole period of pre-heating and supply, the required energy q_s in the time $\tau_p + \tau_d$ will allow:

- to supply the **required amount of water m_d at T_u**
- to compensate the heat **losses through the envelope** of the tank
- To provide the **internal energy variation** in the tank

$$\boxed{q_s\,(\tau_p + \tau_d)} = \boxed{m_d \cdot c\,(T_u - T_A)} + \boxed{q_{dp} \cdot \tau_p + q_{dd} \cdot \tau_d} + \boxed{V_s \cdot c \cdot (T_u - T_A)}$$

Considering only the heat-up period:

$$\boxed{q_s \cdot \tau_p} = \boxed{V_s \cdot c \cdot (T_{max} - T_A)} + \boxed{q_{dp} \cdot \tau_p}$$

SIZING OF THE MIXED HOT WATER STORAGE SYSTEM

The sizing method for the heat stored is based on the choice of two parameters: the thermal peak power $\mathbf{q_s}$ and the capacity $\mathbf{V_s}$ of the storage, once defined the following parameters:

τ_d	supply time
τ_p	pre-heating time
m_d	amount of hot water supplied
T_u	temperature of hot water supplied
T_A	temperature of the available fresh cold water
T_{max}	temperature of the water after the pre-heating period (set-point)

REMARK: The thermal peak power q_s is considered constant

SIZING WITH SIMPLIFIED METHOD

These two equations can be solved together in order to achieve q_S and V_s, once defined the pre-heating time τ_p and the supply time τ_d

MIXED HOT WATER STORAGE SYSTEM

$$\boxed{\mathbf{q_s}\,(\tau_p+\tau_d)} = \boxed{m_d \cdot c\,(T_u - T_A)} + \boxed{q_{dp}\cdot\tau_p + q_{dd}\cdot\tau_d} + \boxed{\mathbf{V_s}\cdot c\cdot(T_u - T_A)}$$

$$\boxed{\mathbf{q_s}\cdot\tau_p} = \boxed{\mathbf{V_s}\cdot c\cdot(T_{max} - T_A)} + \boxed{q_{dp}\cdot\tau_p}$$

INDIRECT SYSTEM WITH INTERNAL HEAT EXCHANGER

$$(\boxed{q_s} - \boxed{q_{dp}})\cdot\boldsymbol{\tau_p} = \boxed{V_s\cdot c\cdot(T_{max} - T_A)}$$

$$(\boxed{q_s} - \boxed{q_{dd}})\cdot\boldsymbol{\tau_d} + \boxed{V_s\cdot c\cdot(T_{max} - T_{min})} = \boxed{m_d\cdot c\cdot(T_u - T_A)}$$

EXERCISE

Size a mixed hot water storage that must supply 100 kg of water at 40°C with a supply time of 1 hour. Assume a preheating time of 5 hours and that the maximum temperature inside the tank is 60°C. For the calculations, assume also that the water from the aqueduct enters the tank at 10°C, the temperature of the room where the tank is installed is equal to 20°C and, for the thermal loss calculations, assume $K = 0{,}8$ kcal/(h m^2 °C) and $S = 1{,}3\ m^2$.

Repeat the calculations neglecting the tank’s thermal losses.

ASSUMPTIONS FOR THE SIZING

In the exercise we had some input data, but what assumptions should be made when *sizing a real system*?

- DHW demand during the peak load (m_d) [L]
- Time of preparation (τ_p) [h]
- Time of demand/supply (τ_d) [h]

➡

Sizing of the system:

- Boiler capacity (V_s)
- Required power (q_s)

There are other variables that we should assume for the calculations:

- The temperature of supply (T_u) → 40°C
- The maximum temperature inside the tank (T_{max}) → 60°C
- The temperature of the water from the aqueduct (T_A) → 10 ÷ 15°C

ASSUMPTIONS FOR THE SIZING

When you use the detailed method for the assessment of the DHW demand, you can use these tables as a reference for the DHW demand and the preparation/delivery time.

Fixture	Water used per fixture [L per use]	Number of fixtures	Amount of water used at 40°C [L]	Times of use during the reference peak period	Total volume per fixture [L]
Bath tub	100	0	0	1.00	0
Shower	60	2	120	1.00	120
Toilet sink	10	2	20	4.00	80
Bidet	8	2	16	2.00	32
Kitchen sink	15	1	15	1.00	15
TOTAL					**247**

from VDI 1988

$\mathbf{S_u}$ [m^2]	$\boldsymbol{\tau}_d$ [h]	$\boldsymbol{\tau}_p$ [h]
50 – 90	1	2
90 - 120	1.5	2
> 120	2	2

DHW DEMAND FOR A RESIDENTIAL BUILDING

The Italian Standard (UNI-TS 11300:2) gives some values aimed at the calculation of the **daily** demand of domestic hot water.

For *residential buildings*, the water volume V_w *[L/day]* is calculated as:

This calculation should NOT be used for the *sizing* of the system, but for the calculation of the *energy need* for DHW

$$V_w = c_0 \cdot S_u + c_1$$

c_0 $[L/(m^2\,day)]$

S_u $[m^2]$

c_1 $[L/day]$

$$V_s \neq V_w$$

	$S_u \leq 35$	$35 < S_u < 50$	$50 < S_u < 200$	$S_u > 200$
c_0	0	2.667	1.067	0
c_1	50	-43.33	36.67	250

Table 30 from UNI-TS 11300:2

EXAMPLE 1 - DHW DEMAND FOR ENERGY NEEDS (RESIDENTIAL)

Case study

Single unit residential building

1 unit hosting 6 people

Net surface area of 180 m^2

Calculation

From Table 30 of the standard 11300-2:

c_0=1,067

c_1= 36,67

The daily volume of DHW is:

$$V_w = c_0 \cdot S_u + c_1$$

$$= 1{,}067 \cdot 180 + 36{,}67$$

$$= 228{,}73 \quad \text{L/day}$$

DHW DEMAND FOR A NON-RESIDENTIAL BUILDING

When referring to a *non-residential building*, the Italian Standard UNI-TS 11300-2 provides the following equation:

$$V_w = c_2 \cdot N_u \qquad [L/day]$$

c_2 $[L/(day \cdot N_u)]$ and N_u [-] are calculated according to the following table:

User/Activity	c_2	N_u
Residences and B&B	40	Number of beds
Hotels *, **, ***	60	Number of beds
Hotels ****, *****	80	Number of beds
Hospitals	80	Number of beds
Day hospitals	15	Number of beds
Sporthall	50	Number of showers
School	0.2	Number of children
Kindergarden	8	Number of children
Offices	0.2	Net floor area

Table 31 from UNI-TS 11300:2

DHW DEMAND FOR A NON-RESIDENTIAL BUILDING

When referring to a *non-residential building*, the Italian Standard UNI-TS 11300-2 provides the following equation:

$$V_w = c_2 \cdot N_u \qquad [L/day]$$

Example 2 – DHW demand for a hotel

3 star hotel - 10 beds
$c_2 = 60\ L/(day \cdot N_u)$
$N_u = 10$ beds

The daily volume of DHW is:
$V_w = c_2 \cdot N_u = 600\ L/day$

UNI 11300 – PART 2 – ENERGY NEEDS FOR DHW

The energy needs to supply the domestic hot water of a building is calculated from the volume required and the temperature difference between the water supplied to the building and the cold water supplied by the aqueduct

kWh/(kg K) m^3/day N. days

$$Q_w = \rho_w \times c_w \times \Sigma_i [V_{w,i} \times (\theta_{er,i} - \theta_0)] \times G \ [\text{kWh}]$$

ρ_w	water density, 1000 [kg/m^3]
c_w	water specific heat 1.162 * 10^{-3} [kWh/(kg K)]
$V_{w,i}$	daily water volume for the i-th activity or service required [m^3/d]
$\vartheta_{er,i}$	water supply temperature for the i-th activity or service required [°C]
ϑ_0	cold water supply temperature (from the aqueduct) [°C]
G	number of days considered in the calculation [d]

EXAMPLES

Example 1 – Energy needs for DHW (Residential)

Single unit residential building in Padova, 1 unit hosting 6 people, net surface area of 180 m^2

Daily volume of DHW: $V_w = c_0 \cdot S_u + c_1 = 1{,}067 \cdot 180 + 36{,}67$

$= 228{,}73$ L/day

229 L/day = 0,229 m^3/day

$Q_w = 1000 \cdot 1{,}162 \cdot 10^{-3} \cdot 0{,}229 \cdot (40-14) \cdot 365 = 2257$ kWh

Example 2 – Energy needs for DHW (Non Residential)

3 star hotel in Padova - 10 beds

Daily volume of DHW: $V_w = c_2 \cdot N_u = 600$ L/day

$Q_w = 1000 \cdot 1{,}162 \cdot 10^{-3} \cdot 0{,}6 \cdot (40-14) \cdot 365 = 6616$ kWh

REPORT - INSTRUCTIONS

1. Size the storage for the DHW ***of your home***, defining capacity V_s and the required power q_s

2. Calculate the yearly energy needs for domestic hot water production ***of your home***

!

You can use the format that you prefer for the calculations (excel, Matlab or other files).
The only requirement is that, together with the report, you submit a file with **ALL** the calculations.

REPORT – INSTRUCTIONS pt.2

For the report, you are required to use a simplified method instead of the detailed one shown in the previous slide.
Use the simplified equation shown below to calculate the *DHW demand* during the peak load and the *supply time*, then, solve the system of equations to calculate the *capacity* and the *power.*

!

$$\boxed{\dot{m}_u = \frac{m_d \, \rho_w}{\tau_d}}$$

SIMPLIFIED EQUATION

$$m_d = 1.9\ S_u + 135 \qquad [L]$$

S_u [m²]	**τ_d** [h]	**τ_p** [h]
50 – 90	1	2
90 - 120	1.5	2
> 120	2	2

The minimum area to be considered for the report is 50 m² with 3 rooms.
If your case study is smaller, use your imagination!