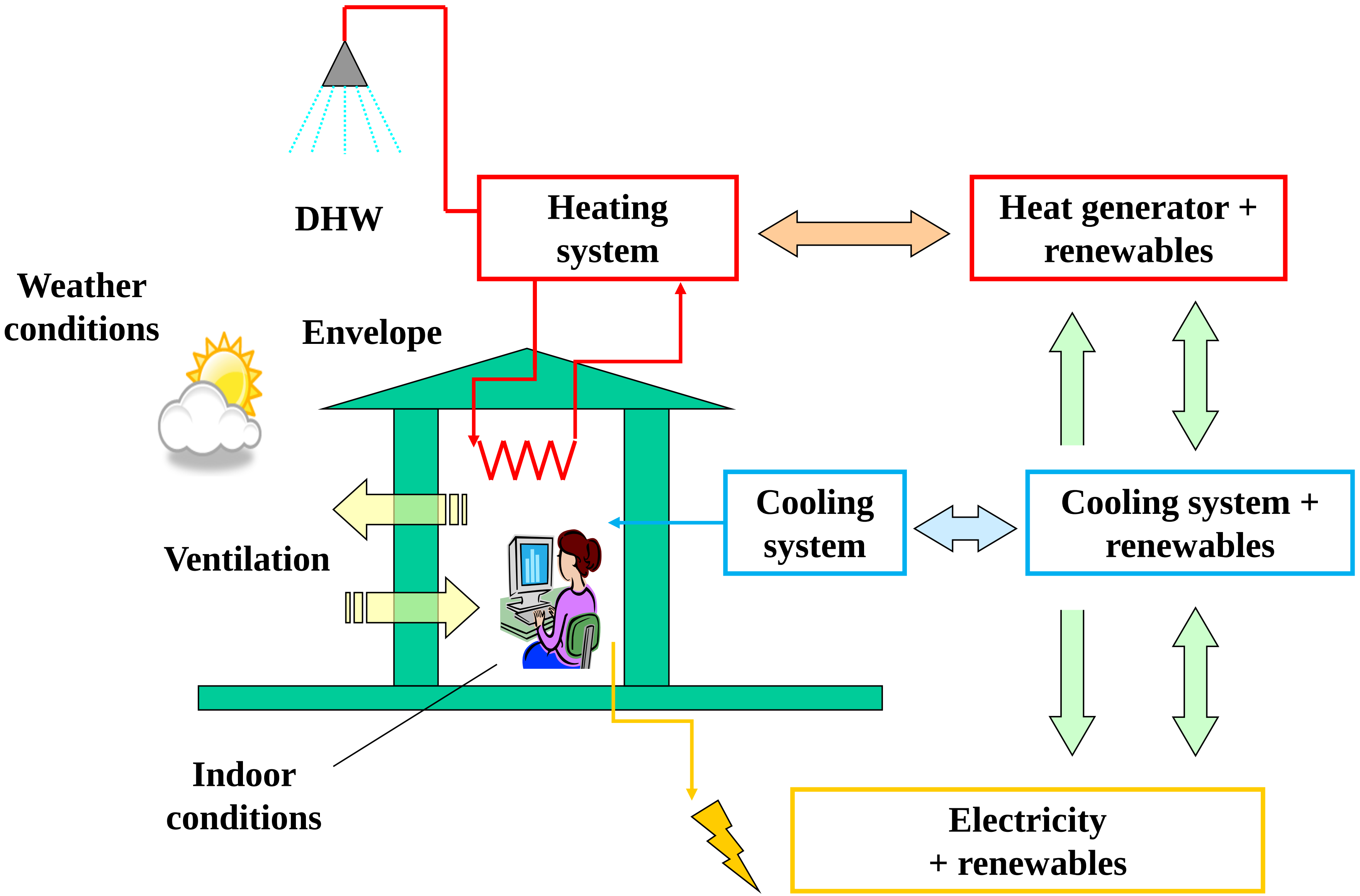
FROM NET ENERGY DEMAND TO PRIMARY ENERGY

Recap on energy use in buildings



What's left?

????

Domestic Hot Water (DHW)

Heating Cooling

Output of building energy models

Electricity

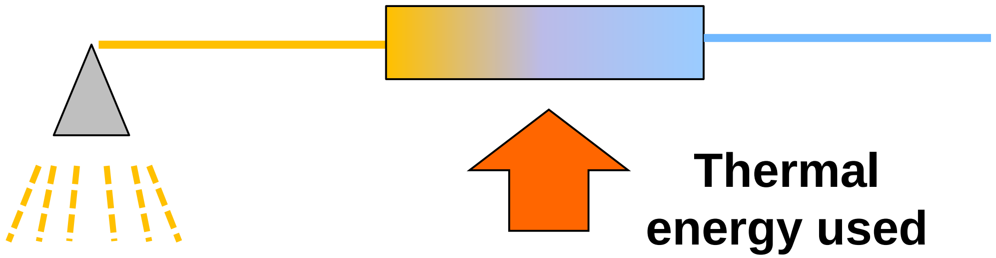
Input for building energy models

1. Independent from building energy models

2. It depends on occupants behaviour

3. It depends on temperature difference between aqueduct and hot water used

User water temperature



Aqueduct temperature

Thermal energy used

Domestic hot water (DHW)

Approach on average energy

Usually it may be assumed to have:

- 40 l/(person day)
- Aqueduct water temperature: 10°C
- Utilisation water temperature: 40°C
- $E_{DHWday} = m\ c\ (\theta_{er} - \theta_{o}) = 40 \times 4.186 \times 30 = 1.4$ kWh/(px day)

Supposing 3 persons in 90 m^2:

- $E_{DHW} = 3 \times 1.4 \times 365 = 1533$ kWh/(year)
- $E_{DHW,sp} = 1533/90 = 17$ kWh/(m^2 year)

There are other buildings/applications where the energy demand for DHW can vary a lot.

Offices: negligible DHW demand, 0.2 l/(day m^2)

Hotels: from 40 l/(day bed) to 70 l /(day bed)

Day-care hospitals: 10 l/(day bed)

Hospitals: 90 l/(day bed)

Sport hall: 100 l/(day shower)

Kindergardens and nurseries; 15 l/(day child)

Restaurants: 10 l/(day guest)

Domestic hot water (DHW)

Peak power

Usually it may be assumed to have:

- 2 washbasins (0.1 l/s each)
- Aqueduct water temperature: 10°C
- Utilisation water temperature: 40°C
- $P_{DHW} = m\ c\ (\theta_{er} - \theta_o) = 0.2 \times 4.186 \times 30 = 25$ kW

In case of gas boiler this is not a problem. In case of heat pump or electric resistance there is a problem with the absorbed electric energy.

Imagine that in design conditions we need 25 kW. For how long?

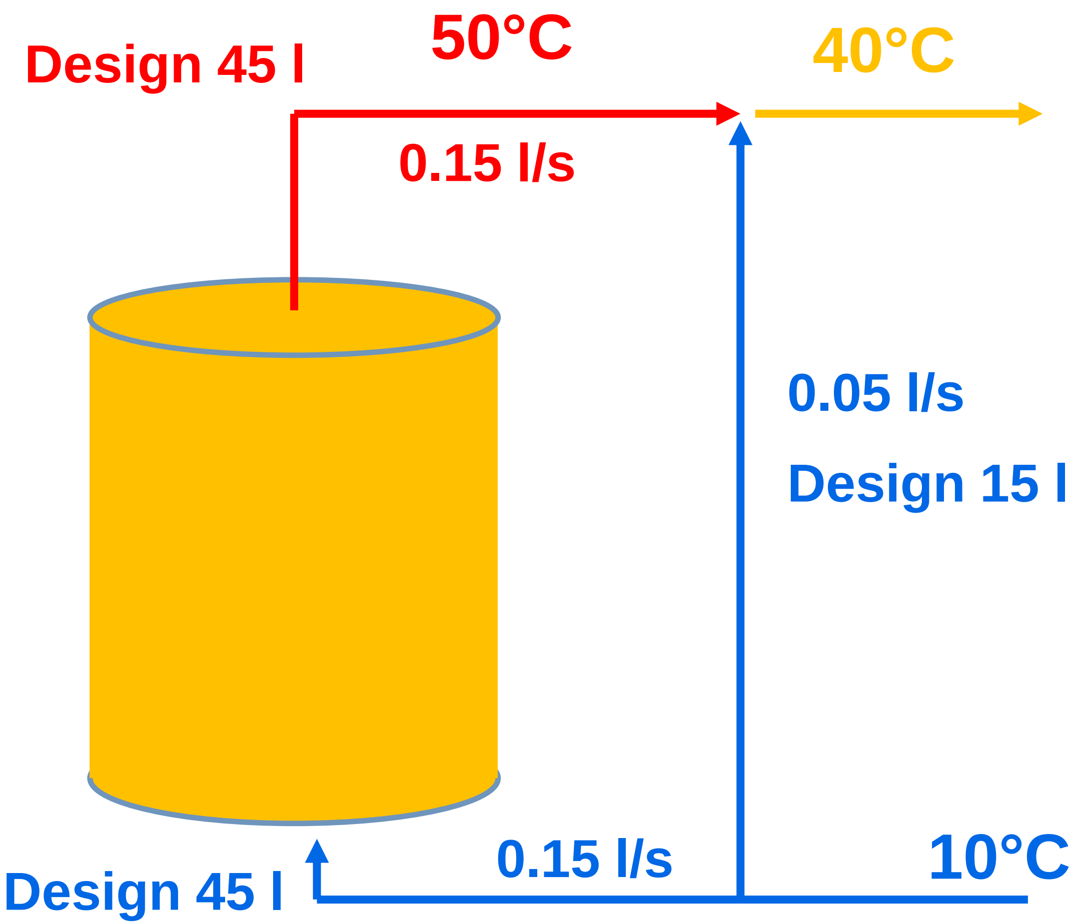
Let's suppose for 5 minutes. This means that we need:

25 kW x 5/60 = 2.09 kWh of thermal energy

At the same time we consumed: 0.2 x 60 x 5 = 60 l

We need to provide heat (45 l from 10°C to 50°C) in design conditions to replace the hot water used during design conditions (5 minutes), i.e. 2.09 kWh.

2 kW thermal power → 63 min
3 kW thermal power → 42 min
4 kW thermal power → 31 min



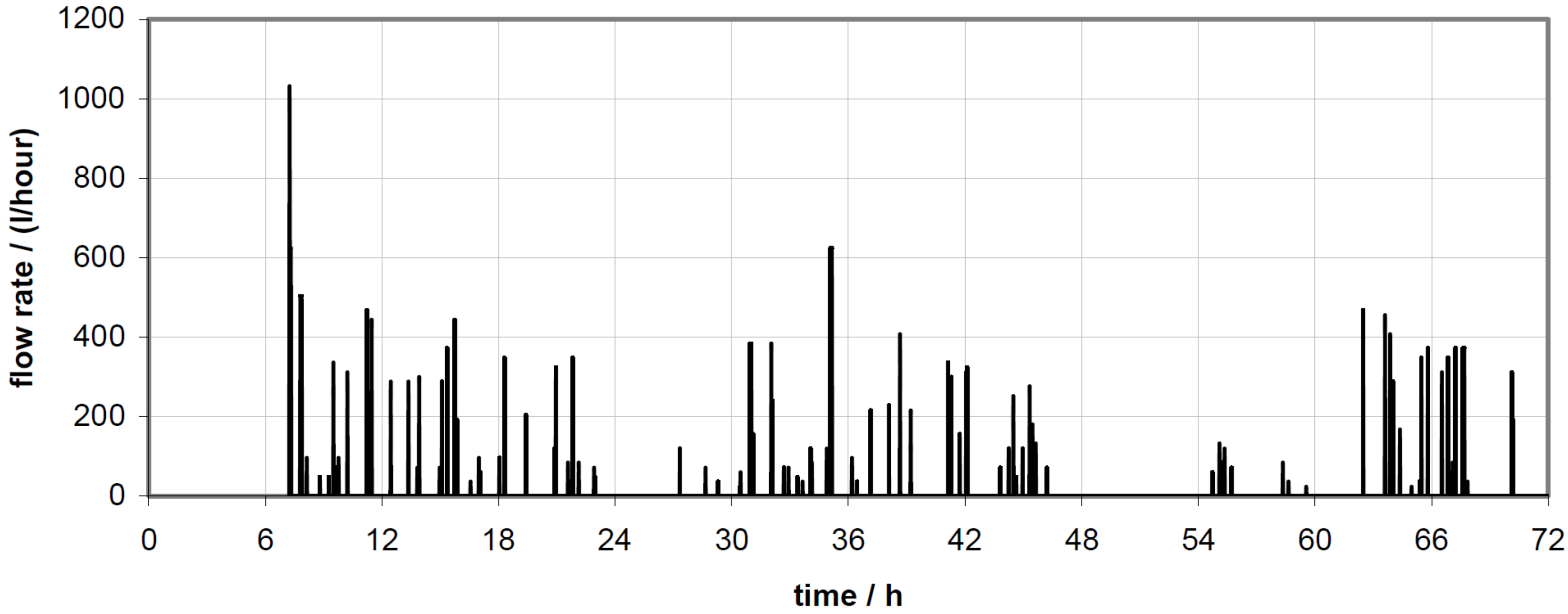
The tank allows to reduce the peak-load and to use RES, but it introduces losses through the envelope

Domestic hot water (DHW)

Approach on dynamic energy demand

The other approach is to look at dynamic energy demand.

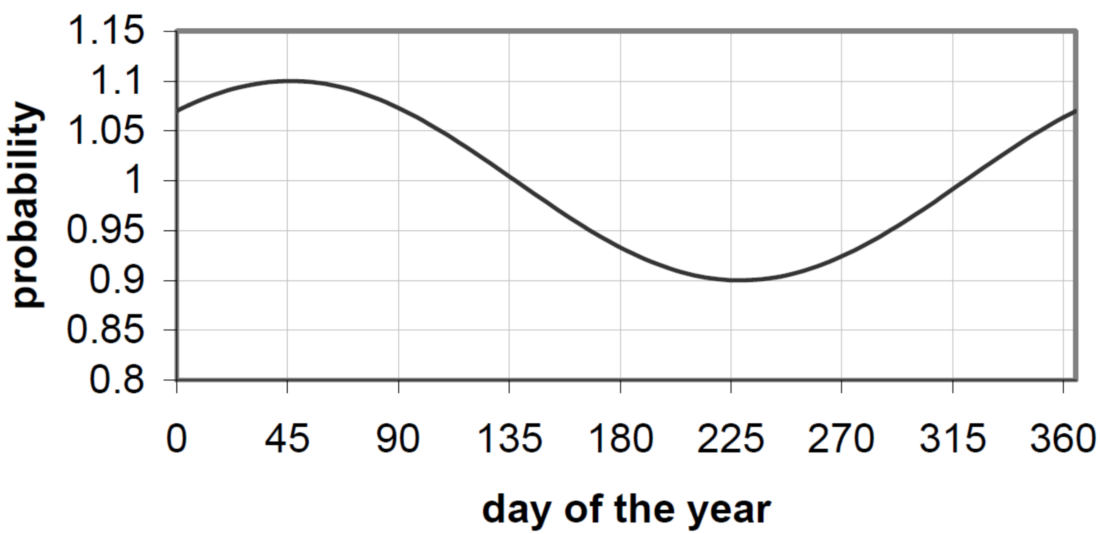
In this case the profile of DHW depends on the amount of users. For single users there is a high variation of water use from day to day.



The Increase of number of users smooths the randomly effect.

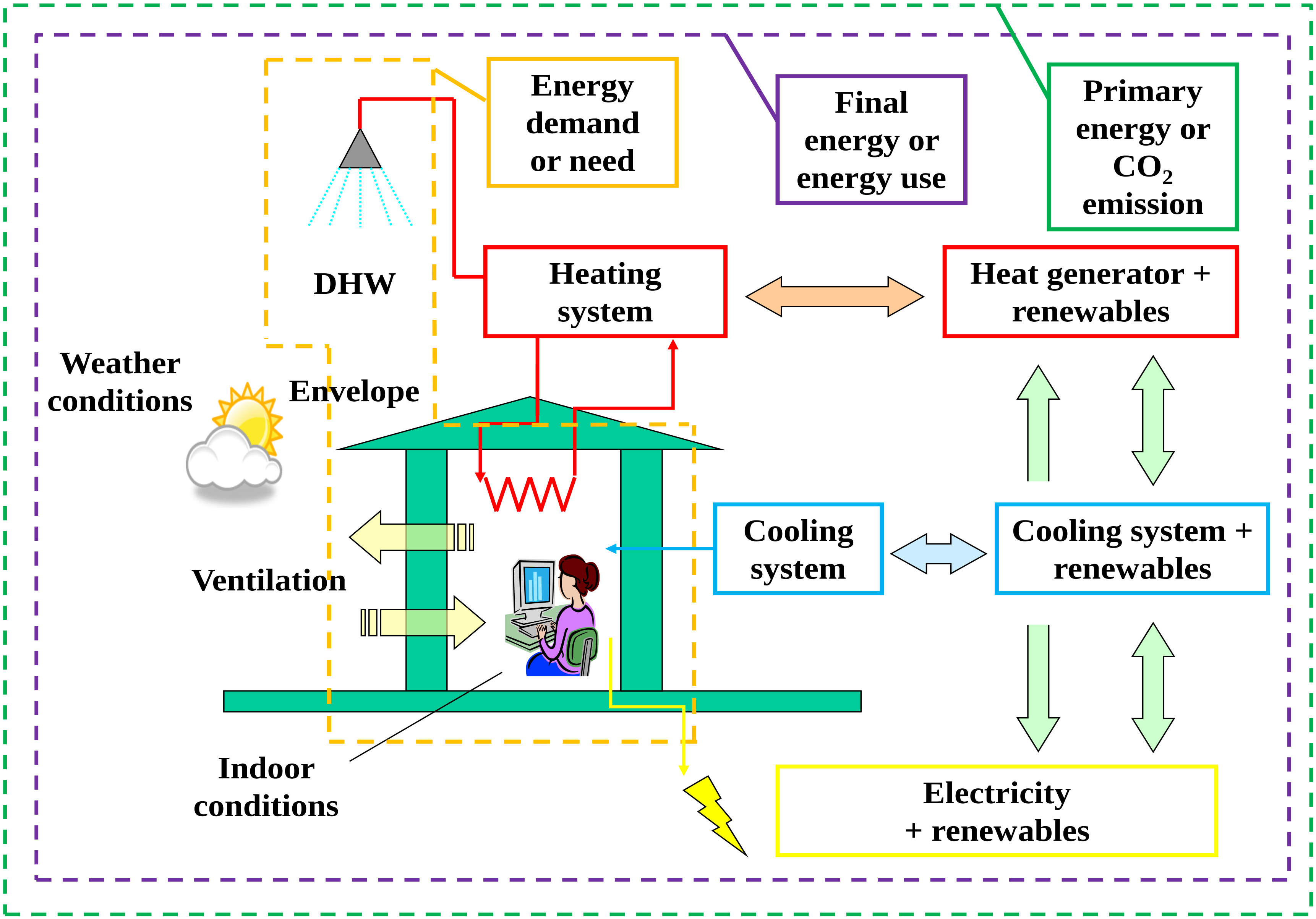
It is also possible to consider the different habots of tenants in the houses during the week (working days) and during the week-ends.

It is possible also to consider a different consumption between winter time and summer period.

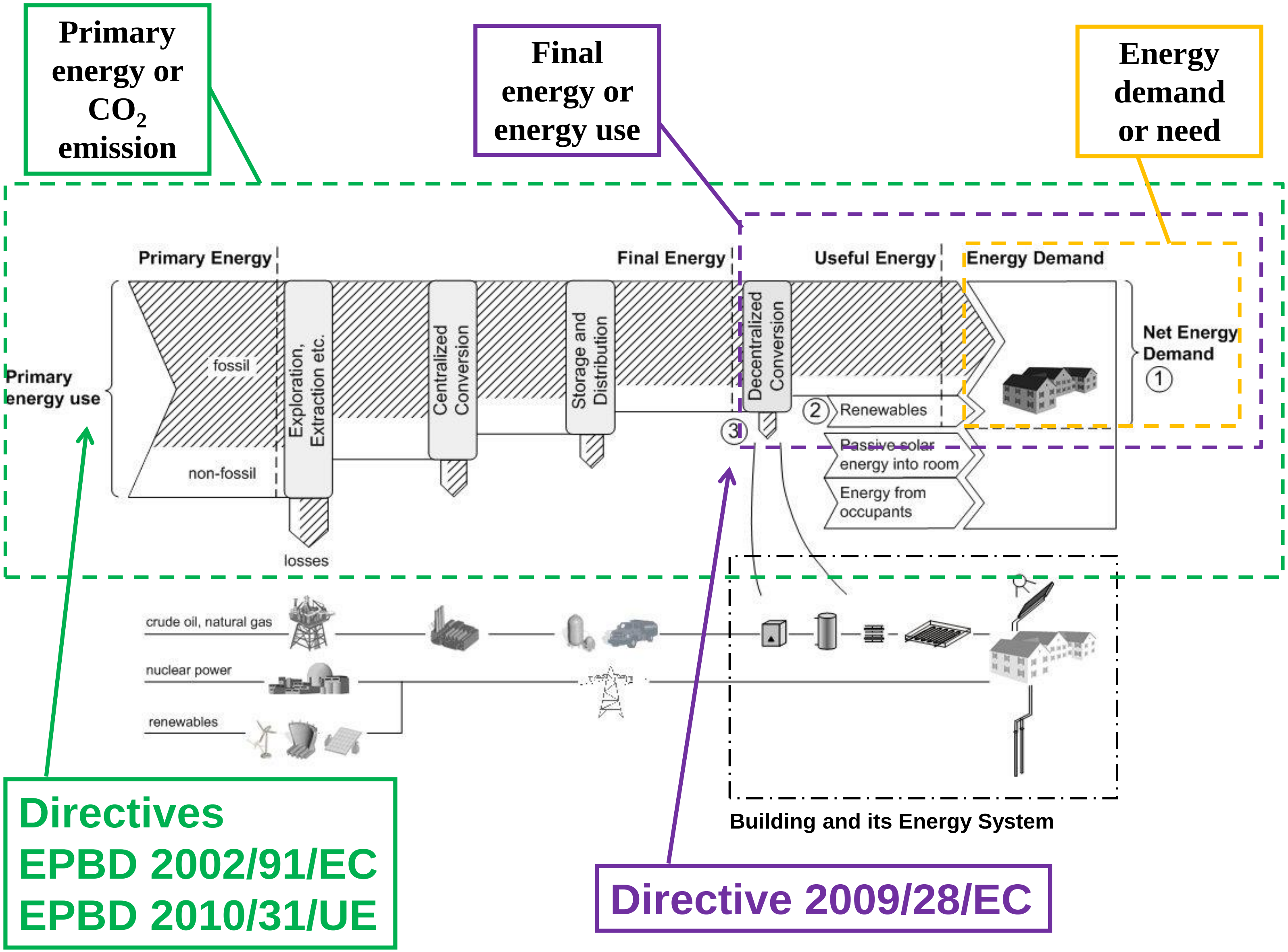


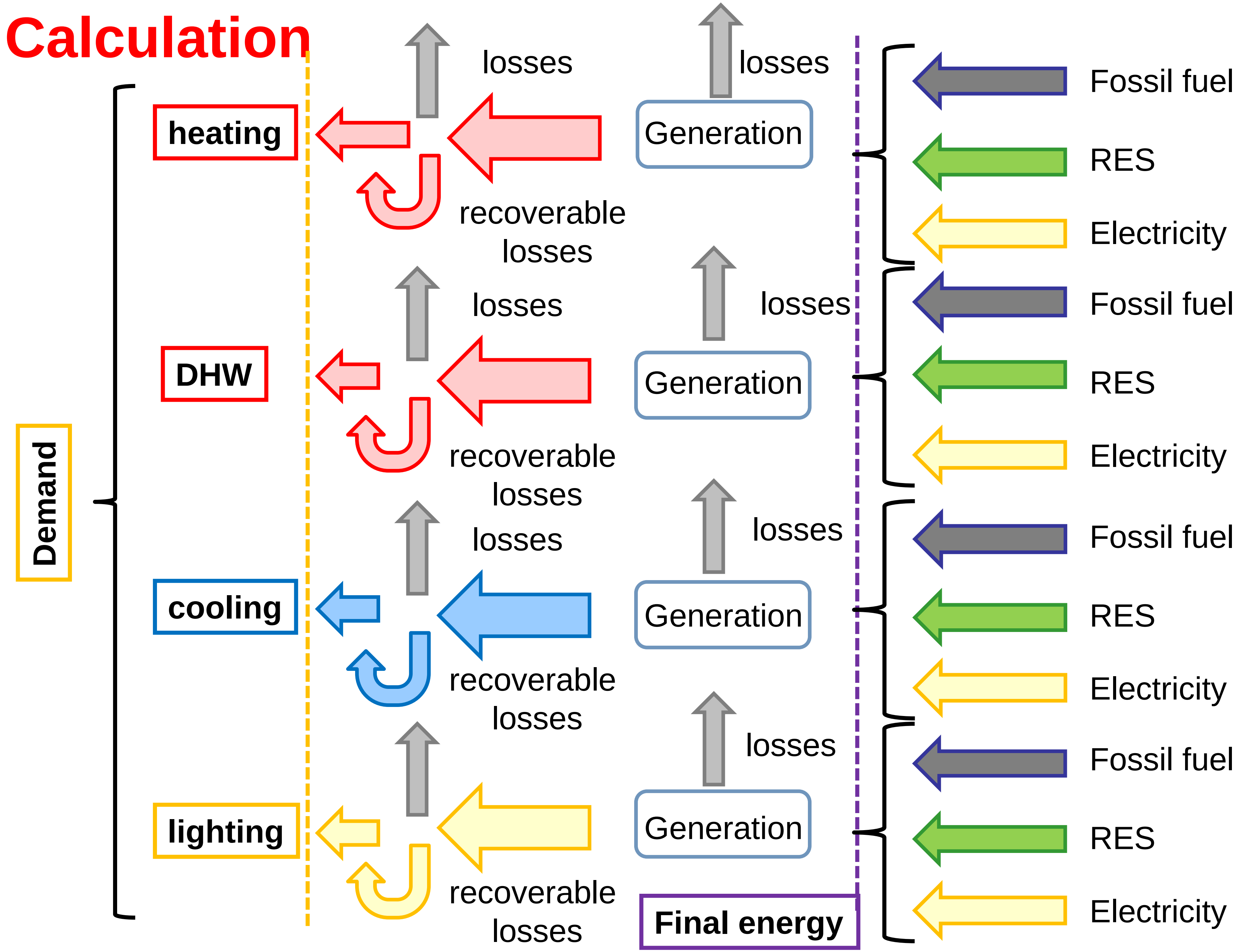
In any case it is possible to define 8760 hourly profiles of DHW.

The different levels of energy

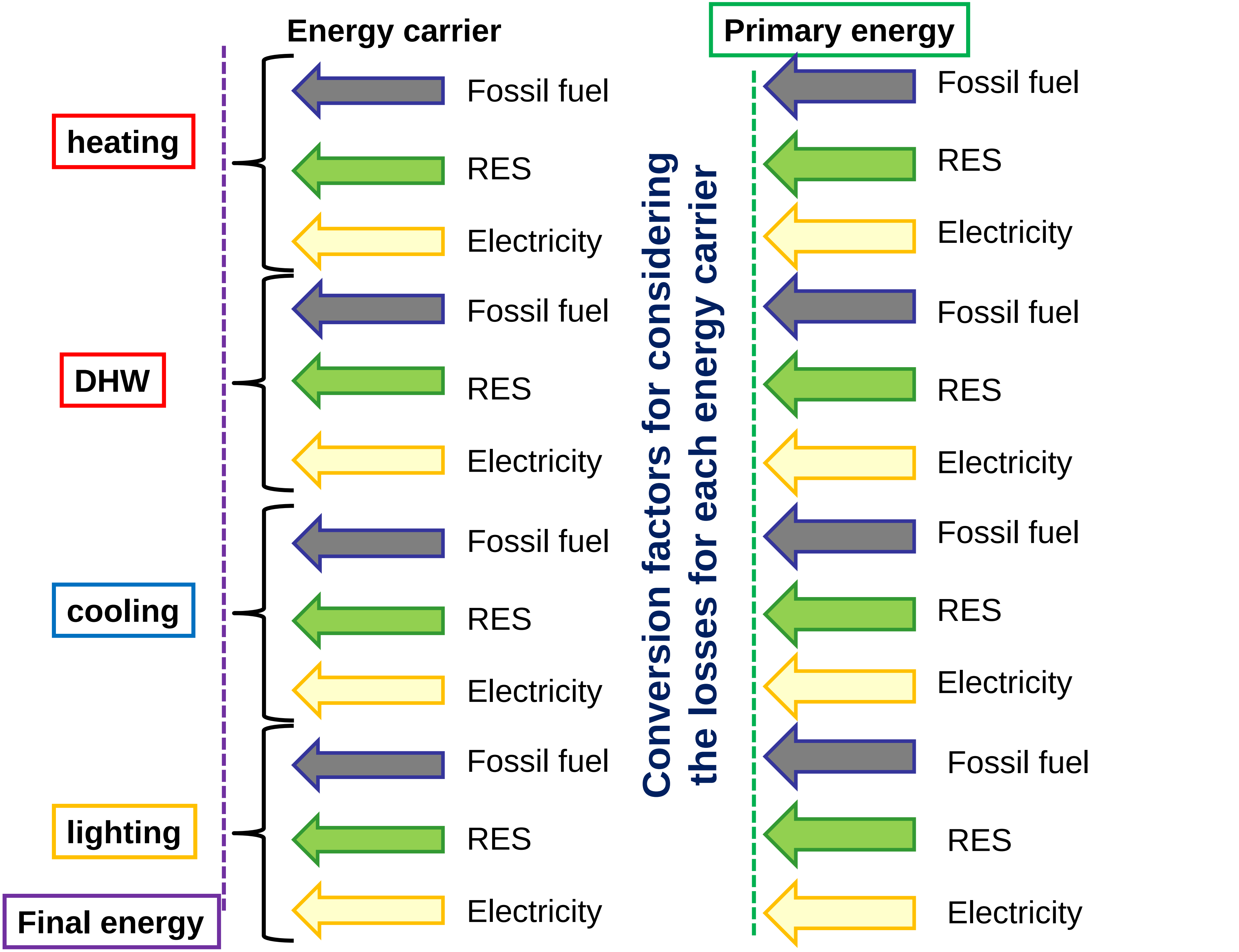


Sankey diagram and levels of energy

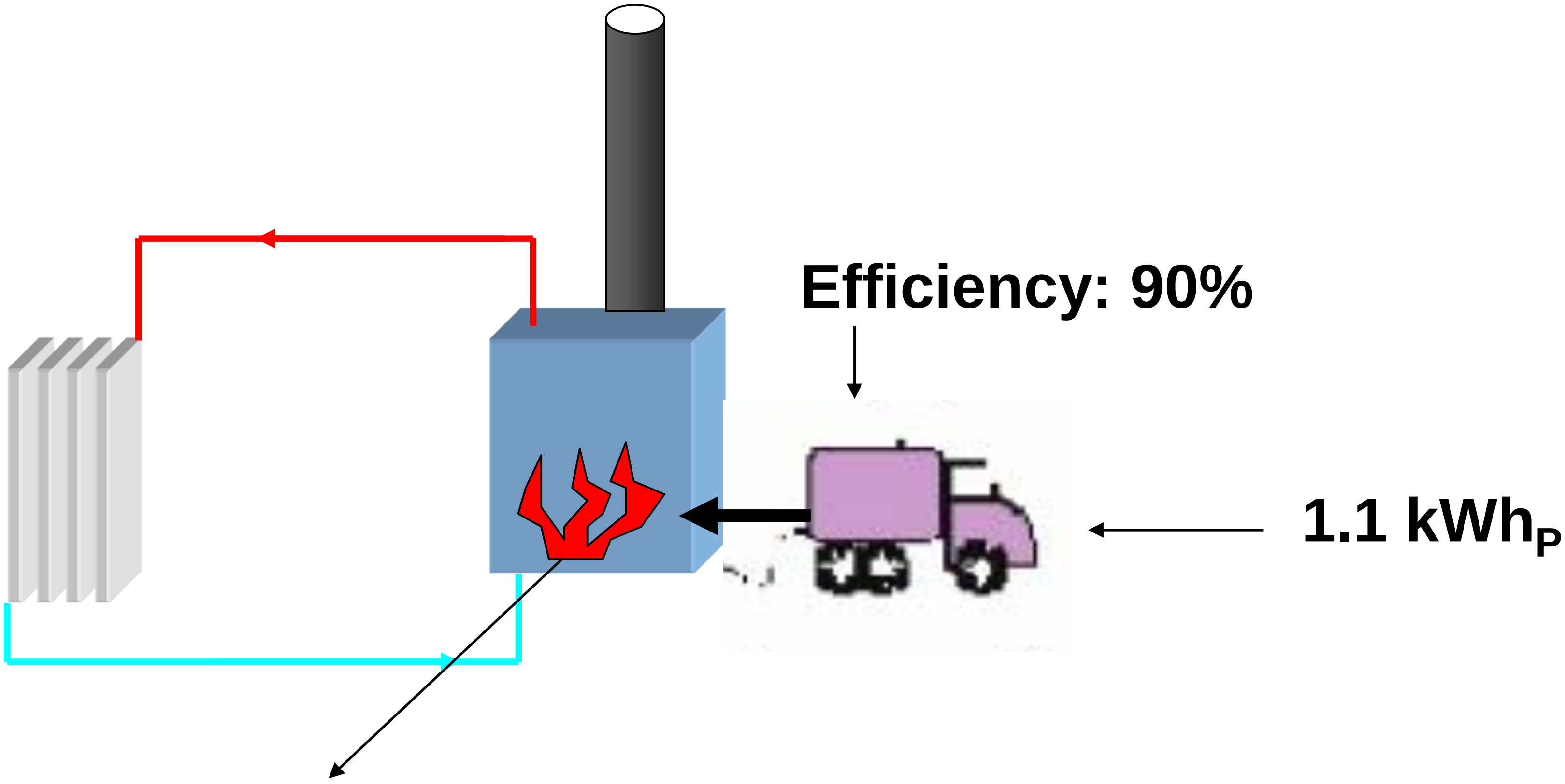




Calculation
Demand
heating
DHW
cooling
lighting
losses
recoverable losses
losses
recoverable losses
losses
recoverable losses
losses
recoverable losses
Generation
losses
Generation
losses
Generation
losses
Generation
losses
Final energy
Fossil fuel
RES
Electricity
Fossil fuel
RES
Electricity
Fossil fuel
RES
Electricity
Fossil fuel
RES
Electricity


Energy carrier
Primary energy
heating
DHW
cooling
lighting
Final energy
Fossil fuel
RES
Electricity
Fossil fuel
RES
Electricity
Fossil fuel
RES
Electricity
Fossil fuel
RES
Electricity
Conversion factors for considering the losses for each energy carrier
Fossil fuel
RES
Electricity
Fossil fuel
RES
Electricity
Fossil fuel
RES
Electricity
Fossil fuel
RES
Electricity

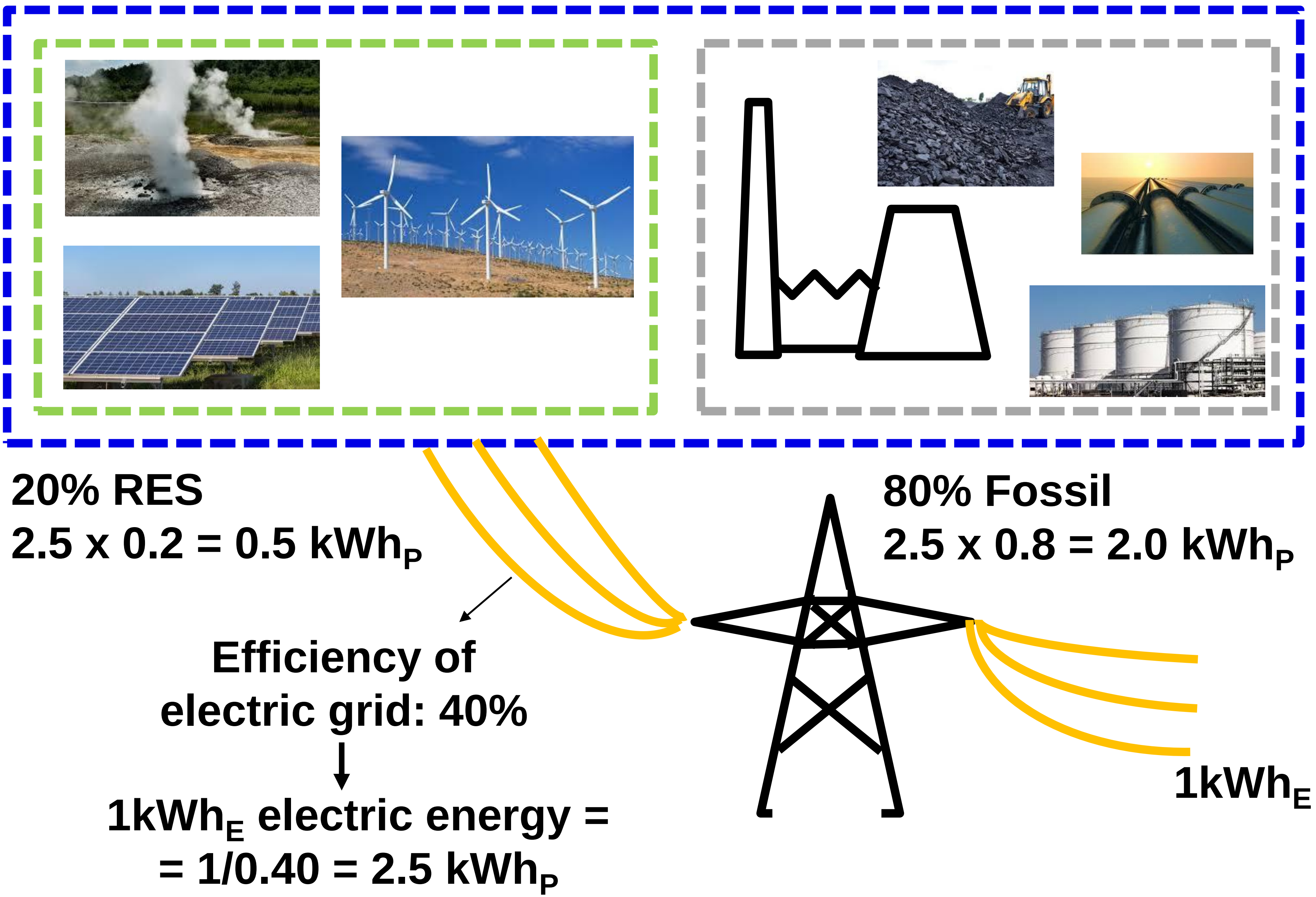
Fossil fuels primary energy



1kWh$_T$ burned = 1/0.9 = 1.1 kWh$_P$ (Primary energy)

Electricity primary energy

2.5 kWh_P



Primary energy factors

Primary energy conversion factors for energy carriers $f_{P,TOT} = f_{P,NREN} + f_{P,REN}$			
Energy carrier	$f_{P,NREN}$	$f_{P,REN}$	$f_{P,TOT}$
Natural gas	1,05	0,0	1,05
LPG	1,05	0,0	1,05
Oil	1,07	0,0	1,07
Coal	1,10	0,0	1,10
Solid Biomass	0,20	0,80	1,00
Liquid and Gas biomass	0,40	0,60	1,00
Electric energy from the grid	1,95	0,47	2,42
District Heating	1,5	0,0	1,5
Urban solid waste	0,2	0,0	0,2
District Cooling	0,5	0,0	0,5
Thermal Energy from solar collectors	0,0	1,00	1,00
Electric energy generated by Photovoltaic systems, mini-wind turbines and small hydro systems	0,0	1,00	1,00
Thermal Energy from the outdoor environment – free cooling	0,0	1,00	1,00
Thermal Energy from the outdoor environment – heat pump	0,0	1,00	1,00

Official Italian values

CO_2 conversion factors

Standard CO_2 emission factors (IPCC 2006) for most common fuel types (EU)

Type	Standard Emission Factor [t CO2/MWh]
Motor Gasoline	0.249
Gas oil, diesel	0.267
Residual Fuel Oil	0.279
Anthracite	0.354
Other Bituminous Coal	0.341
Sub-Bituminous Coal	0.346
Lignite	0.364
Naural Gas	0.202
Municipal Wastes (Non-biomass fraction)	0.330
Wood [a]	0-0.403

a) Lower value if wood is harvested in a sustainable manner, higher if harvesting is unsustainable.

Recap on the report (energy need and consumption of your house)

- Building energy model (hopefully simple)
- Heating & cooling net energy demand of the building
- Calculaiton of DHW demand
- Evaluation of the losses of the plant (heating + DHW)
- Final energy

- Energy consumptions (from bills)
- Normalization (based on Degree days)
- Final energy

Comparison

- Primary energy factors
- Primary energy consumption
- CO_2 conversion factors
- CO_2 emissions

Energy carriers and parameters to be analysed:

- Heating & cooling net energy demand of the building (calculated via Energyplus)
- Final energy (just fuel or mix) for heating & DHW (calculated and from bills)
- Primary energy for heatig & DHW (calculated and from bills)
- CO_2 emissions for heatig & DHW (calculated and from bills)
- Final energy for cooling (calculated)
- Primary energy for cooling (calculated)
- CO_2 emissions for cooling (calculated)

Optional:

- Electrical energy demand (from bills)
- Final energy for electricity (from bills)
- Primary energy electricity (from bills)
- CO_2 emissions electricity (from bills)

Example on final energy calculation for heating and DHW

From calculations (E+):
Heating net energy demand: 150 kWh/(m^2 year)
DHW: 18 kWh/(m^2 year)
Overall losses: 30 kWh/(m^2 year)
Overall final energy: 150 + 18 +30 = 198 kWh/(m^2 year)

Comparison with bills:
Natural gas:
150 kWh/(m^2 year) during 2019
DDH for the year to normalize the consumption.
Let's suppose that the standard DDH is 110%; that leads to the following standardized consumption:
Final energy from bills: 165 kWh/(m^2 year)

Example on primary energy calculation

Overall primary energy for gas (from calculations):
198 kWh/(m^2 year) x 1.05 = 208 kWh/(m^2 year)
Fossil primary energy for heating and DHW: 208 kWh/(m^2 year)

Overall primary energy for gas (from bills):
165 kWh/(m^2 year) x 1.05 = 173 kWh/(m^2 year)
Fossil primary energy for heating and DHW: 173 kWh/(m^2 year)

Example on CO2 calculation

Overall CO2 emissions for gas (from calculations):
198 kWh/(m^2 year) x 0.202 = 40 kg CO2/(m^2 year)
CO2 emission for heating and DHW: 40 kg CO2/(m^2 year)

Overall CO2 emissions for gas (from bills):
165 kWh/(m^2 year) x 0.202 = 33 kg CO2 /(m^2 year)
CO2 emission for heating and DHW: 33 kg CO2 /(m^2 year)

Example on calculation for cooling

From calculations (E+):
Cooling net energy demand: 25 kWh/(m^2 year)
Overall losses: 3 kWh/(m^2 year)
Overall final energy: 25 + 3 = 28 kWh/(m^2 year)
Overall final electrical energy for cooling (Seasonal Performance Factor = 3):
Overall final elecricity: 28/3 = 9.33 kWh/(m^2 year)

Primary energy for cooling:
9.33 kWh/(m^2 year) x 2.42 = 22.6 kWh/(m^2 year)
Overall primary energy for electricity: 22.6 kWh/(m^2 year)
Fossil primary energy for electricity: 1.95 x 9.33 = 18.19 kWh/(m^2 year)
Renewable primary energy for electricity 0.47 x 9.33 = 4.38 kWh/(m^2 year)

CO2 emissions for electricity:
9.33 kWh/(m^2 year) x 0.4 = 3.73 kg CO2/(m^2 year)
CO2 emissions for electricity: 3.73 kg CO2/(m^2 year)

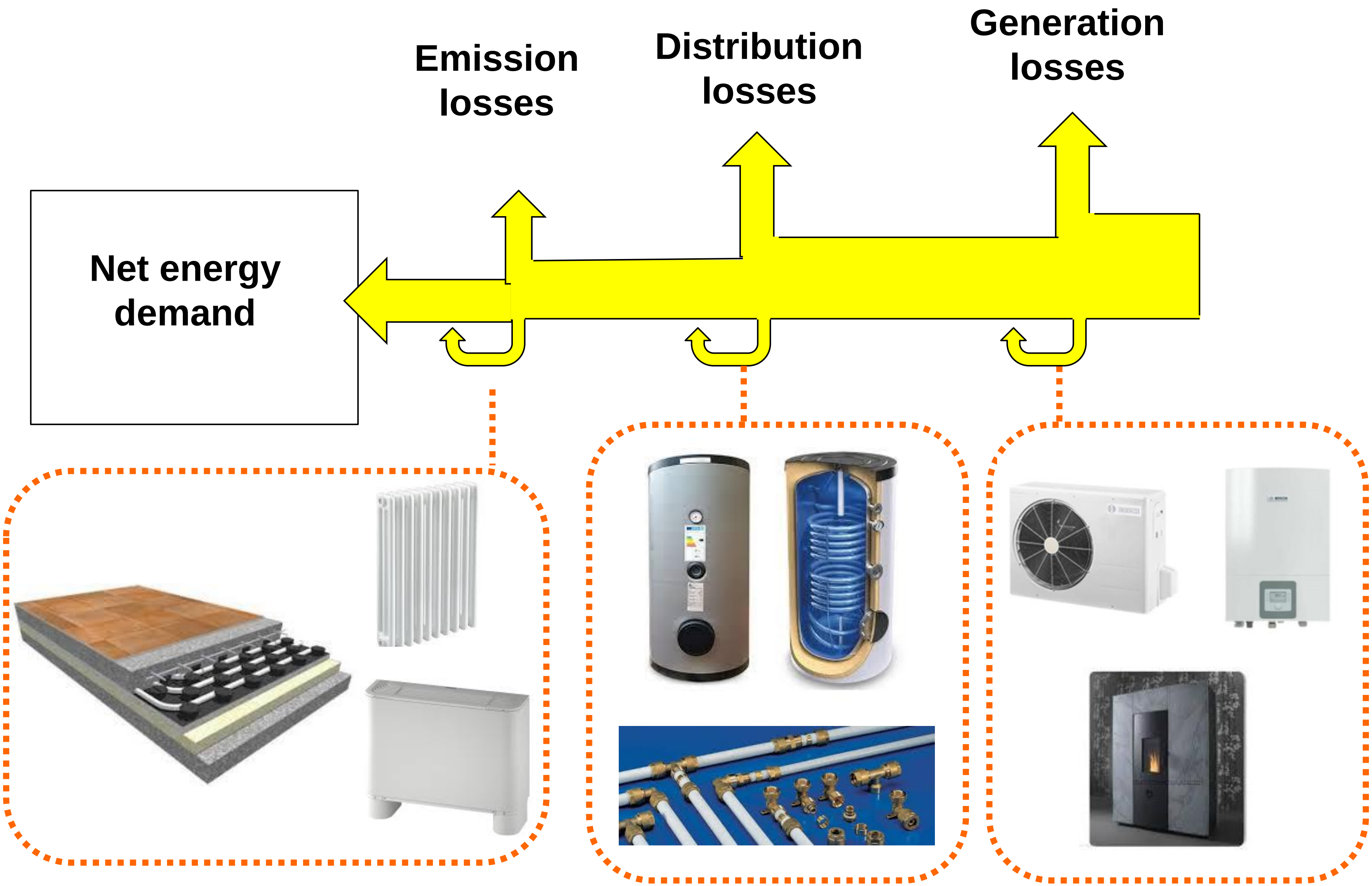
Optional

Electricity from bills:
Electrical energy demand: 30 kWh/(m^2 year)
Final energy for electricity: 30 kWh/(m^2 year)

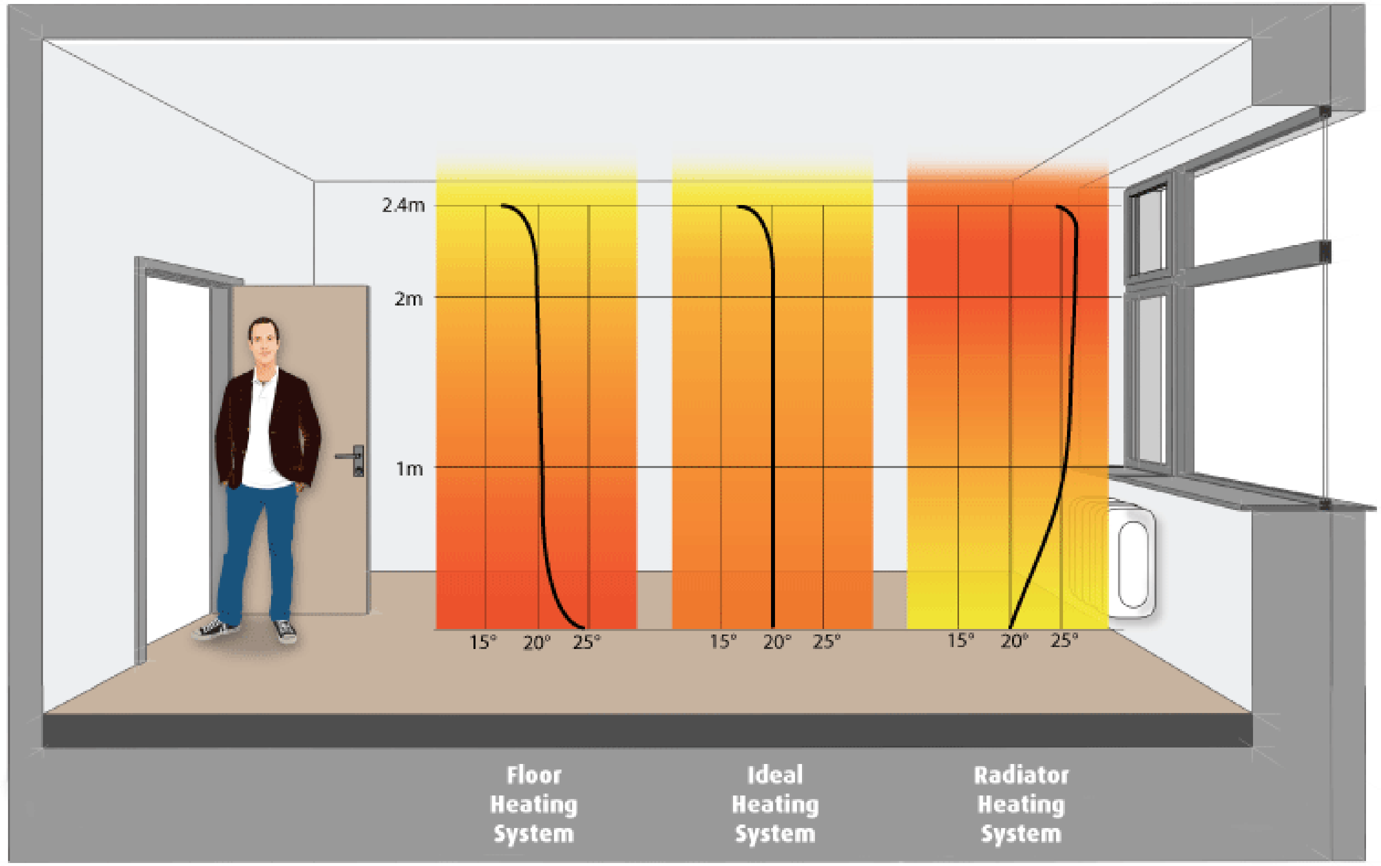
Primary energy for electricity:
30 kWh/(m^2 year) x 2.42 = 72.6 kWh/(m^2 year)
Overall primary energy for electricity: 72.6 kWh/(m^2 year)
Fossil primary energy for electricity: 1.95 x 30 = 58.5 kWh/(m^2 year)
Renewable primary energy for electricity 0.47 x 30 = 14.1 kWh/(m^2 year)

CO2 emissions for electricity:
30 kWh/(m^2 year) x 0.4 = 12 kWh/(m^2 year)
CO2 emissions for electricity: 12 kg CO2/(m^2 year)

Building delivered energy (EN 15316)



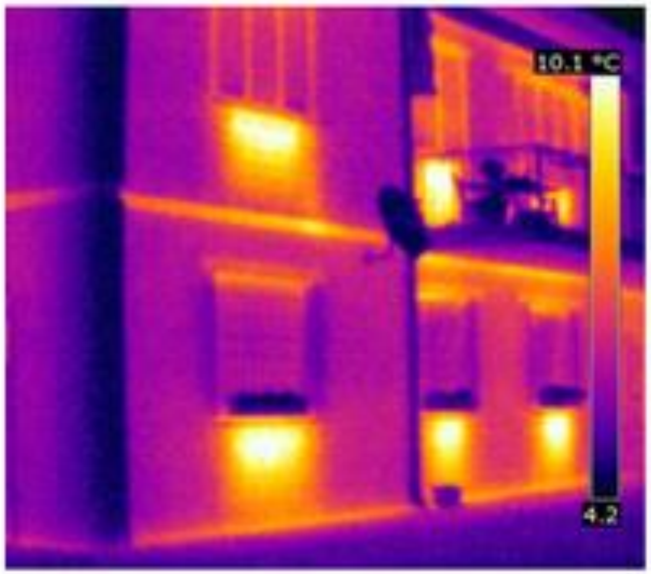
Stratification



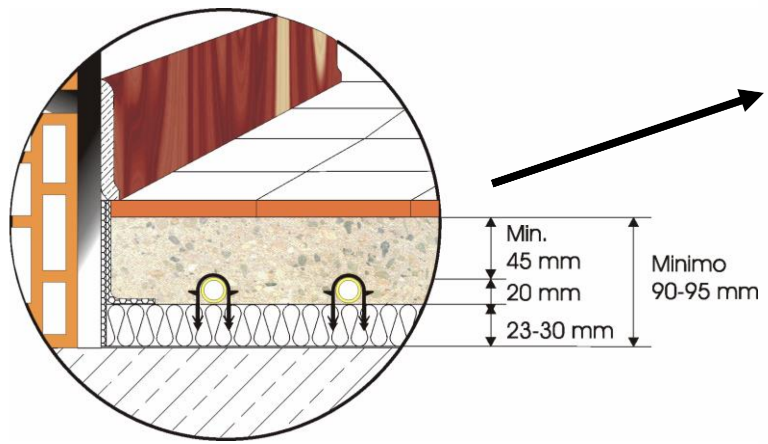
Calculations for the net energy demand are based on the assumption that the indoor air is at uniform temperature.
Depending on the type of emission system (convective or radiant) and on the water temperature inside. The higher the temperature the higher the difference in indoor temperatures

Radiant systems cause less stratification than convective systems (fan-coils, radiators).

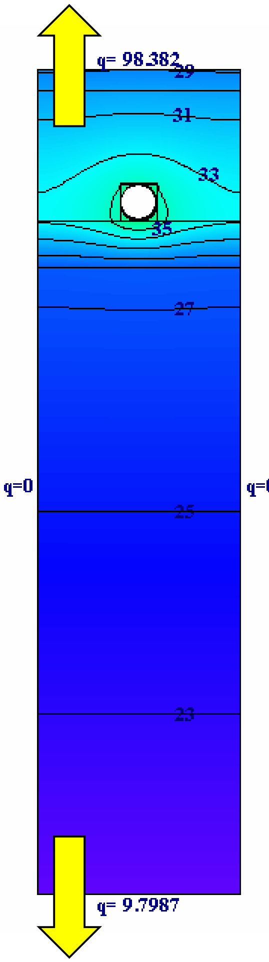
Embedded losses



Radiators



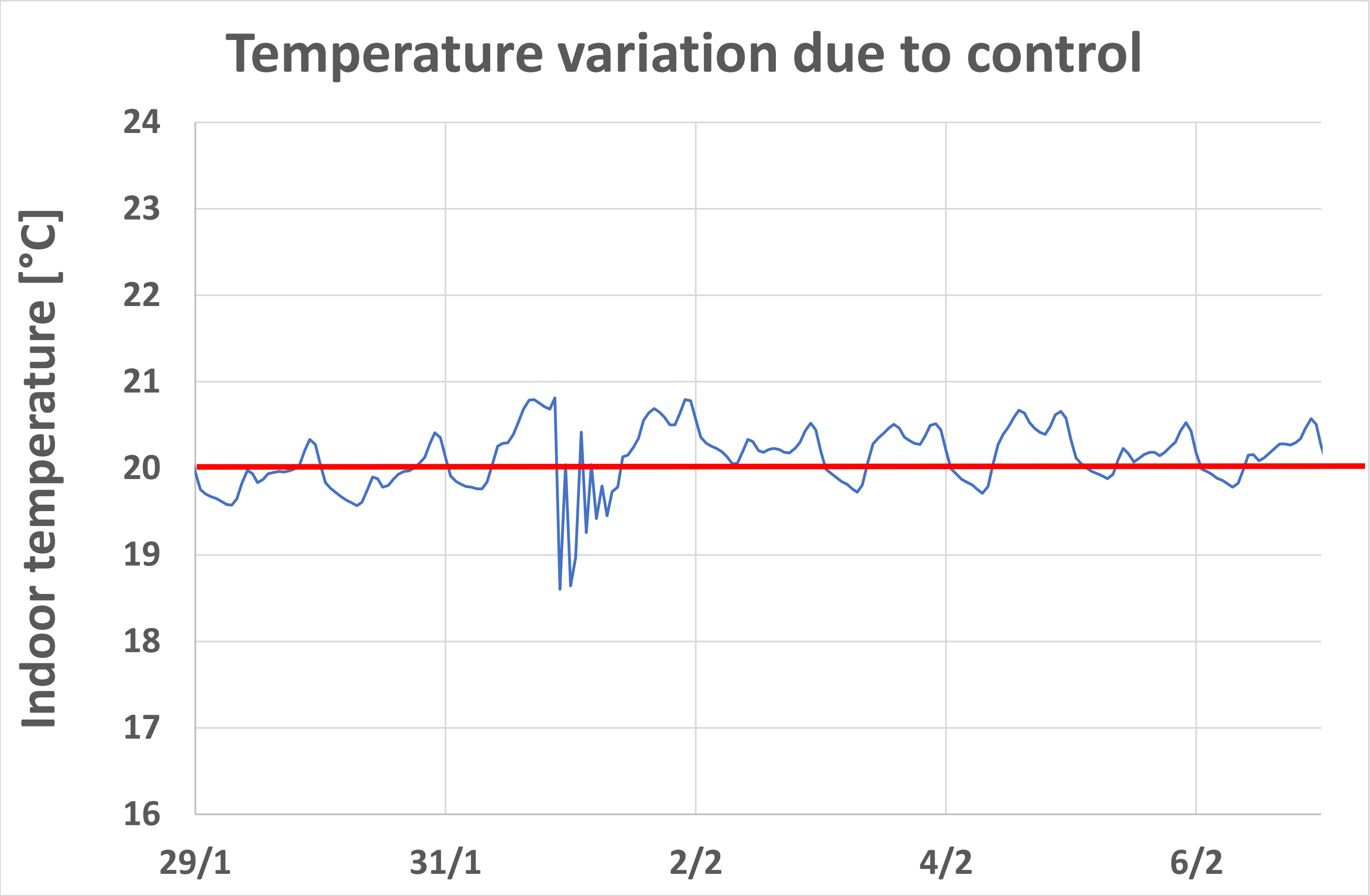
Radiant system



All emission systems present losses towards other rooms or outdoor air.
Backward losses are called embodied or embedded losses due to the energy stored in the back side structure and then they are released to other rooms or the outdoor air.

They depend on the temperature of the water in the emission system as well as the insulation present in the back side structure.

Control

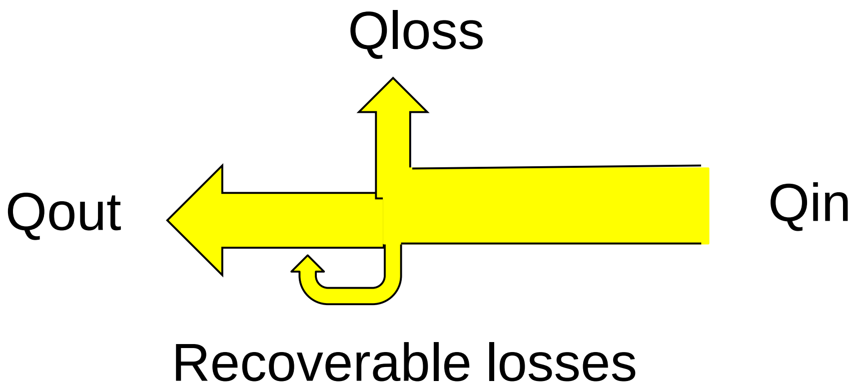


The losses due to control are due to the deviation of temperature from the ideal set-pont temperature assumed in the calculations.

Control efficiency depends on the way the room temperature is controlled. There are several possibilities:

- room by room control
- control in the living room (bed rooms follow living room)
- no room control at all (large centralized heating systems)

Calculation methods for the emission systems losses

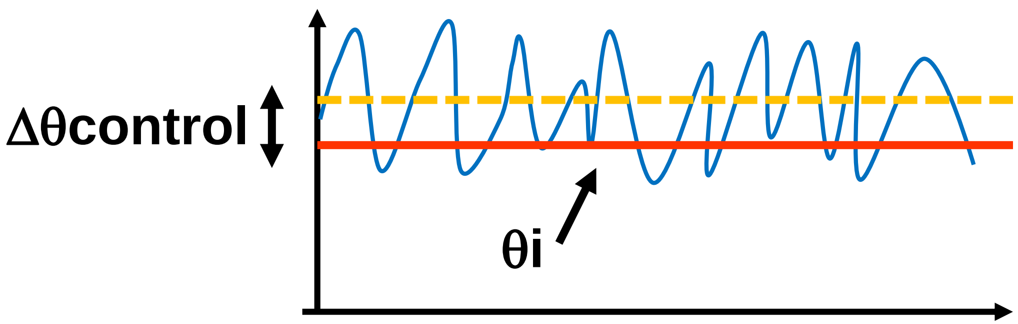


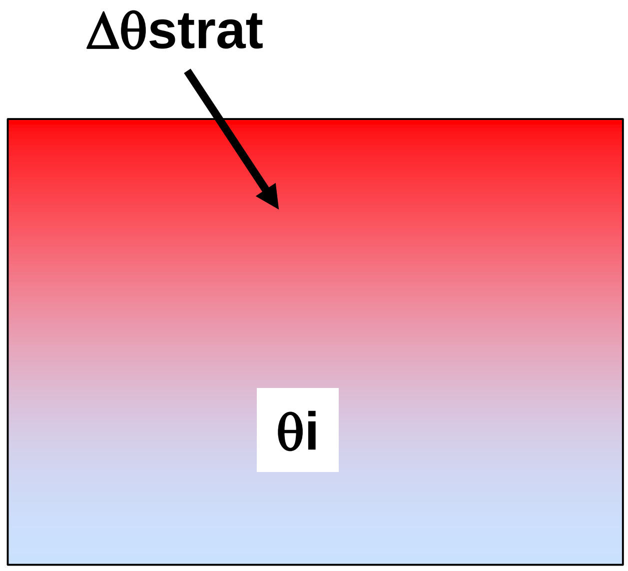
$$Qloss = Qin - Qout$$

Method 1. Emission efficiency approach:

$$\eta = \frac{Qout}{Qin} = \frac{Qin - Qloss}{Qin} = 1 - \frac{Qloss}{Qin}$$

Method 2. Equivalent temperature approach





Δθcontrol and Δθstrat represent extralosses due to the increased effective temperature:

$$\theta effective = \theta i + \Delta\theta strat + \Delta\theta control$$

$$\frac{Qin}{Qout} = \frac{\theta effective - \theta avg,e}{\theta i - \theta avg,e} = 1 + \frac{\Delta\theta strat + \Delta\theta control}{\theta i - \theta avg,e}$$

$$\eta = \frac{Qout}{Qin} = \left(1 + \frac{\Delta\theta strat + \Delta\theta control}{\theta i - \theta avg,e}\right)^{-1}$$

Emission loss for the report (efficiency method)

$$\eta_{em} = \eta_{str} \cdot \eta_{ctr} \cdot \eta_{emb}$$

Table 3.1 — Efficiencies for free heating surfaces (radiators); room heights ≤4 m

Influence parameters		Efficiencies			
		η_{str}		η_{ctr}	η_{emb}
		η_{str1}	η_{str2}		
Room space temperature regulation	unregulated, with central supply temperature regulation			0.80	
	Master room space			0.88	
	P-controller (2 K)			0.93	
	P-controller (1 K)			0.95	
	PI-controller			0.97	
	PI-controller (with optimisation function, e.g. presence management, adaptive controller)			0.99	
Over-temperature (reference Θ_i = 20 °C)	60 K (e.g. 90/70)	0.88			
	42.5 K (e.g. 70/55)	0.93			
	30 K (e.g. 55/45)	0.95			
specific heat losses via external components (GF = glass surface area)	radiator location internal wall		0.87		1
	radiator location external wall				
	- GF without radiation protection		0.83		1
	- GF with radiation protection[a]		0.88		1
	- normal external wall		0.95		1

[a] The radiation protection must prevent 80% of the radiation losses from the heating body to the glass surface area by means of insulation and/or reflection.

Table 3.3 Efficiencies for component integrated heating surfaces (panel heaters); room heights ≤4m

influence parameters		Part efficiencies			
		η_{str}	η_{ctr}	η_{emb}	
Room space temperature regulation	Heat carrier medium water				
	- unregulated		0.75		
	- unregulated, with central supply temperature regulation		0.78		
	- unregulated with average value formation ($\vartheta_V - \vartheta_R$)		0.83		
	- Master room space		0.88		
	- two-step controller/P-controller		0.93		
	- PI-controller		0.95		
	Electrical heating				
	-two-step controller		0.91		
	- PI-controller		0.93		
System	Floor heating			η_{emb1}	η_{emb2}
	- wet system	1		0.93	
	- dry system	1		0.96	
	- dry system with low cover	1		0.98	
	Wall heating	0.96		0.93	
	Ceiling heating	0.93		0.93	
Specific heat losses via laying surfaces	Panel heating without minimum insulation in accordance with DIN EN 1264				0.86
	Panel heating with minimum insulation in accordance with DIN EN 1264				0.95
	Panel heating with 100% better insulation than required by DIN EN 1264				0.99

Distribution losses

Distribution losses are due to the piping and the heating/cooling storages.

There are 2 possible methods:

- Detailed method considering all the pipes in the building (suitable for new projects)
- Simplified method based on tabulated values

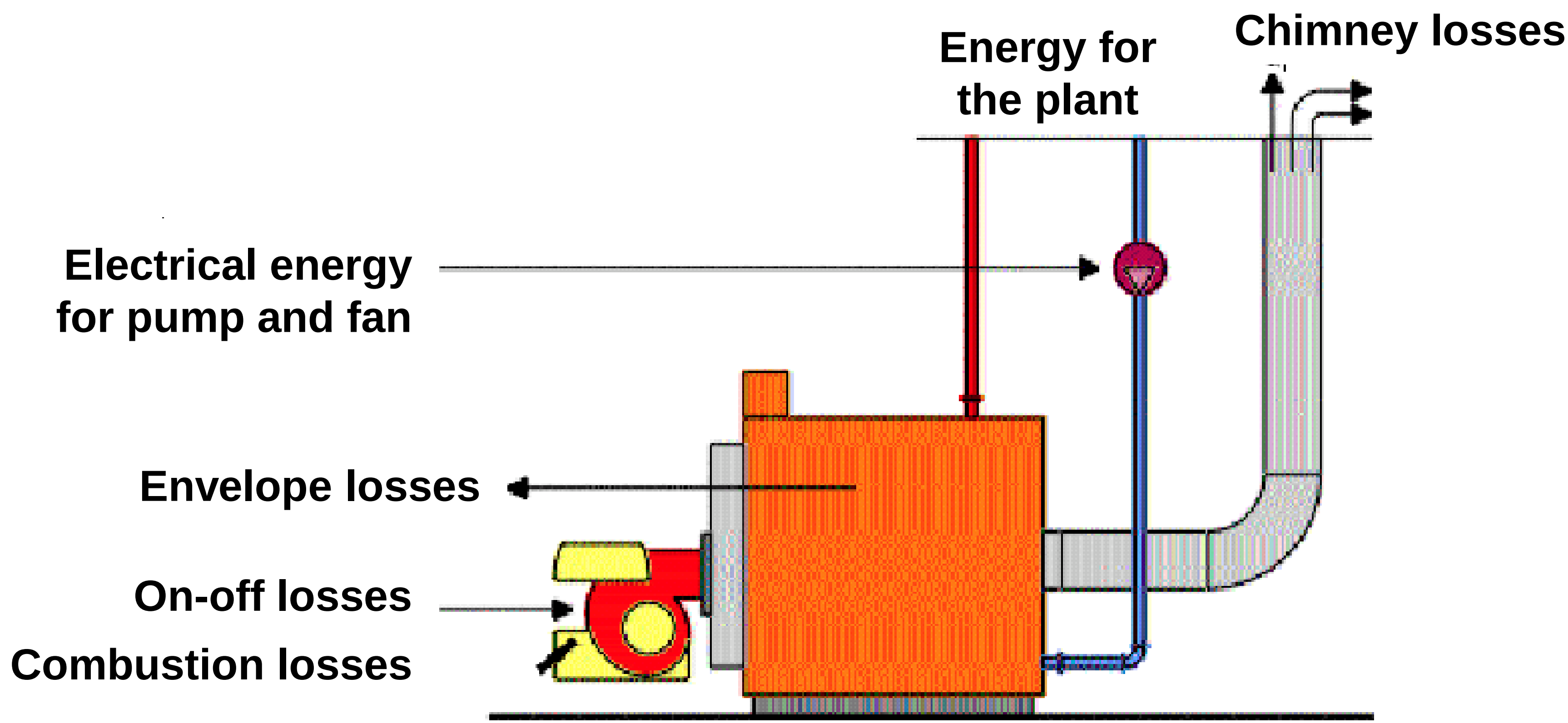
Single user:

Year	η_d
> 2000	0.99
1990-2000	0.97
< 1990	0.95

Centralized system (η_d):

	1 floor	2 floors	3 floors	4 or more
> 2000	0.97	0.96	0.95	0.94
1990-2000	0.94	0.93	0.92	0.91
<1990	0.91	0.90	0.89	0.88

Generation losses



Type of boiler	Generation efficiency η_g
*	0.76
**	0.81
***	0.89
****	1.00

Final energy for heating (from simulations)

$Q_{heating}$: net energy demand for heating (ENERGYPLUS)

Evaluation of $\eta_{em} = \eta_{str} \cdot \eta_{ctr} \cdot \eta_{emb}$

Evaluation of total efficiency $\eta_{tot,h}$:

$$\eta_{tot,heating} = \eta_{em} \cdot \eta_{d} \cdot \eta_{g,heating}$$

$FE_{heating}$: Final energy for heating

$$FE_{heating} = \frac{Q_{heating}}{\eta_{em} \cdot \eta_{d} \cdot \eta_{g}}$$

Net energy demand for DHW

Usually it may be assumed to have:

$Q_{DHWday} = \rho\ c\ (\theta_{er} - \theta_{aqueduct})\ V_{day}$

$\theta_{er} = 40°C$

$V_{day} = a\ A_f + b$

	$A_f \leq 35$	$35 < A_f \leq 50$	$50 < A_f \leq 200$	$A_f > 200$
a [l/(m^2 day)]	0	2.667	1.067	0
b l/day	50	-43.33	36.67	250

For the yearly evaluation the mean outdoor temperature θ_o can be considered as aqueduct temperature:

$Q_{DHW,year} = \rho\ c\ (\theta_{er} - \theta_o)\ V_{year}$

This method is usually used when it is not exactly known the amount of people. As alternative the equation based on 40 l/person can be used

Final energy for DHW

Losses apart generation: about 3%, hence an overall efficiency of 0.97 can be considered (please note that if you do have a tank losses can increase considerably, as well as if hot water is flowing in the pipes constantly in centralized solutions).
Calculate the generation deficiency as the generation efficiency – 5%.

$Q_{DHW,year}$: net energy demand for Domestic Hot Water

Efficiency of the DHW: $\eta = 0.97$

Evaluation of generation efficiency $\eta_{g,DHW}$:

$$\eta_{g,DHW} = \eta_{g,heating} - 0.05$$

FE_{DHW} : Final energy for DHW

$$FE_{DHW} = \frac{Q_{DHW,year}}{0.97 \cdot \eta_{g,DHW}}$$

Cooling losses

Embedded and stratification per system	$\eta_{strat} \times \eta_{emb}$
Hydronic fan-coil units	0.98
Direct evaporating systems (split systems)	0.97
Chilled beams	0.97
Full-air (mixing & dicplacement ventilation) solutions	0.97
Radiant floor	0.97
Radiant ceiling	0.98

System	Technology	η_{contr}
Centralised control	On-off	0.84
	Modulating	0.90
Zone control	On-off	0.93
	Modulating (2°C band)	0.95
	Modulating (1°C band)	0.97
Room control	On-off	0.94
	Modulating (2°C band)	0.96
	Modulating (1°C band)	0.98

Distribution efficiency in cooling and seasonal performance factor

Year	η_d
> 2015	0.99
2010-2015	0.97
< 2010	0.95

Year	SPF
> 2015	3.0
2010-2015	2.7
< 2010	2.5

Final energy for cooling (from simulations)

$Q_{cooling}$: net energy demand for cooling (ENERGYPLUS)

Evaluation of $\eta_{em} = \eta_{str} \cdot \eta_{ctr} \cdot \eta_{emb}$

Evaluation of total efficiency $\eta_{tot,c}$:

$$\eta_{tot,cooling} = \eta_{em} \cdot \eta_{d}$$

$FE_{cooling}$: Final energy for cooling

$$FE_{cooling} = \frac{Q_{cooling}}{\eta_{em} \cdot \eta_{d}}$$

$FEE_{cooling}$: Final electrical energy for cooling

$$FEE_{cooling} = \frac{FE_{cooling}}{SPF}$$

Example of evaluation of the final energy: heating

Table 3.1 — Efficiencies for free heating surfaces (radiators); room heights ≤4 m

Influence parameters		Efficiencies			
		η_{str}		η_{ctr}	η_{emb}
Room space temperature regulation	unregulated, with central supply temperature regulation			0.80	
	Master room space			0.88	
	P-controller (2 K)			0.93	
	P-controller (1 K)			0.95	
	PI-controller			0.97	
	PI-controller (with optimisation function, e.g. presence management, adaptive controller)			0.99	
		η_{str1}	η_{str2}		
Over-temperature (reference Θ_i = 20 °C)	60 K (e.g. 90/70)	0.88			
	42.5 K (e.g. 70/55)	0.93			
	30 K (e.g. 55/45)	0.95			
specific heat losses via external components (GF = glass surface area)	radiator location internal wall		0.87		1
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	- GF without radiation protection		0.83		1
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	- normal external wall		0.95		1

[a] The radiation protection must prevent 80% of the radiation losses from the heating body to the glass surface area by means of insulation and/or reflection.

Evaluation of $\eta_{em} = \eta_{str} \cdot \eta_{ctr} \cdot \eta_{emb}$

$$\eta_{em} = 0.97 \cdot 0.95 \cdot 1 = 0.92$$

Centralized system (η_d):

	1 floor	2 floors	3 floors	4 or more
> 2000	0.97	0.96	0.95	0.94
1990-2000	0.94	0.93	0.92	0.91
<1990	0.91	0.90	0.89	0.88

η_g:

Type of boiler	Generation efficiency η_g
*	0.76
**	0.81
***	0.89
****	1.00

$\eta_{tot,heating} = \eta_{em} \cdot \eta_d \cdot \eta_{g,heating} = 0.92 \times 0.91 \times 1.00 = 0.84$

$Q_{heating}$: 150 kWh/(m^2 year) (ENERGYPLUS)

$FE_{heating}$: Final energy for heating

$$FE_{heating} = \frac{Q_{heating}}{\eta_{em} \cdot \eta_d \cdot \eta_g} = \frac{150}{0.84} = 179 \text{ kWh/(m}^2\text{ year)}$$

Example of evaluation of the final energy: DHW

$A_f = 100$ m2

$V_{day} = a\,A_f + b = 1.067 \times 100 + 36.67 = 143.4$ l/day

$$Q_{DHW,year} = \rho\, c\, (\theta_{er} - \theta_o)\, V_{year} = \frac{143.4 \times 365 \times 4.186 \times (40-13)}{3600} = 1643 \text{ kWh}$$

$Q_{DHW,year} = 1643/100 = 16.4$ kWh/(m^2 year)

Efficiency of the DHW: $\eta = 0.97$

$\eta_{g,DHW} = \eta_{g,heating} - 0.05 = 0.95$

FE_{DHW} : Final energy for DHW

$$FE_{DHW} = \frac{Q_{DHW,year}}{0.97 \cdot \eta_{g,DHW}} = \frac{16.4}{0.97 \cdot 0.95} = 17.8 \text{ kWh/(m}^2\text{ year)}$$

Example of evaluation of the final energy: cooling

$Q_{cooling}$: net energy demand for cooling (ENERGYPLUS)

$Q_{cooling}$ = 25 kWh/(m^2 year)

Evaluation of $\eta_{em} = \eta_{str} \cdot \eta_{ctr} \cdot \eta_{emb} = 0.97 \times 0.95 = 0.92$

System	Technology	η_{contr}
Centralised control	On-off	0.84
	Modulating	0.90
Zone control	On-off	0.93
	Modulating (2°C band)	0.95
	Modulating (1°C band)	0.97
Room control	On-off	0.94
	Modulating (2°C band)	0.96
	Modulating (1°C band)	0.98

Year	η_d
> 2015	0.99
2010-2015	0.97
< 2010	0.95

Year	SPF
> 2015	3.0
2010-2015	2.7
< 2010	2.5

Evaluation of total efficiency $\eta_{tot,c} = \eta_{em} \cdot \eta_d = 0.92 \times 0.97 = 0.89$

$Q_{cooling}$: net energy demand for cooling (ENERGYPLUS)

$FE_{cooling}$: Final energy for cooling

$$FE_{cooling} = \frac{Q_{cooling}}{\eta_{em} \cdot \eta_d} = \frac{25}{0.89} = 28 \text{ kWh/(m}^2\text{ year)}$$

$FEE_{cooling}$: Final electrical energy for cooling

$$FEE_{cooling} = \frac{FE_{cooling}}{SPF} = \frac{28}{2.7} = 10.4 \text{ kWh/(m}^2\text{ year)}$$