ENERGY IN BUILDINGS

Michele De Carli

Typical heating final energy in mild climates:

	kWh/(m^2y)
Conventional buildings without energy reduction strategies	150-250
Conventional buildings with energy reduction strategies	80-100
Low energy buildings	30-50
Passive buildings	< 15
Zero Energy Buildings (ZEB)	~ 0

An extensive database of buildings can be found in Tabula-Episcope

Typical final energy in a mild-cold climate:

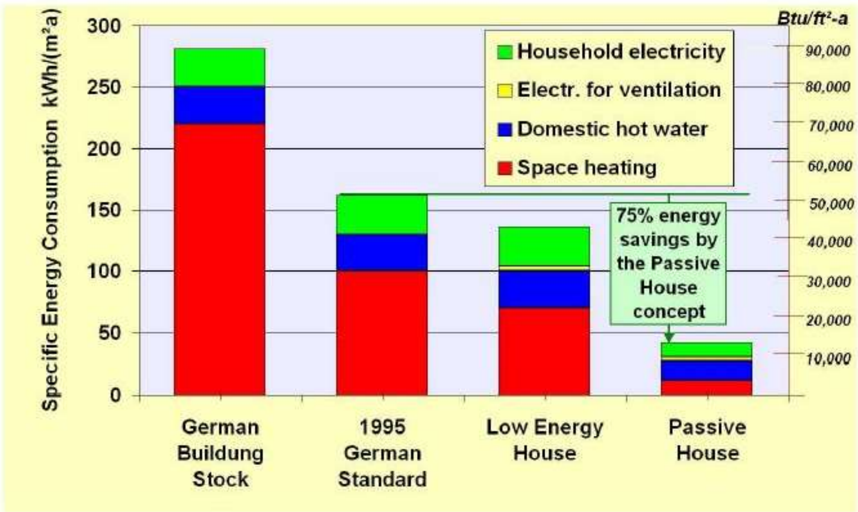
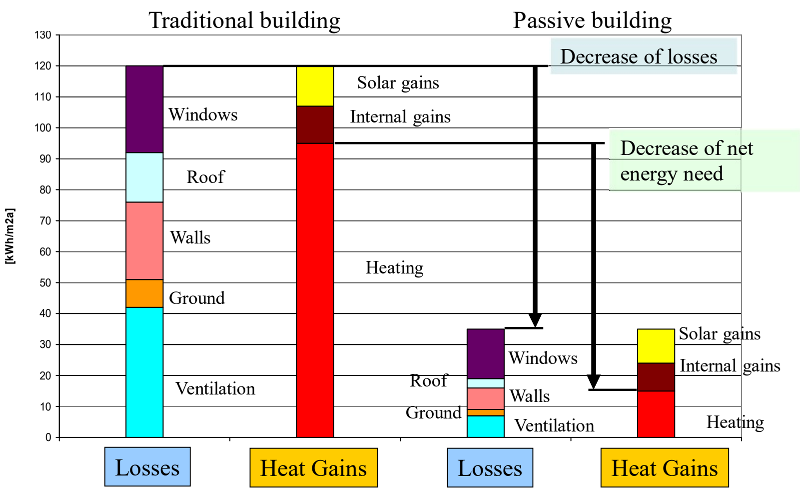
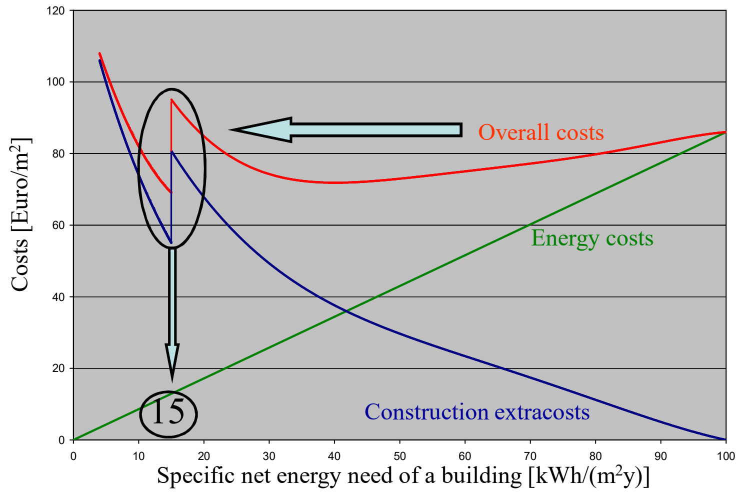


Figure 1: Comparison of specific energy consumption levels of dwellings

Comparison between an usual building and a passive building

Passive buildings are buildings with increased insulation. This leads to an energy need which is so low to allow the installation of a simplified (poor) heating system (electrical resistance).





A comparative analysis

Let's consider a 100 m^2 apartment. Typical consumptions:

- Stock building: natural gas used for heating, DHW, cooking. Electricity for cooling (split-system), lighting and appliances
- Building '90ies: natural gas used for heating, DHW, cooking. Electricity for cooling (split-system), lighting and appliances
- Low Energy Building (LEB): all consumptions with electricity. Heat pump for heating, cooling & DHW. Cooking (induction), lighting and appliances as the other cases.
- Passive House (PH): all consumptions with electricity. Solar collectors (50%) + el. Resistance. Heating with el. Resistance. Cooling (split-system). Cooking (induction). Lighting and appliances as the other cases.

	Final energy [kWh/(m² y)]					
	heating	**DHW**	**cooling**	**cooking**	**electricity**	**overall**
Stock	200	20	25	10	35	290
Buildings '90ies	100	20	25	10	35	190
LEB	40	20	25	10	35	130
PH	15	10	25	10	35	95

Boiler: η = 100%
Split-system: SPF cooling: 3.0
Electric resistance: SPF (heating & DHW: 1.0)

Heat pump: SPF heating: 3.5
SPF DHW: 2.5
SPF cooling: 3.0

Based on the above mentioned efficiencies, the following table resumes the specific final energy per energy carrier:

	Final energy per energy carrier [kWh/(m² y)]								
	heating		DHW		cooking		cooling		
	gas	electr.	gas	electr.	gas	electr.	electr.	electr.	overall
Stock	200	-	20	-	10	-	8	35	273
Buildings '90ies	100	-	20	-	10	-	8	35	173
LEB	-	11	-	8	-	6	8	35	68
PH	-	15	-	10	-	6	8	35	74

Considering for the conversion factors for primary energy 1.04 kWh_p/kWh_f for natural gas and 2.42 kWh_p/kWh_f for electrical energy:

	Primary energy per energy carrier [kWh/(m² y)]								
	heating		DHW		cooking		cooling		
	gas	electr.	gas	electr.	gas	electr.	electr.	electr.	overall
Stock	210	-	21	-	11	-	20	85	346
Buildings '90ies	105	-	21	-	11	-	20	85	241
LEB	-	28	-	19	-	13	20	85	165
PH	-	36	-	24	-	13	20	85	179

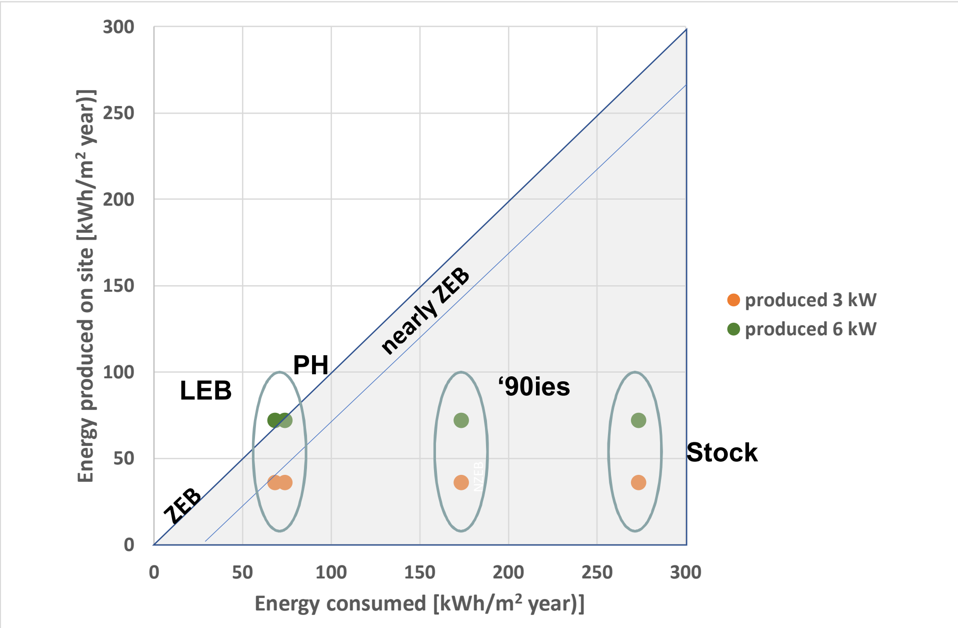
Let's suppose to install 3 kW (3600 kWh electricity produced) and 6 kW (7200 kWh electricity produced), i.e. 36 kWhe/(m^2 year) and 72 kWhe/(m^2 year) respectively.
The following table resumes the final energy consumptions (on yearly base)

	Final energy [kWh/(m² y)]			Percentage of sharing	
	No RES	PV (3 kW)	PV (6 kW)	PV (3 kW)	PV (6 kW)
Stock	273	237	201	13%	26%
Buildings '90ies	173	137	101	21%	42%
LEB	68	32	-4	53%	105%
PH	74	38	2	49%	97%

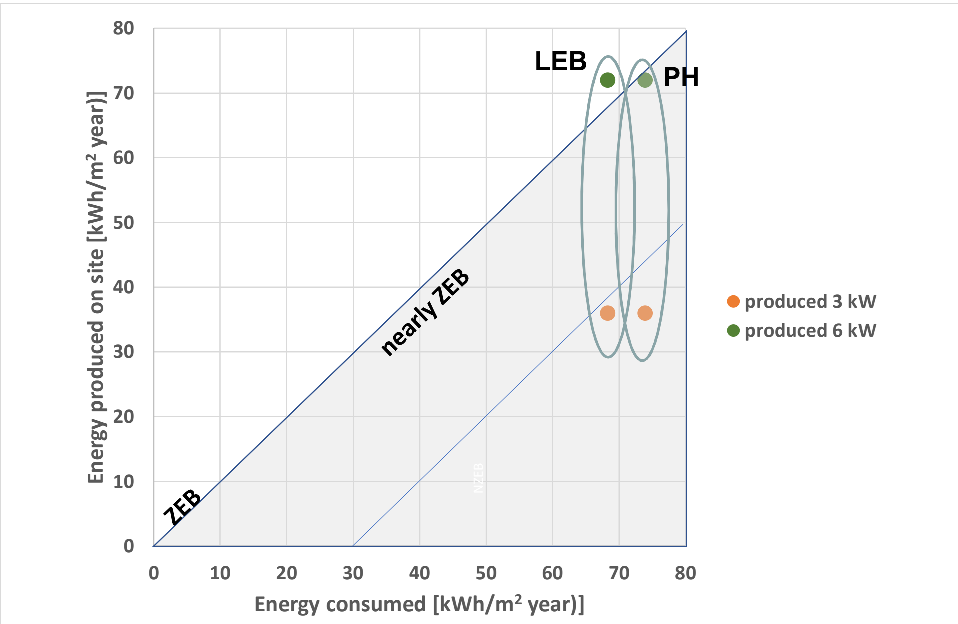
.
The following table resumes the primary energy consumptions (on yearly base), considering the primary energy produced by the PV, i.e. 87 kWhp/(m^2 year) and 174 kWhp/(m^2 year) respectively

	Primary energy [kWh/(m² y)]			Percentage of sharing	
	No RES	PV (3 kW)	PV (6 kW)	PV (3 kW)	PV (6 kW)
Stock	346	259	172	25%	50%
Buildings '90ies	241	154	67	36%	72%
LEB	165	78	-9	53%	105%
PH	179	92	5	49%	97%

Final energy



Zooming in



Costs

Natural gas costs 0.08 €/kWht and electricity costs 0.22 €/kWhe.
The costs assume that 50% of electricity produced is self-consumed and 50% is sold, leading to an average value of 0.15 €/kWhe as cost value of the electricity produced with PVs

	Overall costs		
	Without PV	**With 3 kW PV**	**With 6 kW PV**
Stock	**2,790 €**	**2,250 €**	**1,710 €**
Buildings '90ies	**1,990 €**	**1,450 €**	**910 €**
LEB	**1,500 €**	**960 €**	**420 €**
PH	**1,630 €**	**1,090 €**	**550 €**

Lessons learnt from Passive houses

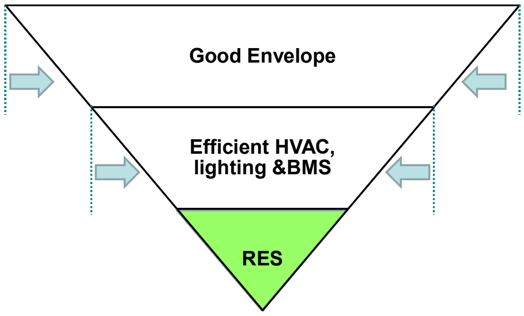
Despite the limits of the initial concepts of the Passive house, there are some positive points:

1. It has been demonstrated that we had to go towards low U-values
2. We can allow the HVAC not to fully cover 100% of the time the comfort
3. It is important to work first of all on the envelope

Criteria for improving the energy efficiency of a building

1. Increase the thermal insulation of the building and limit the unnecessary air infiltrations
2. Control of solar heat gains
3. Increase the efficiency of HVAC (including auxiliaries) and electrical plants (lighting & BMS)

Hierarchy of solutions



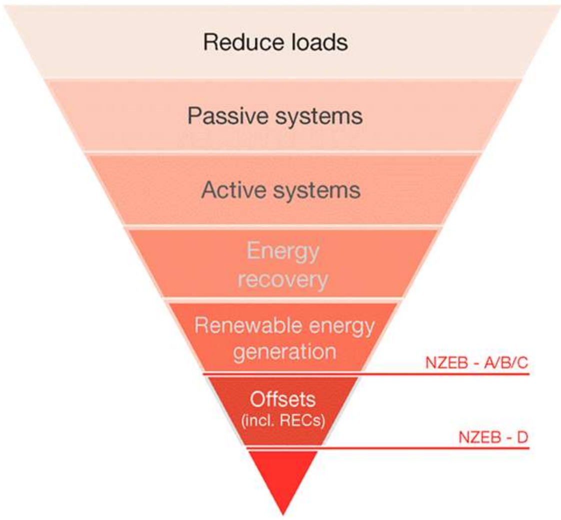
What is a Net Zero Energy Building (ZEB) ?

- Simplest definition:
  - Over a year, use zero net energy
- More complicated (but all based on one year):

Definitions	Descriptions
Net zero **site** energy building	Building produces as much energy as it consumes when measured on site
Net zero **source** energy building	Building produces the same amount of energy as the amount of source (primary) energy it consumes.
Net zero energy **cost**	Cost of the energy added to the grid by the building is same as the cost of the energy consumed by it.
Net zero **emission**	Net emission due to building energy consumption is zero.

P. Torcellini et al., Zero energy buildings: a critical look at the definition, www.nrel.gov/docs/fy06osti/39833.pdf

Net Zero Energy Buildings – Setting priorities

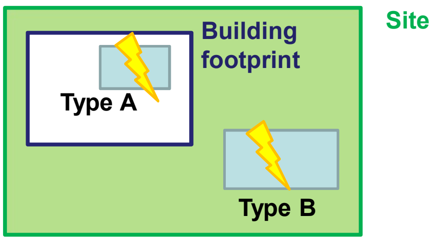


Source: Two Degrees, Chap 6, McGregor, Roberts & Cousins

How to reach a ZEB

Buildings Classified as NZEB:A
NZEB:A buildings generate and use energy through a combination of energy efficiency and RE collected within the building footprint.

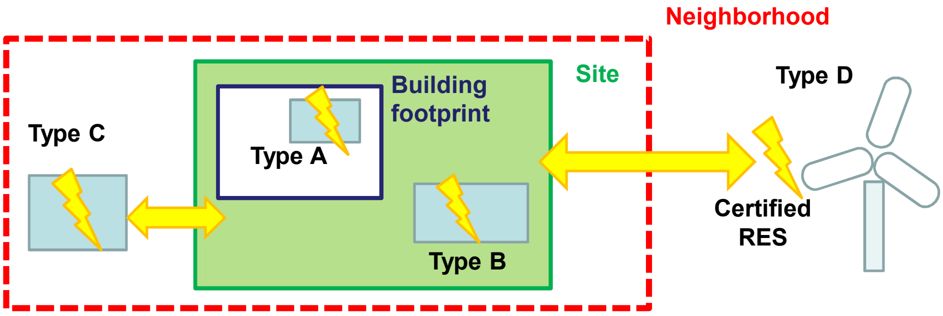
Buildings Classified as NZEB:B
NZEB:B buildings generate and use energy through a combination of energy efficiency, RE generated within the footprint, and RE generated within the site.



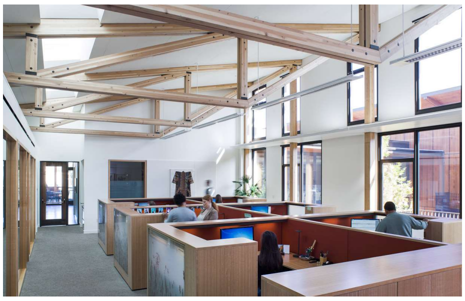
The energy Pyramid aas a guiding principal in the move to net zero, Michael Barancevwicz and John Lord

Buildings Classified as NZEB:C
NZEB:C buildings use the RE strategies as described for NZEB:A and/or NZEB:B buildings to the maximum extent feasible.
These buildings also use Option 3, off-site renewable resources that are brought on site to produce energy.

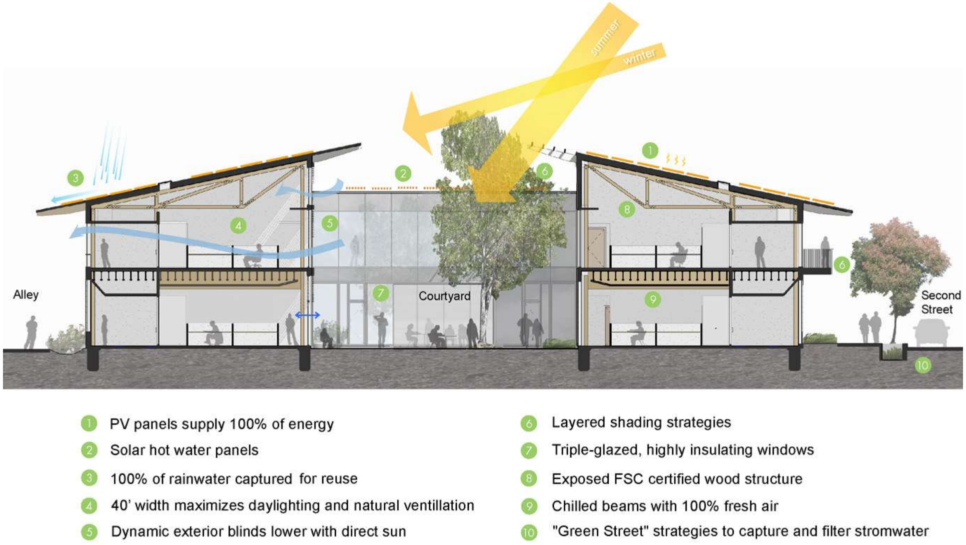
Buildings Classified as NZEB:D
NZEB:D buildings use the energy strategies as described for NZEB:A, NZEB:B, and/or NZEB:C buildings. On-site renewable strategies are used to the maximum extent feasible.
These buildings also use Option 4, purchasing certified off-site RE such as utility-scale wind and RECs from certified sources.



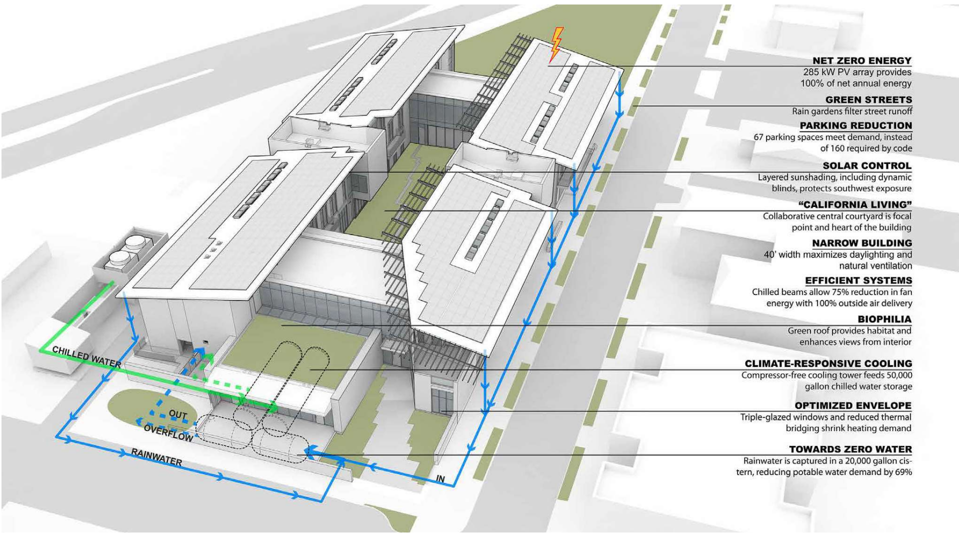
An example of ZEB



David and Lucile Packard Foundation HQ – EHDD

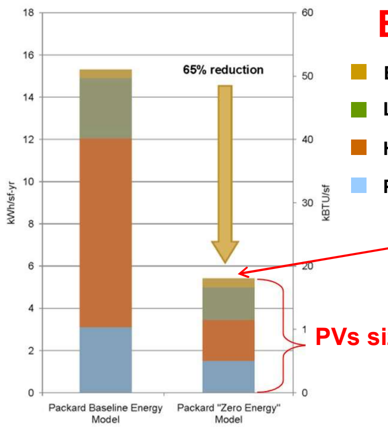


Source: Packard F



Source: Packard F

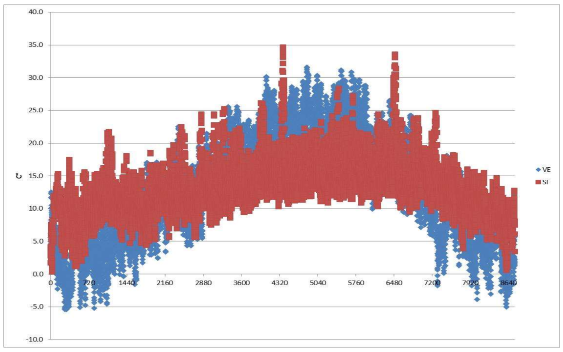
Estimated annual energy use



- Electric car charging stations
- Lighting
- HVAC
- Plug loads

Around 60 kWh/(m^2 year)

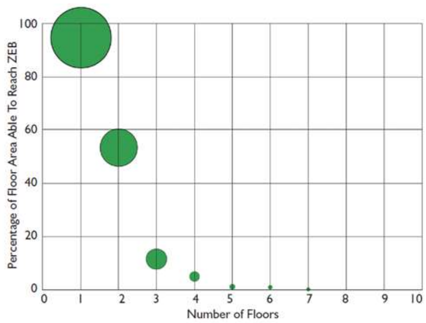
PVs sized to meet 100% of energy needs



But …

The climate in San Francisco is more favorable

Some considerations

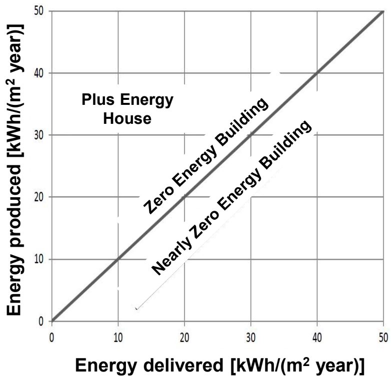


Torcellini et al 2006

- Increasing the height of the building lowers the probability to reach a ZEB
- More than 50% of ZEB are public buildings
- Usually a ZEB takes into account other sustainable issues (e.g. water)

- Plug loads play an important impact on the energy consumption
- Beauty imperative issue: Beauty + Spirit and Inspiration + Education
- The availability of solar radiation on site is imperative (roof area and shading from surrounding buildings)

Plus Energy Buildings



- It is a building that produces more energy than it consumes during one year
- A plus energy house has to optimize the final energy demand

- The key challenge for a PEH is to ensure the adequate synchronism of electricity between requests and supplies (maximize self-consumed energy)

Self-consumption: compares the self-used energy with the overall generation, i.e.

$$SC = \frac{E_{self\text{-}used}}{E_{generated}} \quad [\%]$$

Self-sufficiency: shared of self-used energy on the total need, i.e.

$$SS = \frac{E_{self\text{-}used}}{E_{demanded}} \quad [\%]$$

The first example of PEH 1/2

The German Federal Ministry of Transport, Building and Urban Developments has erected a model building to expand the new initiative «Efficiency House Plus» It was realized in Berlin at the end of 2011.

- Wall heat transfer 0.33 W/(m^2 K)
- A_f = 149 m^2
- Air/water heat pump with a thermal power of 5.8 kW, and storage tank
- Mechanical ventilation with heat recovery
- Photovoltaic array, 22 kW
- Lithium battery with capacity of 40 kWh
- Building management system

The first example of PEH 2/2

What was supposed to happen:

- The annual generation from the PV system should be 16625kWh
- The annual whole energy demand (electricity for the house and for electro-mobility) should be 15380kWh

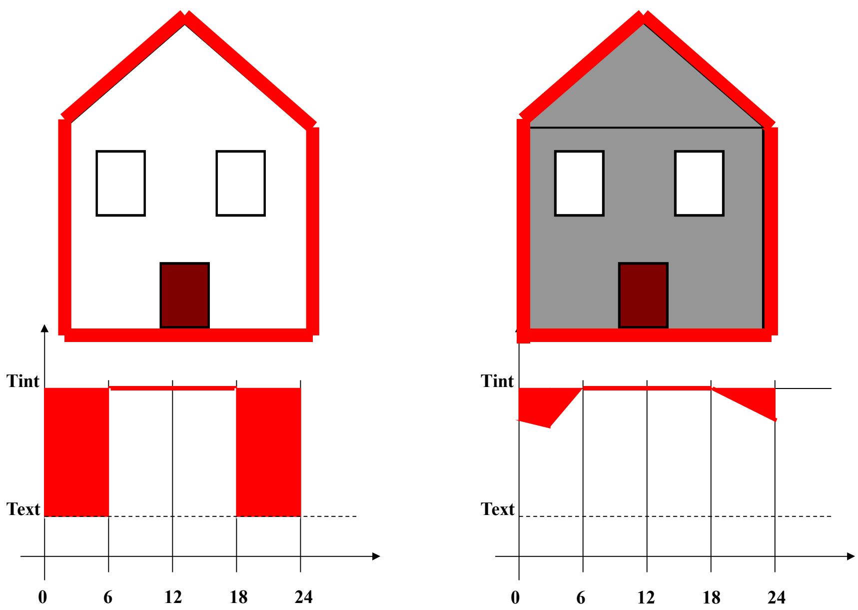
What happened:

- The first year of operation resulted in 13306 kWh produced by the PV
- 6555 kWh self-consumed
- House energy consumption was 12400 kWh (almost 7000 kWh more than predicted)

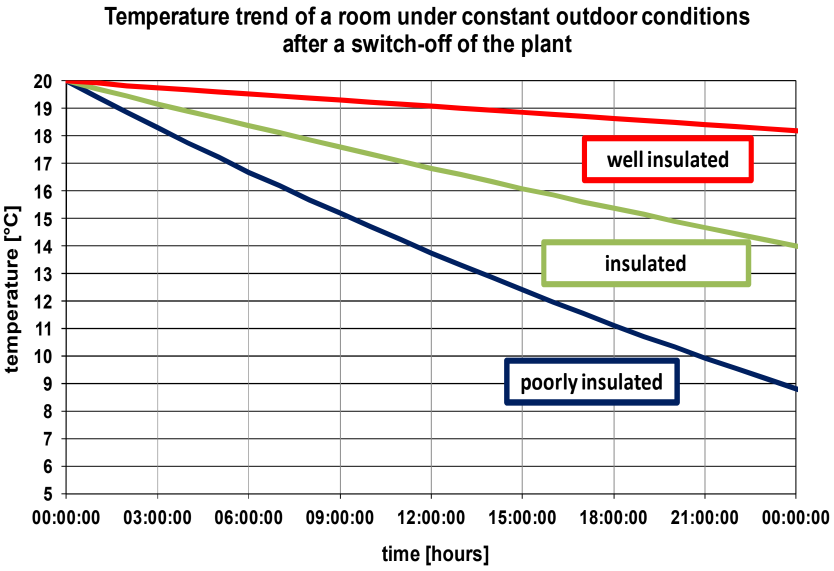
CLICHÉ ON BUILDINGS

1. If you want to save energy the system has to run less time
2. In Mediterranean climates the mass of the building is important to limit the cooling demand
3. In cold climates the buildings consume more than in mild/warm climates
4. In buildings the windows have to be installed South, maximizing the surface while in the other orientations the windows have to be small
5. In well insulated buildings the heating/cooling system needs to present with low thermal intertia
6. And so on ……

CLICHÉ 1: INTERMITTENT OPERATION

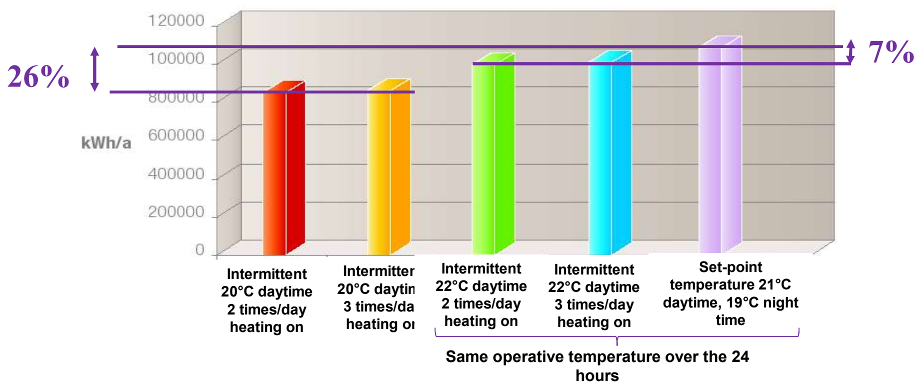


Decay of temperature of a room



Cliché 1: If you want to save energy the system has to run less time

Answer 1: In old buildings this could happen: usually the difference in a residential building without insulation is about 26% if we consider the different operation before and after retrofit. But the comfort previously was not as high as afterwards. Maintaining the same comfort the difference is 7%.



Answer 2: In new buildings the difference is negligible (< 2%)

CLICHÉ 2: IN MEDITERANEAN CLIMATES THE MASS OF THE BUILDING IS IMPORTANT TO LIMIT THE COOLING DEMAND

There are today mainly these different types of constructions:

Traditional masonry construction

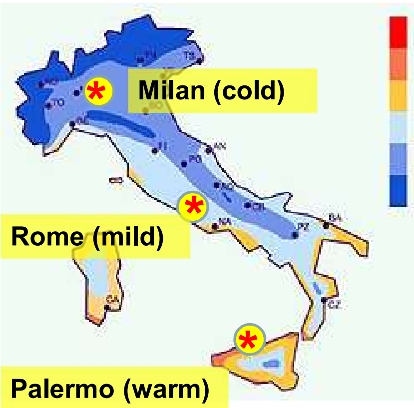
Concrete

Mixed concrete & bricks

Balloon Frame

Metal Frame

Wooden CLT



Zone A < 600 DDH
Zone B < 900 DDH
Zone C < 1400 DDH
Zone D < 2100 DDH
Zone E < 3000 DDH
Zone F > 3000 DDH

P. Cesaratto, M. De Carli
Analisi delle prestazioni dinamiche del sistema edificio-impianto
ENEA report. 2010

Case study: residential building well insulated in three locations:

- Milan (U-value 0.27 W m^{-2} K^{-1}),
- Rome (U-value 0.29 W m^{-2} K^{-1}),
- Palermo (U-value 0.34 W m^{-2} K^{-1})

Two structures: one massive (traditional) and one light building (CLT)
Same U-value of the envelope in each location

Cases investigated (net energy demand):

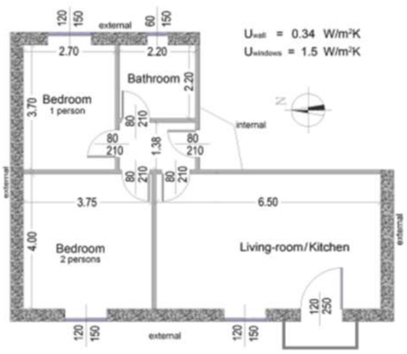
		Net energy demand for heating [kWh/m²]	Sensible & latent net energy demand for cooling [kWh/m²]			DHW [kWh/m²]	Overall [kWh/m²]
		Q_{heat}	Q_{Sens}	Q_{Lat}	$Q_{tot.\ cool}$	$Q_{h,w}$	Q_{total}
Milan	Massive	**52**	10	5	**15**	17	**84**
	Light	**50**	9	7	**16**	17	**83**
Rome	Massive	**20**	20	15	**35**	17	**72**
	Light	**19**	18	15	**33**	17	**69**
Palermo	Massive	**8**	33	19	**52**	17	**77**
	Light	**7**	29	20	**49**	17	**73**

Same specific energy need in the same climate. The thermal capacity of the building envelope does not affect the energy need which depends on the climate.

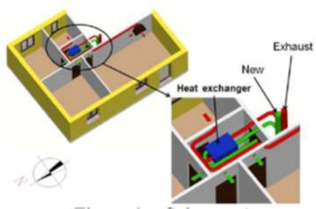
Answer In a well insulated building the capacity of the structure is not relevant

Additional question: how much does the latent load affect the energy required?

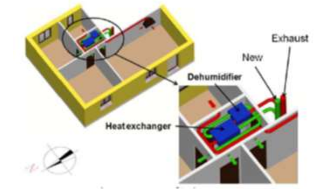
Apartment (well insulated) with radiant ceiling for heating & cooling and mechanical vebtilation with heat recovery



Case A: no dehumidification

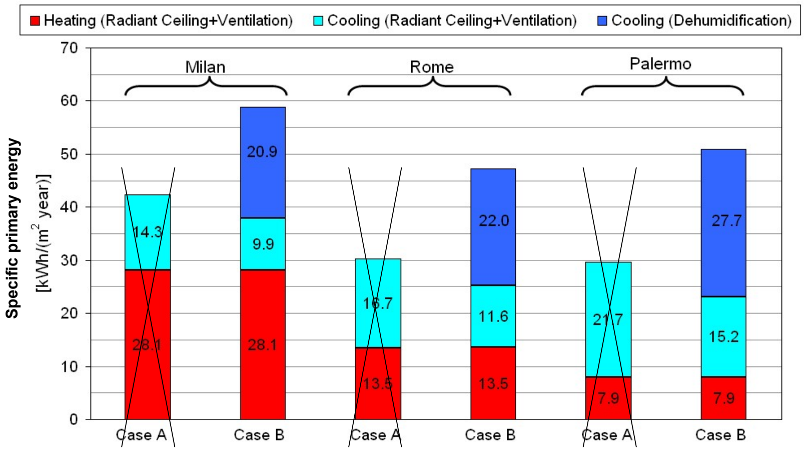


Case B: with dehumidification



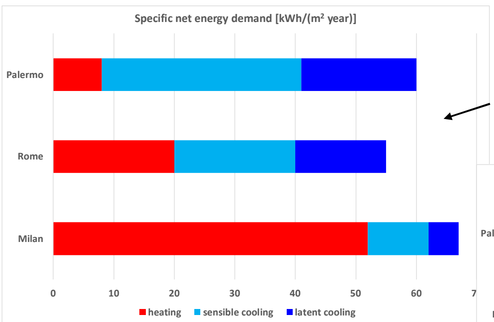
Case A: no dehumidification. Less energy need but no comfort in cooling season (dehumidification is needed in Italy)

Case B: with dehumidification of the supply air of the mechanical ventilation unit. More energy, but comfort is fulfilled.

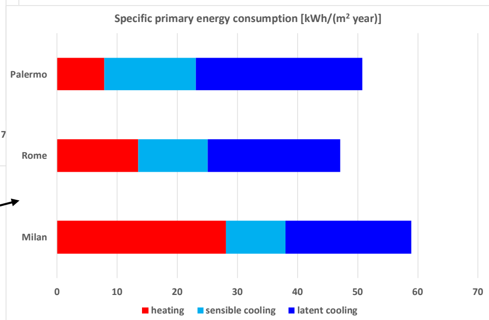


Answer: the latent load is important in Italian climate. In terms of primary energy as much important as sensible load.

CLICHÉ 3: IN COLD CLIMATES THE BUILDINGS CONSUME MORE THAN IN MILD/WARM CLIMATES



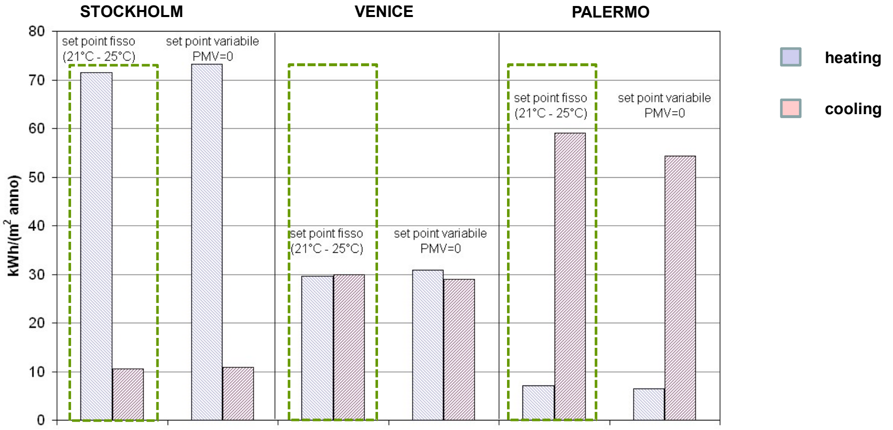
Example on the effect of the thermal inertia. The results show similar overall net energy demands in the 3 climates.



Example on the radiant ceiling coupled with dehumidified mechanical ventilation. The results show similar overall primary energy coinsumptions in the 3 climates.

Answer: In residential buildings the overall amount of energy is almost the same in all climates both as net energy demand and as primary energy.

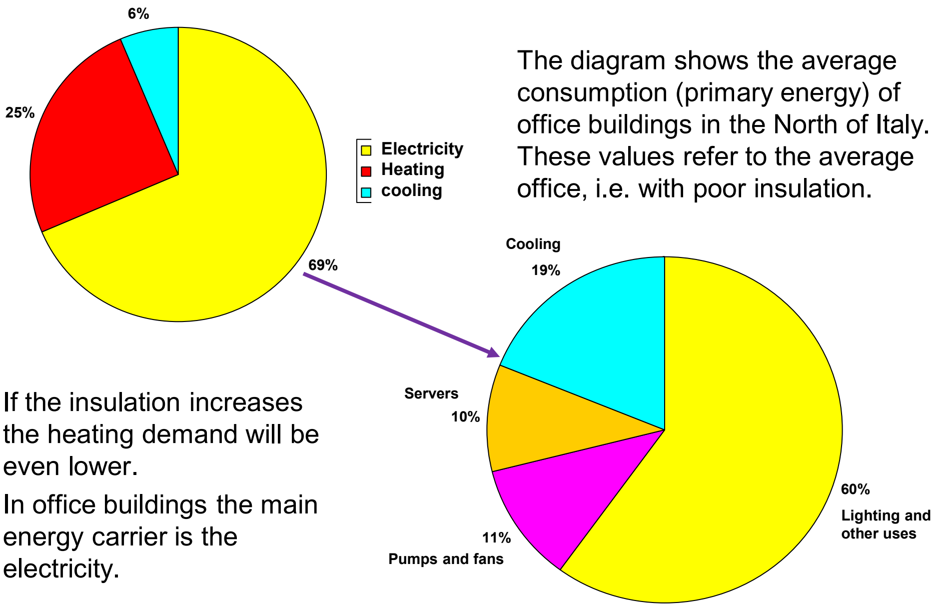
Additional question: and in office buildings? Do we consume more in cold climates?



Building with glazed areas West and East oriented. Left bars are with fixed set-point. Right bars are with variable set-point as a function of comfort conditions.

Answer: In office buildings the overall amount of energy is almost the same in all climates as net energy demand.

Some considerations about office buildings: primary energy consumption as average



The diagram shows the average consumption (primary energy) of office buildings in the North of Italy. These values refer to the average office, i.e. with poor insulation.

If the insulation increases the heating demand will be even lower.

In office buildings the main energy carrier is the electricity.

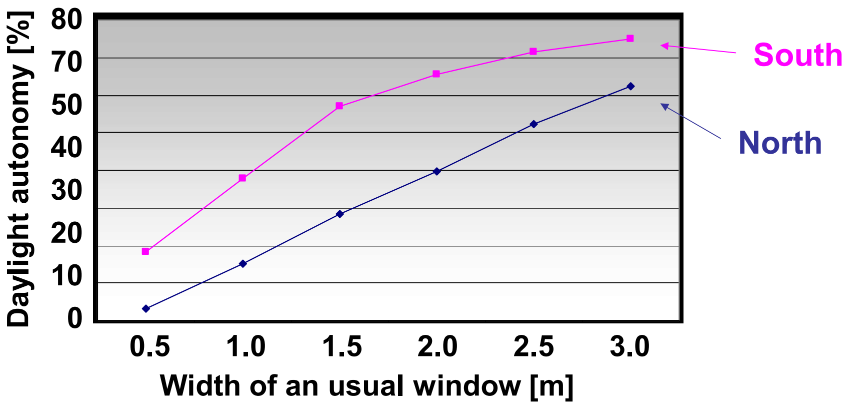
CLICHÉ 4: IN BUILDINGS THE WINDOWS HAVE TO BE INSTALLED SOUTH, MAXIMIZING THE SURFACE WHILE IN THE OTHER ORIENTATIONS THE WINDOWS HAVE TO BE SMALL

In the past the buildings in mild/cold climates were built with a wide windows surface South and small window in the other orientations. This was due to the single glass windows which caused high losses. Hence in the past, maximizing the South window surface allowed to have the maximum incoming solar radiation as heat gain to counterbalance the losses.

The problems today are different. People live inside a building (they work, they study, etc.). Windows are better insulated and the loss is 1/3 to 1/6 than before the ‘70ies.

Windows allow entering the light. It is not only a question of heating demand but also of lighting demand.

Daylight autonomy: percentage of time when the illuminance level in the centre of the room is greater than 500 lx between 6 am and 6 pm.

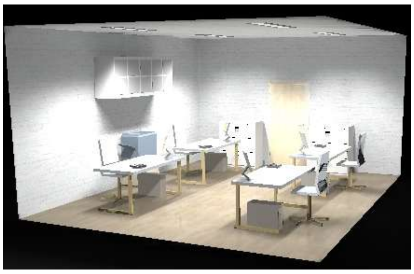


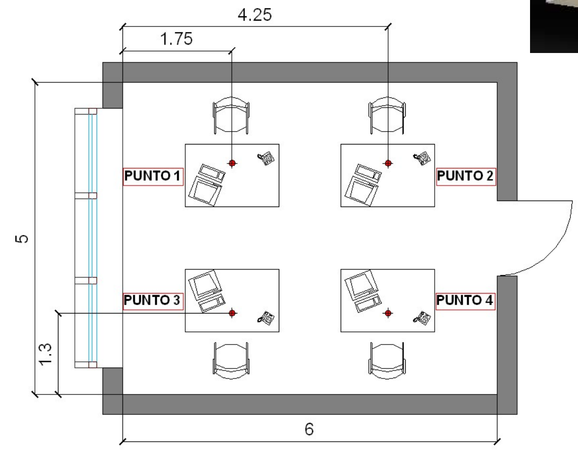
A multi-parameter analysis should be done in order to check the optimal solution.

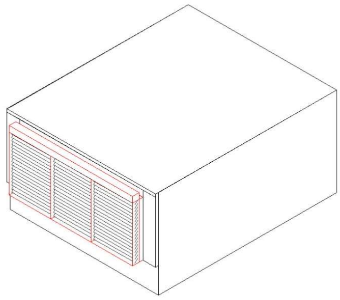
Moreover numerous case studies of wide glazed surfaces South oriented lead to overheating problems in summer period. Hence energy saving in winter has been counterbalanced either by discomfort in summer or in high consumption in cooling

Additional example for cliché 4

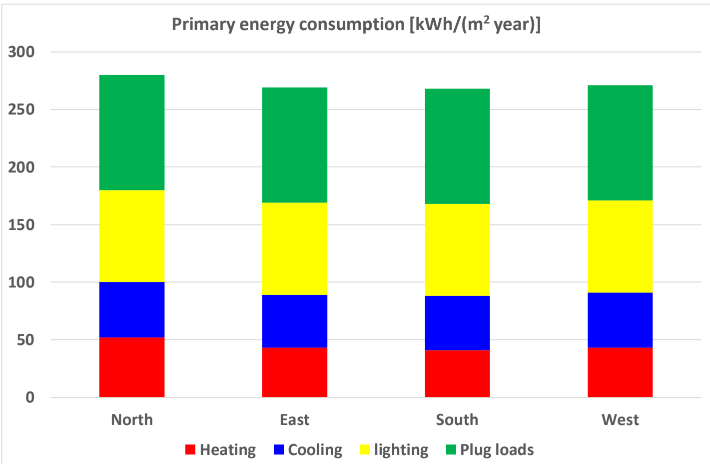
Building in Venice.
Floor area: 30 m²
4 people and 4 pc
One wall facing outside
Rotation of the building towards East, South, West and South







The energy consumptions are very similar, in type of energy requested by the building.
Heating is very similar, as well as cooling.
Ewlectricity for lighting is similar to the sum of heating & cooling.
Plug loads present the same energy consumption of the lighting.
Lighting in this case is not optimized as energy consumption.



Answer:

In new buildings it is not necessary to design and install large windows South, but it is recommended to try to use windows in all the orientations, in order to have enough natural lighting in the building (lighting autonomy).

The low U-values of windows today allow to install the windows in any orientation.

Attention has to be paid on the shading system to avoid glare and overheating.

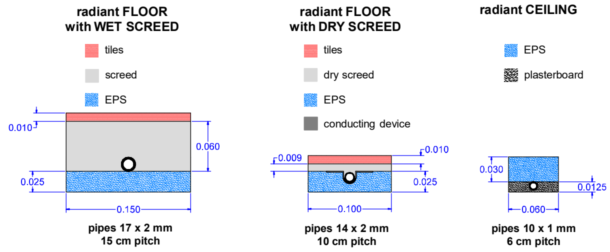
CLICHÉ 5 IN WELL INSULATED BUILDINGS THE HEATING/COOLING SYSTEM NEEDS TO PRESENT WITH LOW THERMAL INTERTIA

Flat on a middle floor of a building:

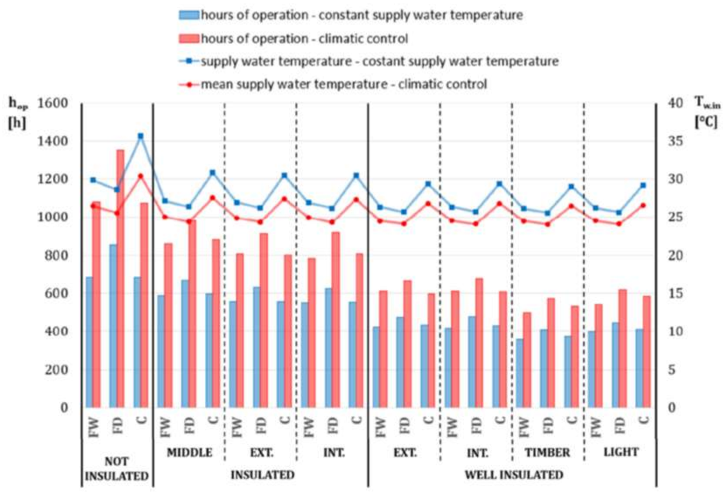
8 types of building structures:

- not insulated
- insulated - in the middle
- insulated - on the external surface
- insulated - on the inner surface
- well insulated - on the external surface
- well insulated - on the inner surface
- well insulated - cross laminated timber
- well insulated - light structure

	U [W m^{-2} K^{-1}]				
	ext. wall	int. wall	floor	roof	window
NI	**1.33**	2.07	1.45	1.81	**3.0**
IM	**0.57**	2.07	0.95	0.55	**1.5**
IE	**0.48**				
II	**0.47**				
WIE	**0.22**	2.07	0.72	0.25	**1.5**
WII	**0.22**				
WIX	**0.15**	0.38	0.20	0.14	**1.5**
WIL	**0.19**				

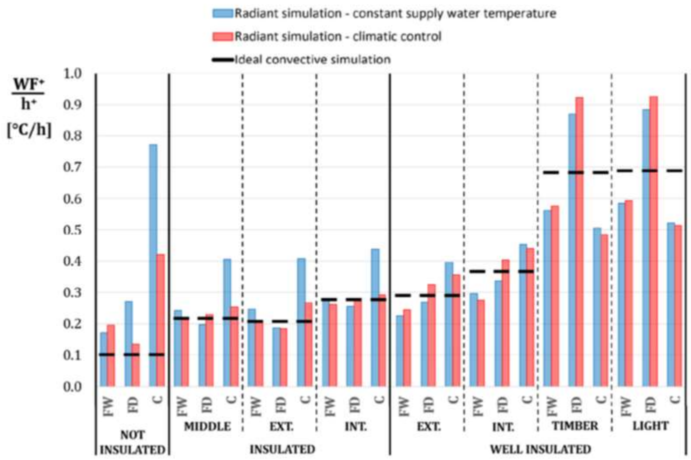


Water temperature supply and operation of the system



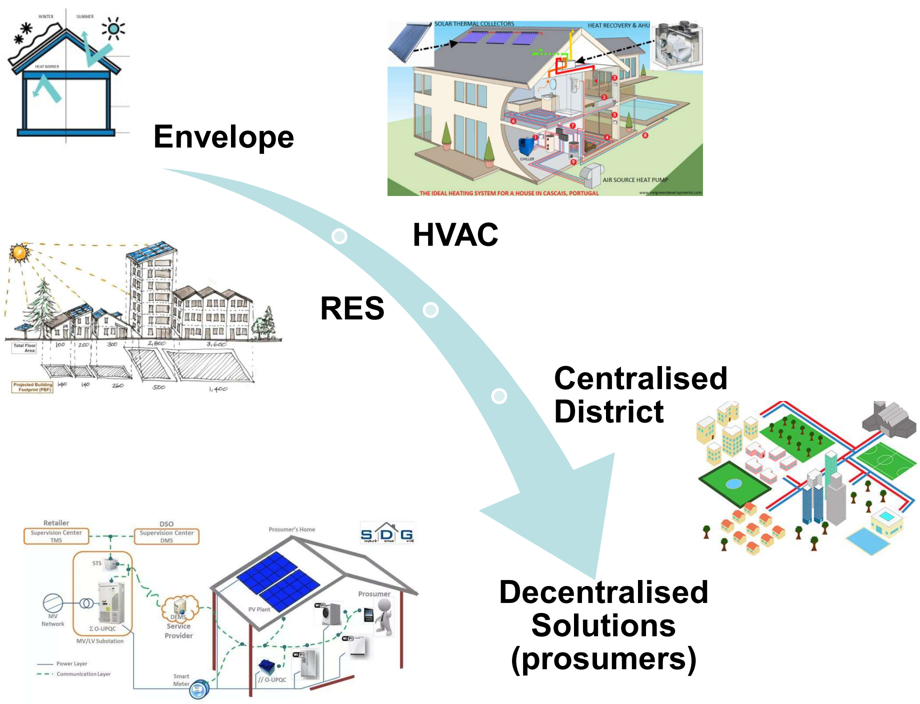
Answer: In new low energy/zero energy buildings you can choose any kind of radiant system. Running the system with a variable water temperature (supply temperature decrease when outside temperature increase) has a beneficial effect on the overall performance although the running hours (pumping energy costs) are higher

Intensity of discomfort during the heating period



Answer: In new low energy/zero energy buildings it is not necessary to design and install low thermal inertia systems which may be more responsive. The overheating occurs because of the insulation of the building in any case (dot lines) even with an ideal convective system. The effect of a radiant system is negligible in the overheating, which is caused by good insulation and solar gains

SOME EXAMPLES OF BUILDINGS AND HVAC SYSTEMS. WHERE ARE BUILDINGS GOING?

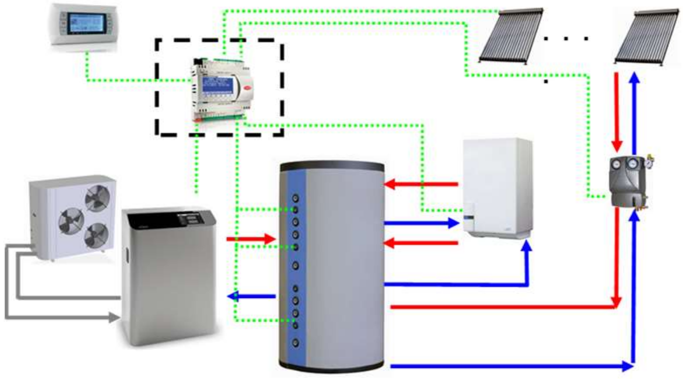


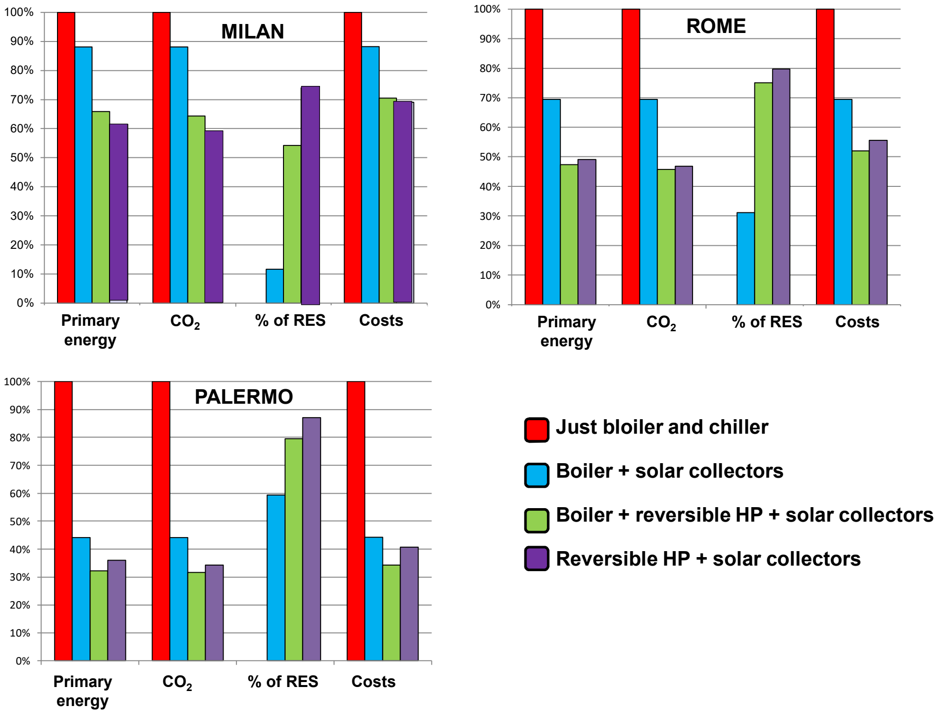
First examples of combined system

Detached house in 3 climates: Milan, Rome and Palermo

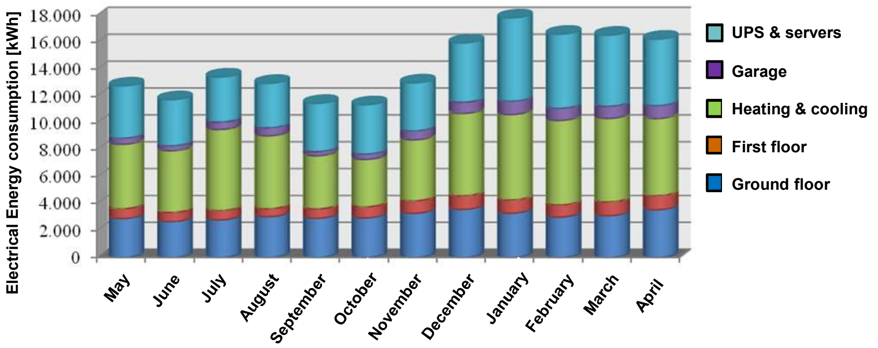
Four cases:

1. Just bloiler and chiller
2. Boiler + solar collectors
3. Boiler + reversible HP + solar collectors
4. Reversible HP + solar collectors

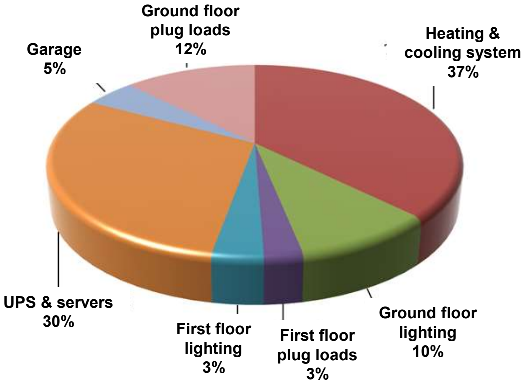


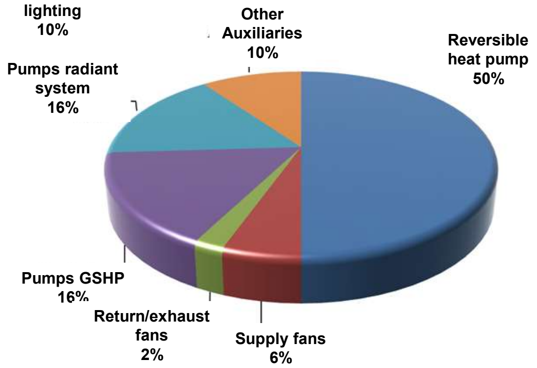


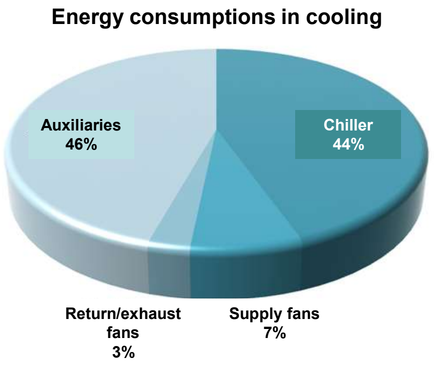
A retrofitted office building in Mestre (Venice)

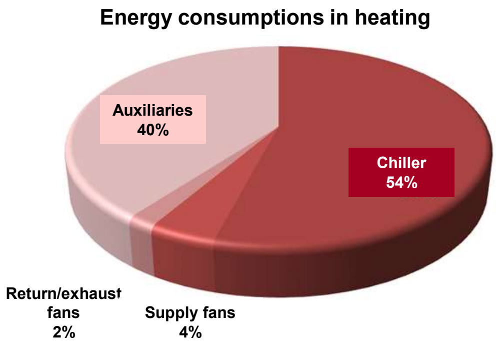


	Ground floor	First Floor	HVAC	Garage	UPS	TOTAL
Overall yearly final energy [kWh]	37.108	10.150	63.589	7.907	51.190	169.944
Specific yearly final energy [kWh/m²]	17,2	4,7	29,4	3,7	23,7	78,7
Specific yearly final energy [kWh/m³]	6,1	1,7	10,5	1,3	8,4	28,0
Sharing	**22%**	**6%**	**37%**	**5%**	**30%**	**100%**









Ex Geriatrico (University of Padua)

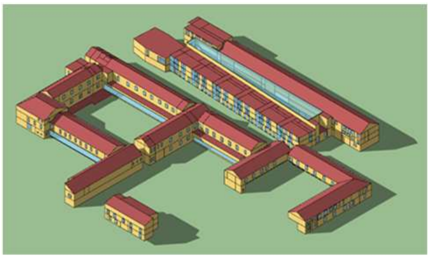
Historical complex mainly of the late 1800, with a deep retrofit process in order to build the new humanistic pole of the University of Padua
Location: Padova (Italy)
Volume: 104672 m^3
Surface: 16667 m^2

- about 4300 m^2 of space for libraries,
- 2300 m^2 for new lecture rooms
- 3800 m^2 for offices.

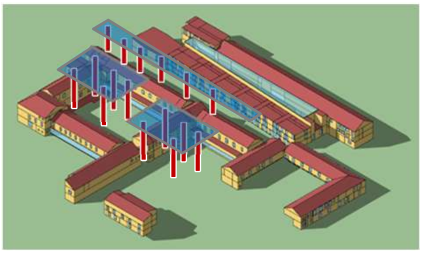
New thermal transmittance 0.25 W/(m^2K).
The thermal transmittance of glazing surfaces:

- 1.4 W/(m^2 K) with a solar factor of 0.36
- 1.5 W/(m^2 K) with a solar factor of 0.42.

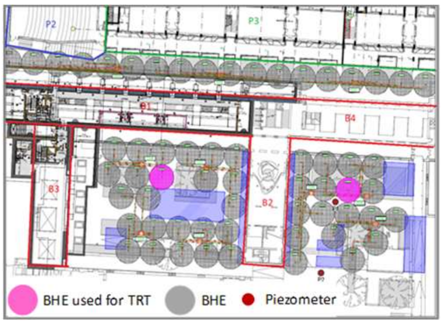
The glass roof of the new glazed corridor has a thermal transmittance of 0.5 W/(m^2 K) with a solar factor of 0.18.

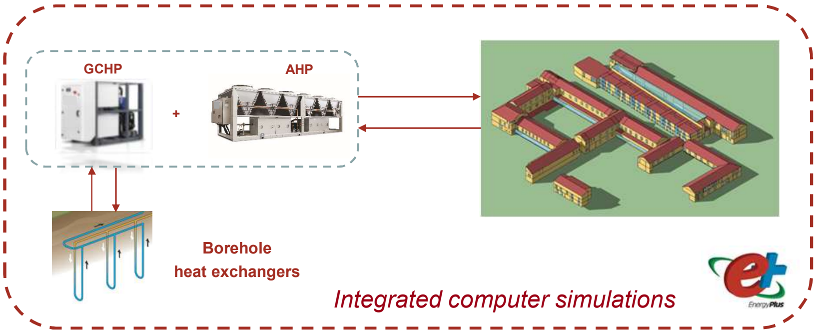


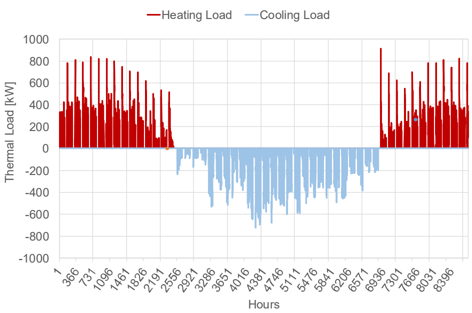
Fan-coils, Radiant floor, Air Handling Units
Two air-to-water heat pumps, each one with thermal capacity of 447 kW in cooling and 318 kW in heating.
Two GCHP heat pumps each one with thermal capacity of 168 kW in cooling and 192 kW in heating respectively.

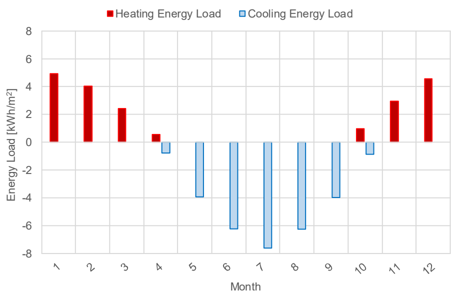


- Borehole type: 2 U-shaped tube (32-26 mm)
- Borehole depth: 120 m
- Ground thermal conductivity: 1.62 W/(m K)
- Specific ground thermal capacity: 2.5 MJ/(m^{3}K)
- Undisturbed ground temperature: 17.5°C
- Number of borehole heat exchangers: 60









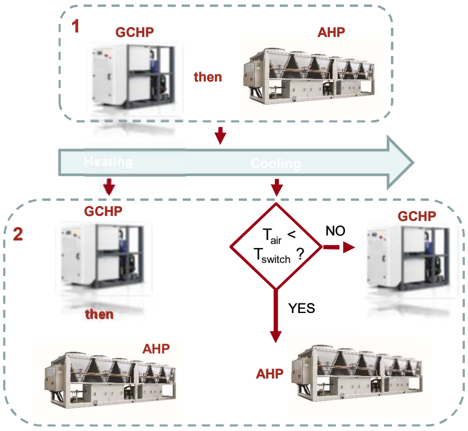
Control strategy:

1. The first one maximizes the operation of the GCHP to exploit its higher nominal energy efficiency compared to that of the air-to-water heat pump:

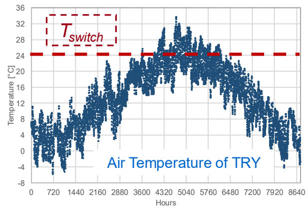
   ➢GCHP starts, if it is not sufficient, air-to-water heat pumps are switched on

2. The second one controls the thermal drift of the ground temperature over the years.

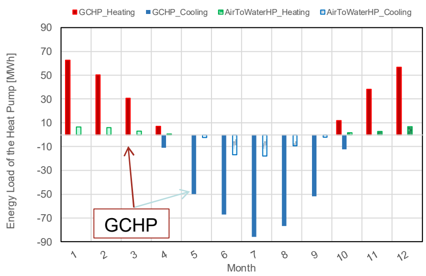
   ➢In heating mode, the control maximizes GCHPs operation,
   ➢In cooling mode, GCHPs start only when the external air temperature exceeds the switch temperature



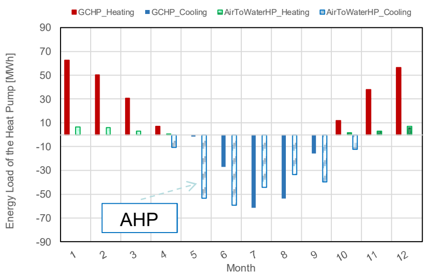
Using an iterative procedure, making use of computer simulations and the load profile of this building, the switch temperature resulted equal to 24°C



GCHP priority

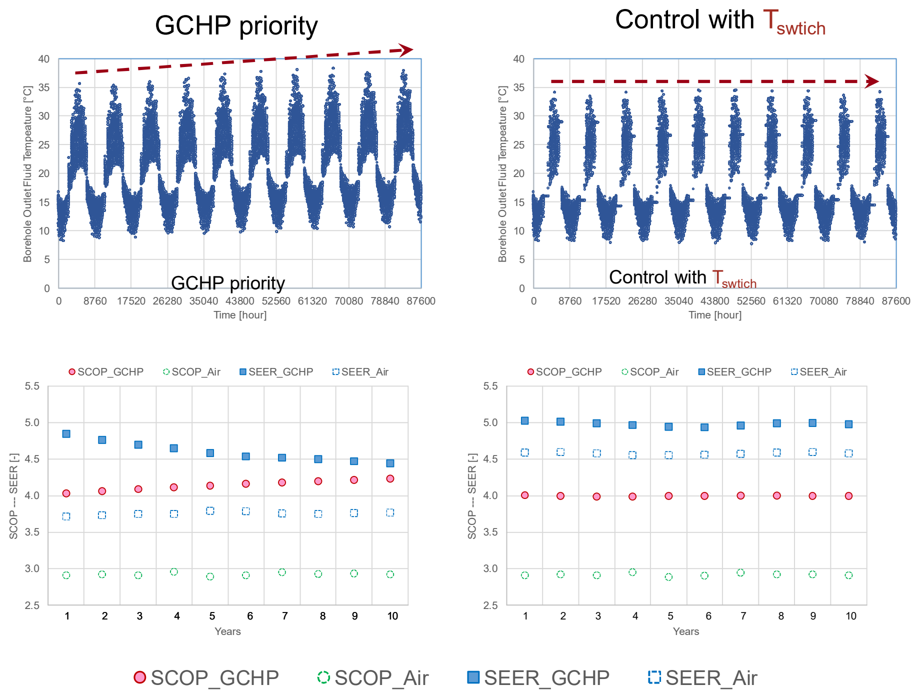


Control with T_{swtich}



GCHP:
427 MWh into the ground in cooling
193 MWh from the ground in heating

GCHP:
190 MWh into the ground in cooling
192 MWh from the ground in heating



The hospital in Monselice

Energy	Amount [toe/year]	
	Standard	With PV, GHSHP & cogenetarion
Natural gas for the boiler	2.432	312
Natural gas for cogeneration	0	2.342
Electrical energy from the grid	2.327	689
Electrical energy sold	0	- 57
Total	**4.759**	**3.286**

-31%