Retrofitting an existing heating system with a heat pump.

Gert Nielsen
Managing Geek
Xrgy AS
gert.nielsen@xrgy.no

What are we looking at today

- We will be looking at retrofitting an older building, designed according to the Norwegian BF1987[1], but located in London, with a heat pump system.
- Year of build 1990. (Make believe)
- We will look into what data you will have to gather, how to acquire these data.

BF = Byggeforskrift = Building Code

What are we looking at today

- Cosmetic changes on the inside might occur.
- Carpets will be replaced with laminate. (Much better for indoor climate)
- If at all possible the pipework for radiators, heating and cooling coils will be kept.
- New air handling units will be installed. At an age of 30+ years their technical life has expired.

Most buildings have already been built.

- When retrofitting an existing building to accommodate a heat pump, you have to know / find out the following:
- Design conditions for the building
  - Design ambient temperature.
  - Design temperatures in the radiator system.
  - Design heat delivery from the radiator system.
  - Design temperatures in the ventilation heating system.
  - Design air flow for the ventilation heating system. Not necessarily the same as the total design air flow.
  - Recuperator efficiency.
  - Fan power demand in the AHUs, especially on the incoming air.

Most buildings have already been built.

- In short, all the design parameters that affect the thermal performance of the building, and hopefully taken into consideration originally.

- You would think this information is readily available from when the building was built.

HA!! Think again.

But first, a trip to Oslo

- A client needed to replace a run down chiller.
- 4 circuit R22 unit, 2 circuit didn't work.
- My colleague on site (a man with 50 years of experience) suggested a reversible unit.
- Supplying ventilation heat during winter.
- Why not use it to supply building heat as well?
- Problems or more PC :
- Challenges

Documentation

- The building owner is basically only interested in money.

- The level of documentation of the systems are fundamentally non-existent.
- Historical energy demands exist only as invoices in NOK.
- The old oil boiler had been converted to electrical heating. The boiler itself had not been replaced
- No overall control systems, unitary control of the individual subsystems.

Documentation

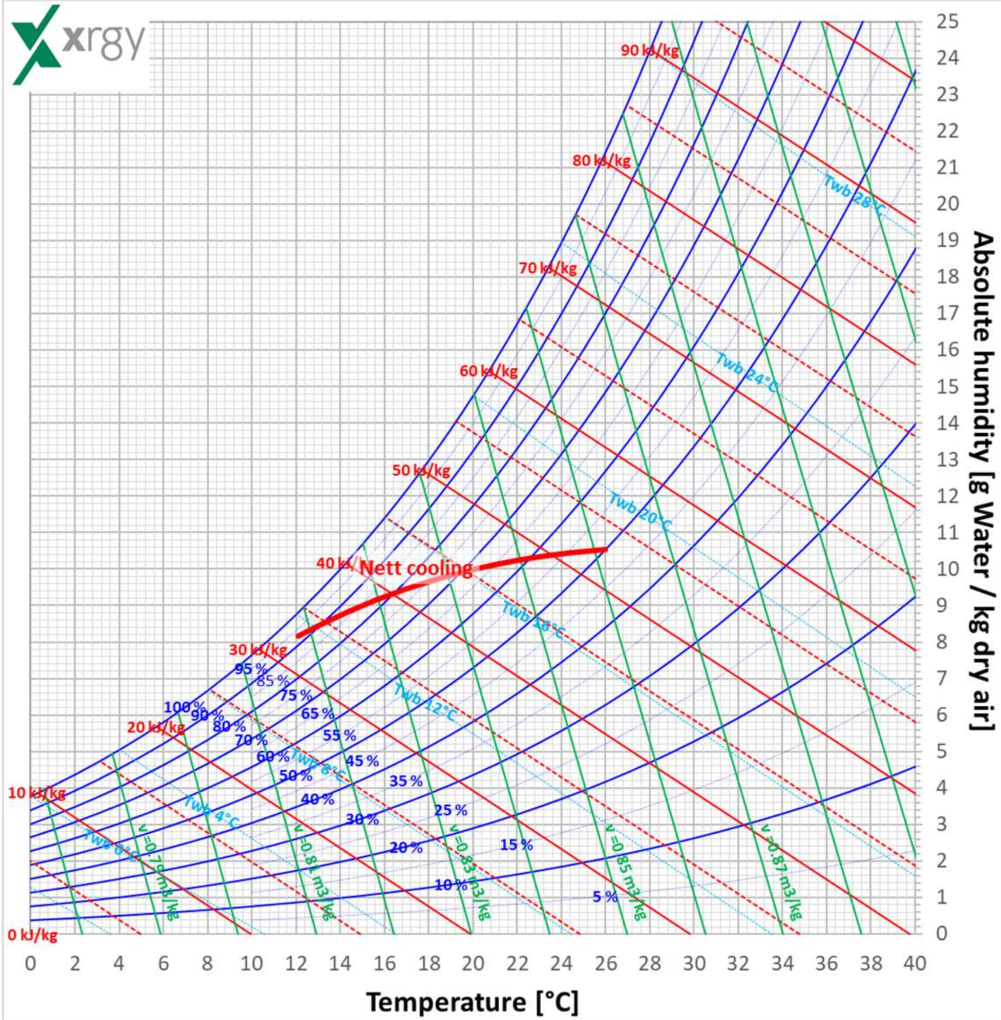
- The only documentation was a ventilation service report from 2012.
- Riddled with errors.
- The heating coil was not able to supply enough heat to reach set point temperature, so to electrical heating coils had been added in the duct system.
- The service contractor had missed this, and believed that the coil recuperator system was hugely efficient at 45%.
- Our combined experience of 80 years said "No effing way"
- Taking into account the total electrical coil performance, the efficiency ended up at 27% which fits our experience.

Documentation

- Summer Airflow supply 15 000 m^3/h Fan power 14 kW
- Winter Airflow supply 9 570 m3/h Fan power 3,6 kW
- The winter air flow and fan power is assessed from the model laws.
- Temperature rise from fan power
  - Summer 2,8K
  - Winter 0,7K
- Cold demand is design performance for the heat pump.
- The existing chiller was designed for 100 kW at 7°C/12°C.
- The inlet temperature should be app. 15°C to remove internal heat loads.

Cold demand

- Parasitical load from fan power is app. 23% of the cold demand.
- New requirements for fan power reduces the cold demand significantly



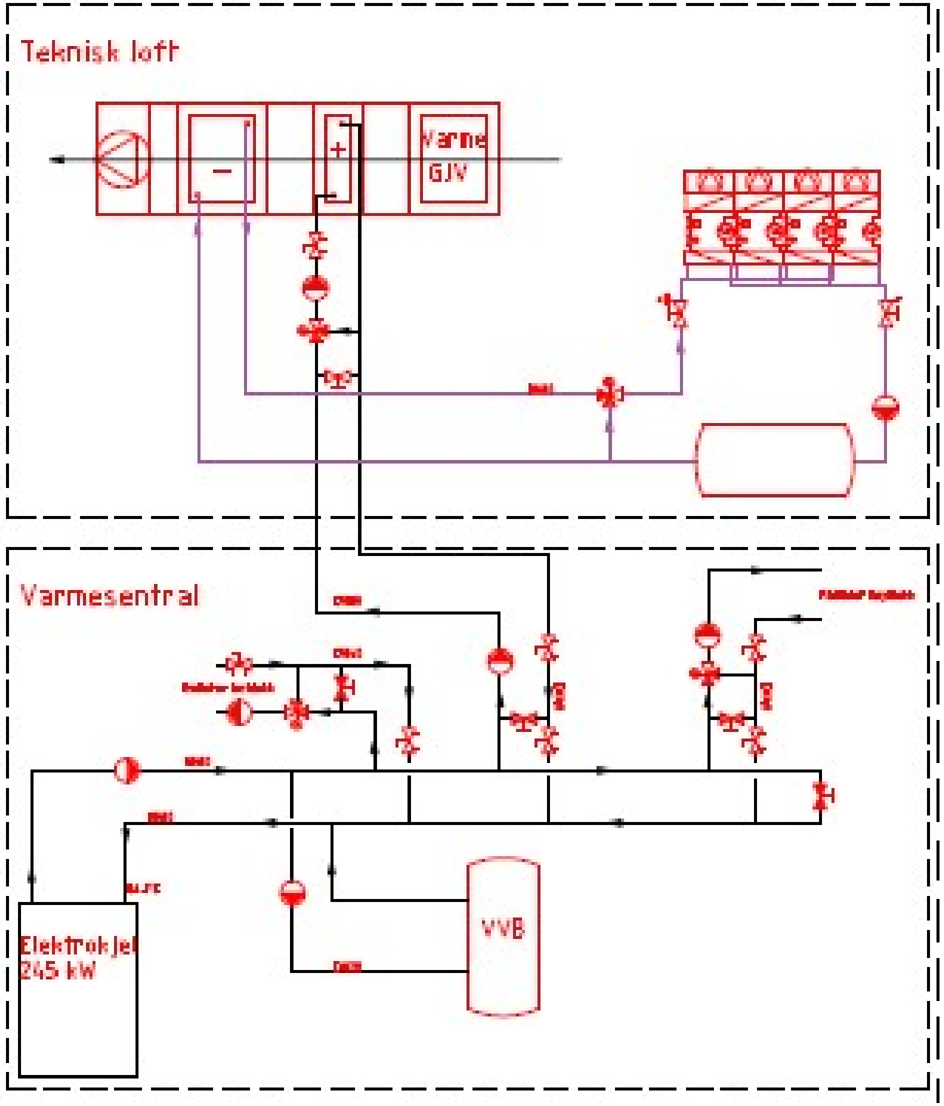
Heat demand

- All of these are assessments based on building area and experience.
- Heat demand building heating 105 kW
- Heat demand ventilation heating 100 kW

Structural issues

- Air handling unit and chiller are located on the roof
- Boiler and headers are located in the basement, 3 storeys below the roof.
- In the system as it is today, there is no connection between the chiller and the heating system.

Situation today



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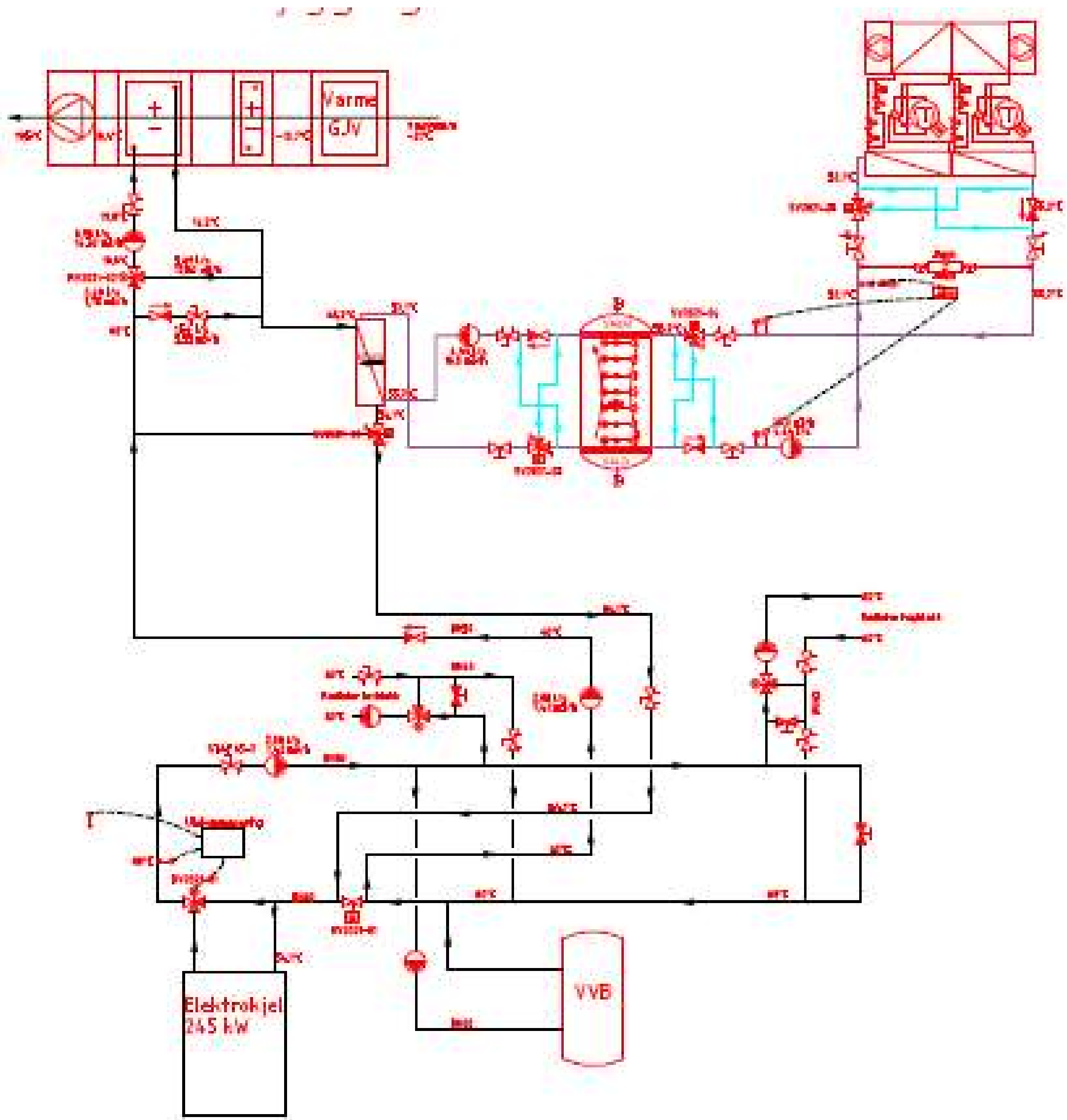
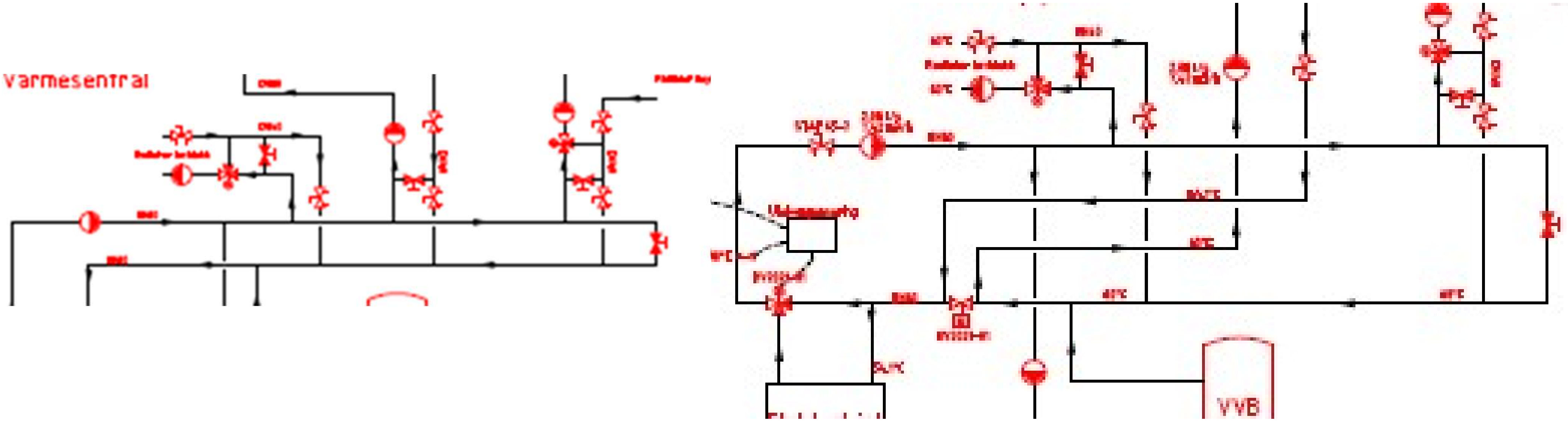
Seeing the Big Picture

New system



New system



Changes from today to planned system

- The cooling coil now works as a combicoil
- The header connection to ventilation heating is in series with the building heating strings.
- The heating system gets heat from the heat pump before being heated from the boiler.
- The controls are expanded to handle the entire building in a top system.

Basically we knew nothing

- This project is a very good example of why experience is important.

- We will know take a 10 minute break, and return to London.

Data acquisition

- Knowing what demands you need to cover NOW is crucial.
- Old Building Management Systems are usually only good at telling if someone has stolen the equipment.
- The following statement started as a provocation, but turns out to be largely true :
- "**The intelligence of the Building Management System will over time drop to reach the level of the building operators**"
- The fault here is largely management.
- Management will usually not give priority to keeping the operators educated and well trained

Typical organisational problems

- Buildings are usually managed by accountants.
- Goal is to maximise profits
- => reduce cost.
- Maintenance
- Avoid maintenance.
- Education of operators
- I am not going to pay for others getting better operators!!

Typical organisational problems

- Avoid education of operators.
- Result : Reduced quality over time.
- Result of that: Tenants leaving.
- To keep the building occupied and some money coming in =>
- Rent reduction => decrease in profits

- Downward spiral of cost cutting, quality reduction, reduced rent.

- And the poor sod in charge doesn’t understand what is going on.

Typical organisational problems

- What we must teach the building managers :
- Maintenance
- Good and proper maintenance maintains the quality of the building.
- Good and proper maintenance avoids downtime and repairs
- Repairs
- Good quality = higher rent.
- Education of operators
- Education of operators :
- Upward spiral of profitability and an easier job!
- Making more money while working less, and having more fun at work!!

Typical organisational problems

- Engineers and technicians have to learn to speak economy.
- We might have the ideas and the know-how.
- But it is the economy that decides if it will be done.

- Don't talk in kWh, kW or similar
- Talk in money and MAYBE in CO_2-equivalents.

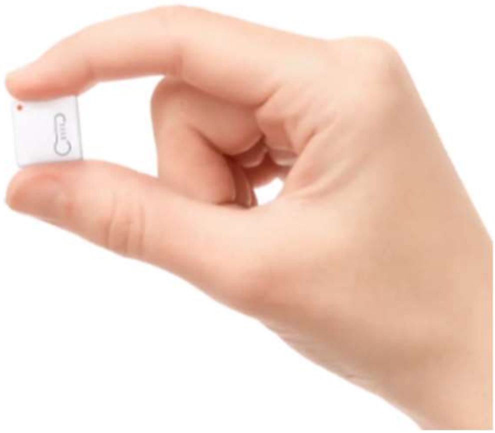
- But to convert kWhs and kWs into money, we have to establish some basics that we can work from

Data acquisition

- Typically
  - The points of measurement are too few.
  - The time steps of measurement logging are too long. Normally due to very limited memory capacity on the computers handling the BMS.
- At this time in the life of a building, especially before a major technical overhaul, installing new measurement equipment might be difficult.
- All is not lost...

Data acquisition

- Small Wi-Fi or Bluetooth temperature sensors can be placed everywhere.
- This picture was taken from the homepage of Disruptive Technologies (https://www.disruptive-technologies.com/)
- 19x19x2 mm
- Easily installed, even under insultation.



- What we need most is the energy leaving the machinery room.
- In old systems like this, it is usually constant flow headers. We therefore only need to know the ΔT.

Data acquisition

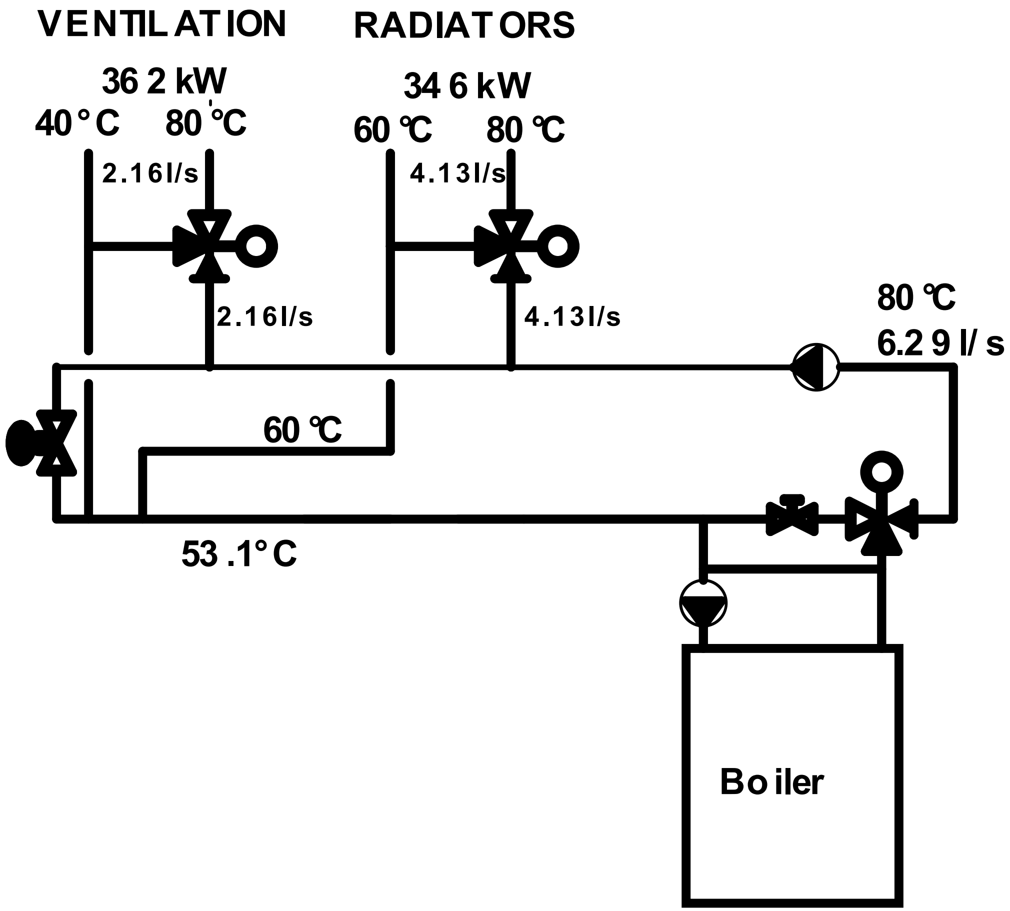
- We also need to know the design winter ventilation rate.
- In systems this old, there will typically only be 50% / 100% flow rates.
- But what is the design performance of the heating coils?
- In my experience they are designed for full flow, even though winter flow is half.
- From that, we end up with

Baseline assessment

Assesment of heat demand covering transmision and infiltration losses and ventilation heat demand at winter design ventilation rate											
Floor space	17 000	m2	**Minimum demands from building code**	BF1987		Maximum air leakage from building codes	4		Hygienic minimum ventilation rate, building	0	m3/h/m2
Occupance design	850		U floor	0.3	W/m2K				Hygienic minimum ventilation rate, people	21.6	m3/h/pers
			U window	2.4	W/m2K				Total hygienic minimum ventilation rate	1.08	m3/h/m2
T soil. Set to annual mean temperature	12	°C	U wall	0.3	W/m2K				Actual minimum ventilation rate (9.26)	10	m3/h/m2
T Indoor	22	°C	U roof	0.2	W/m2K	Air change due to infiltration	0.28	per hour	Efficiency recuperator in AHU. Highest.	60 %	
Design Ambient temperature	-4	°C	leakage number at 50 Pa	4	1/h				ΔT supply air / room temperature	2	K
			Recuperator efficiency	0 %					ΔT supply air from fan power	2.1	K
Length of the building	125	m							**Your recuperator efficiency demand**	60 %	
Width	17	m	**Transmision**			**Infiltration**			**Ventilation**		
Number of storeys	8	stk	U floor	0.3	W/m2K	Volume of the building	51 000	m3	Total air flow	170 000	m3/h
Storey hight	3	m	U window	2.4	W/m2K	Air change	0.280	per hour	Supply air temperature	20	C
Window share of building envelope	40 %		U wall	0.3	W/m2K	Air flow	14 280	m3/h			
			U roof	0.2	W/m2K				Supply air temperature after recuperator	11.6	C
Incline roof	12	°									
Roof width	17.38	m	Heat loss floor	6 375	W				Supply air temperature after heating coil	17.9	C
			Heat loss windows	170 127	W				ΔT heating coil	6.3	K
Area floor to ground (footprint)	2 125	m2	Heat loss walls	32 138	W						
Area building fasades	6 816	m2	Heat loss roof	11 297	W				Heat demand heating coil	362 355	W
Area windows	2 726	m2									
Wall area from gable/roof incline	30.7	m2	**Total transmision heat loss**	**219 938**	**W**	**Q infiltrasjon**	**125 616**	**W**	Heat demand from subtemperature suplly air	115 033	W
Area wall	4 120	m2									
Area roof	2 172	m2	**Q trans og inf.**	*345 554*	W						
									q trans&inf	20.3	W/m2
			Q tot, design building heating	**460 587**	W				q vent	28.1	W/m2
									q tot des	48.4	W/m2
			Q tot, design, heating system	**822 942**	W		822.9	kW			

Design demand = 708 kW when built

Basic system design



Design

What has happened from building until today?

- Since the building was erected usually some things have changed.
- Example:
- Windows to more energy efficient.
- Matching the demand from TEK07

Baseline ajustment

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Seeing the Big Picture

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			Heat loss windows	85 064	W				ΔT heating coil	6.3	K
Area floor to ground (footprint)	2 125	m2	Heat loss walls	32 138	W						
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Area wall	4 120	m2									
Area roof	2 172	m2	**Q trans og inf.**	*260 490*	**W**						
									q trans&inf	15.3	W/m2
			Q tot, design building heating	**375 524**	**W**				q vent	28.1	W/m2
									q tot des	43.4	W/m2
			Q tot, design, building heating system, includir	**737 879**	**W**		737.9	kW			

New demand = 623 kW with new windows

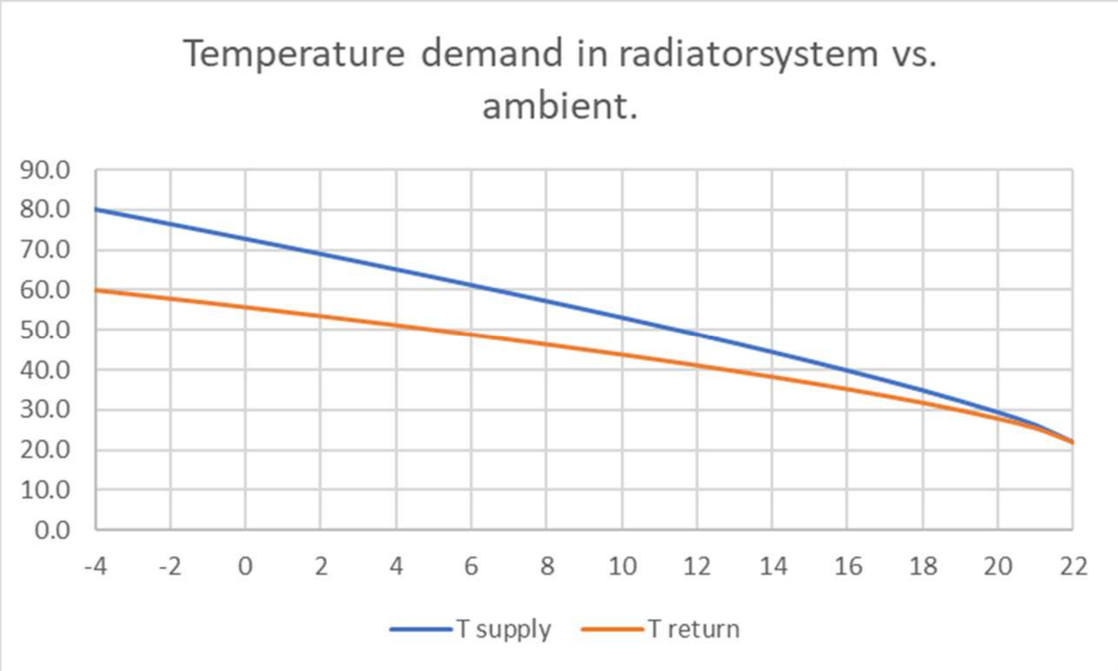
What has happened from building until today?

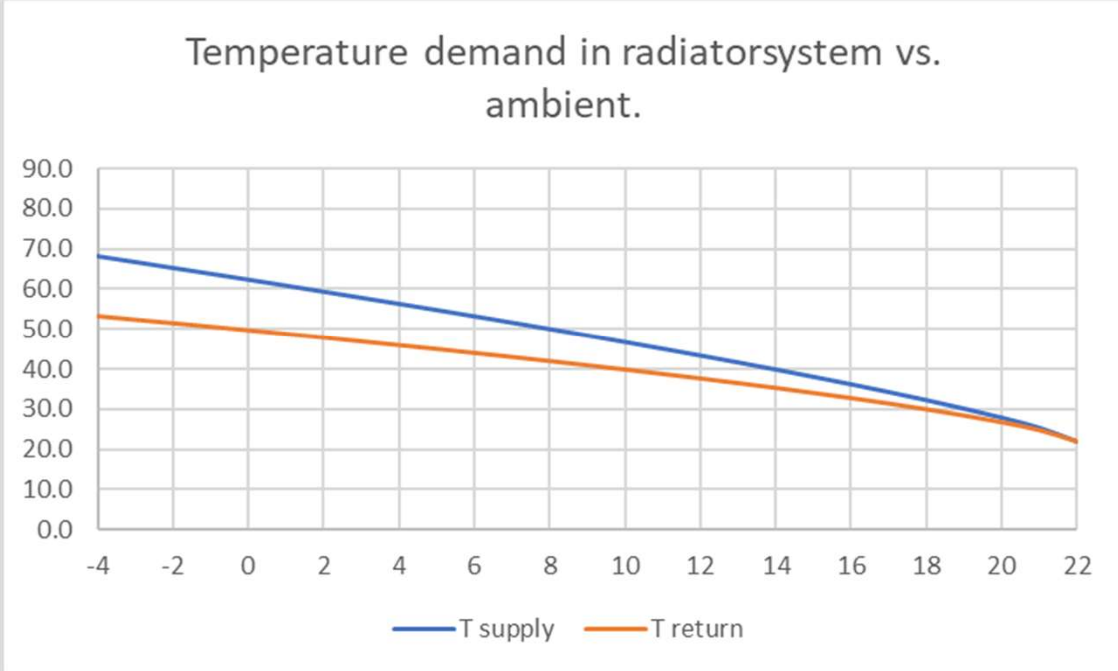
- Since the building was erected usually some things have changed.
- Windows to more energy efficient.
- Matching the demand from TEK07.
- The heat demand of the building envelope is reduced by 86 kW or 25%.
- What will that mean for the maximum supply temperature to the radiator system?
- 10 minutes.

New temperature demand radiators

- $\Delta T_{M,RAD,ACT} = (\frac{\dot{Q}_{RAD,ACT}}{\dot{Q}_{RAD,DES}})^{\frac{1}{1,3}} \times \Delta T_{M,RAD,DES}; \Delta T_{M,RAD} = \frac{T_{SUPPLY}+T_{RETU}}{2} - T_{ROO}$
- $\Delta T_{M,RAD,DES} = \frac{80+}{2} - 22 = 48K$
- $\Delta T_{M,RAD,ACT} = (\frac{260}{346})^{\frac{1}{1,3}} \times 48 = 38.6K \Rightarrow T_{M,RAD,ACT} = 38.6 + 22 = 60.6°C$
- $\Delta T_{RAD,ACT} = \left(\frac{260}{346}\right) \times 20 = 15.1K \Rightarrow$
- $T_{SUPPLY,RAD,ACT} = 60.6 + \frac{15.1}{2} = 68.2°C$
- $T_{RETURN,RAD,ACT} = 68.2 - 15.1 = 53.1°C$

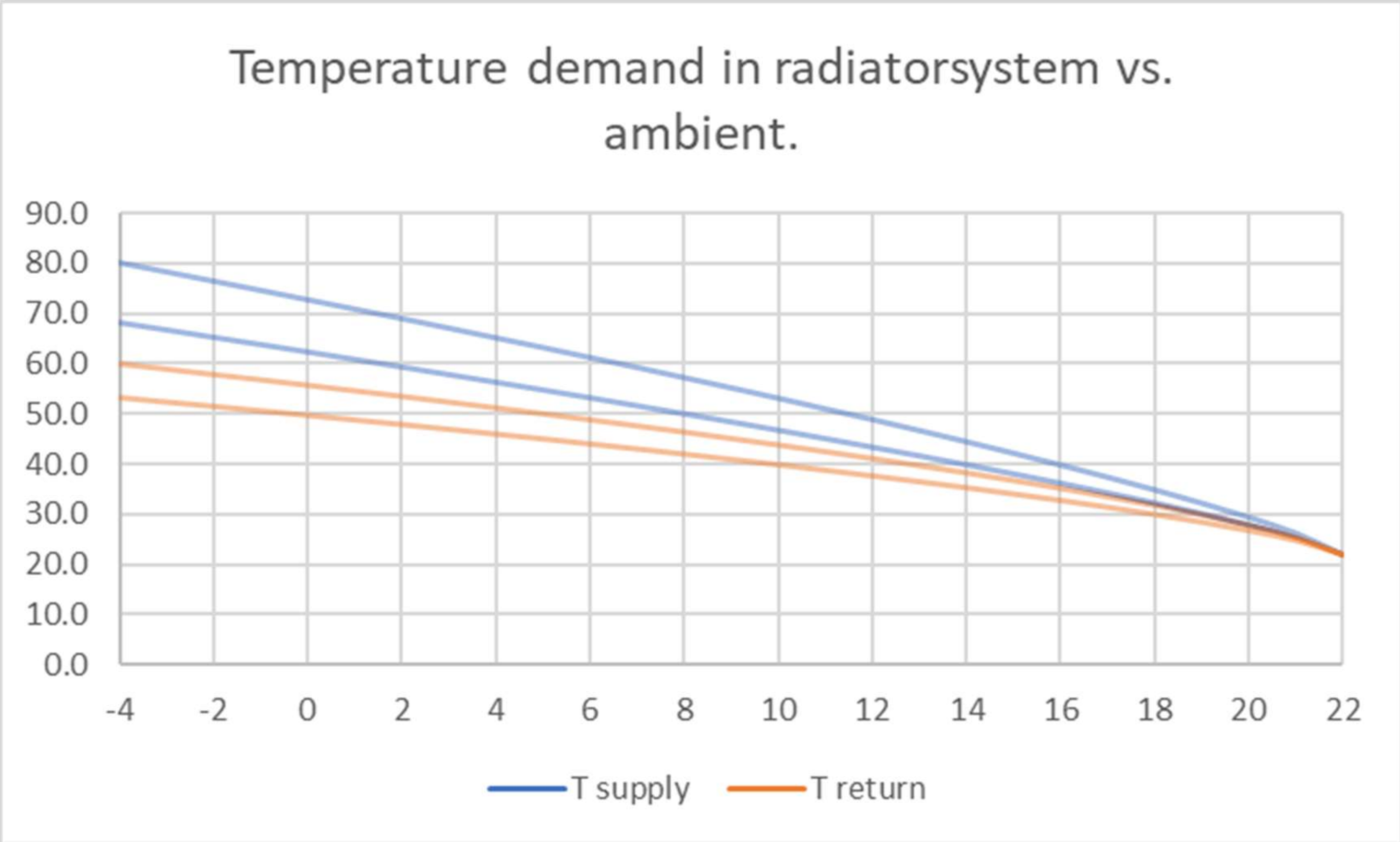
New temperature demand radiators





New temperature demand radiators

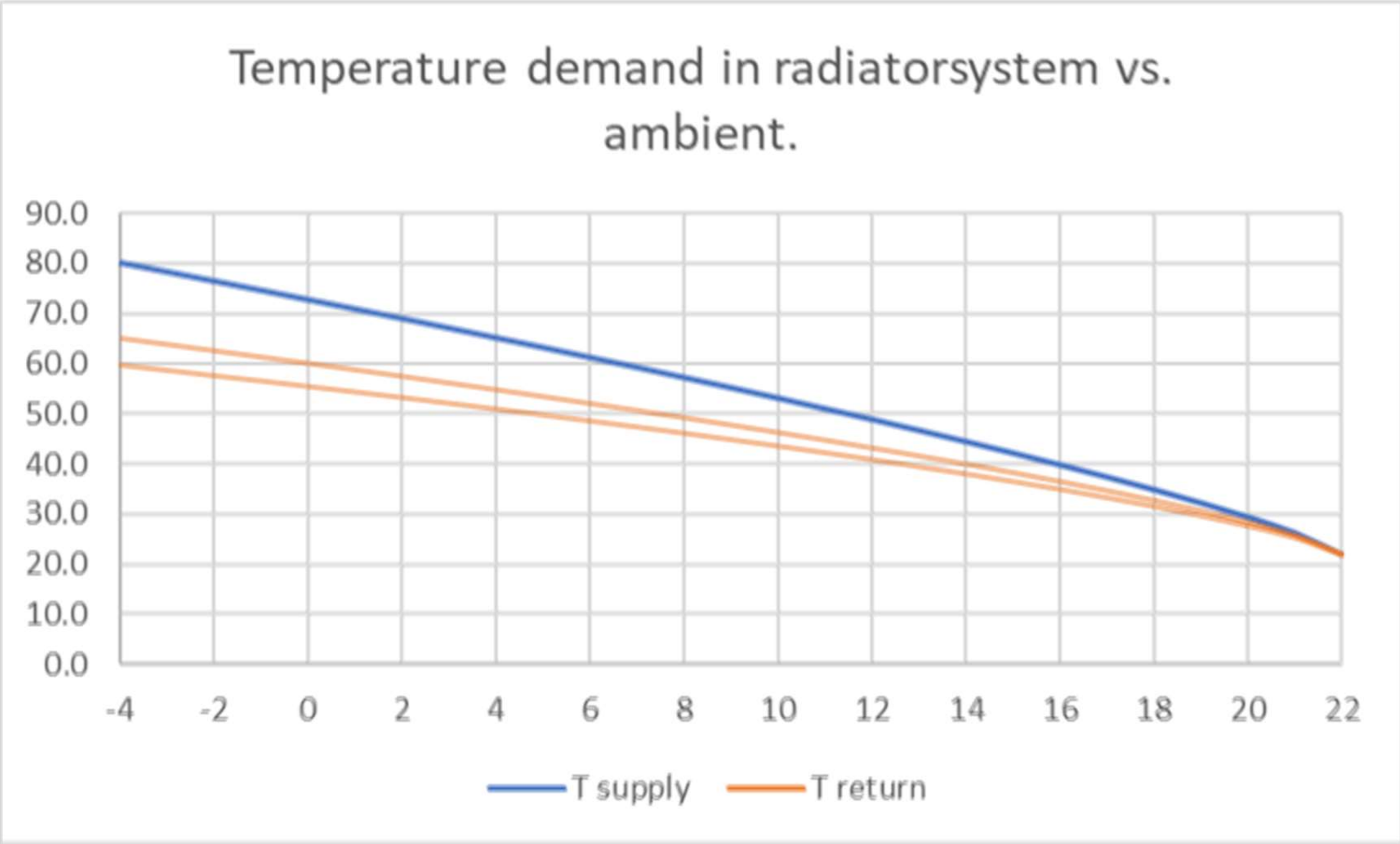
- As we see, there is a significant drop in the radiator temperature demand.



New temperature demand radiators

The result:

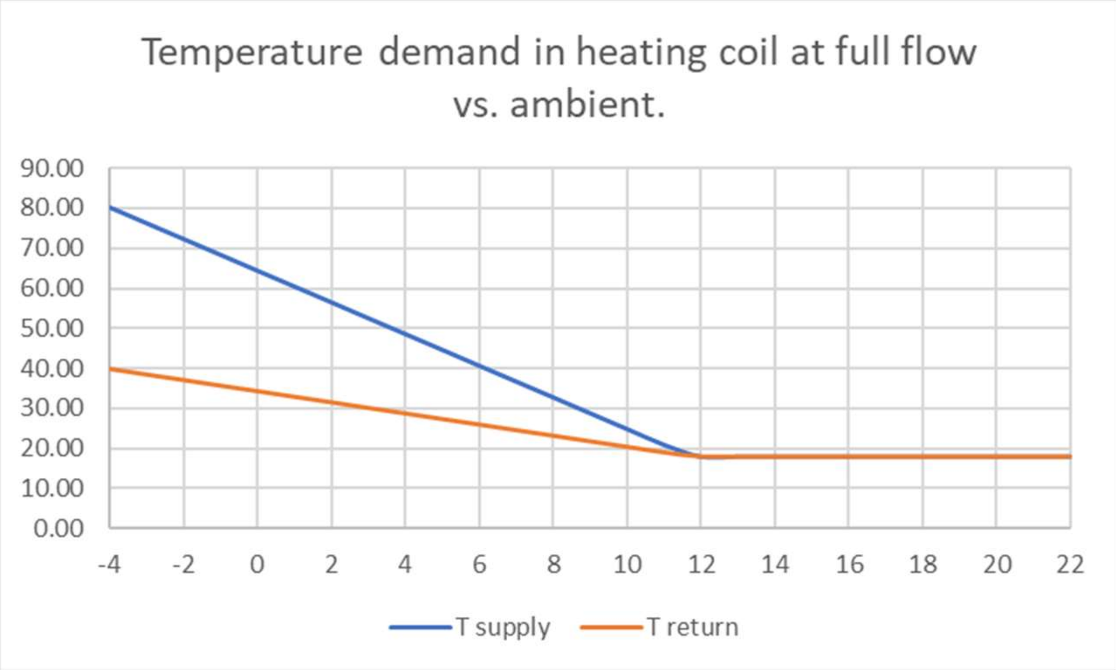
Increase in return temperature

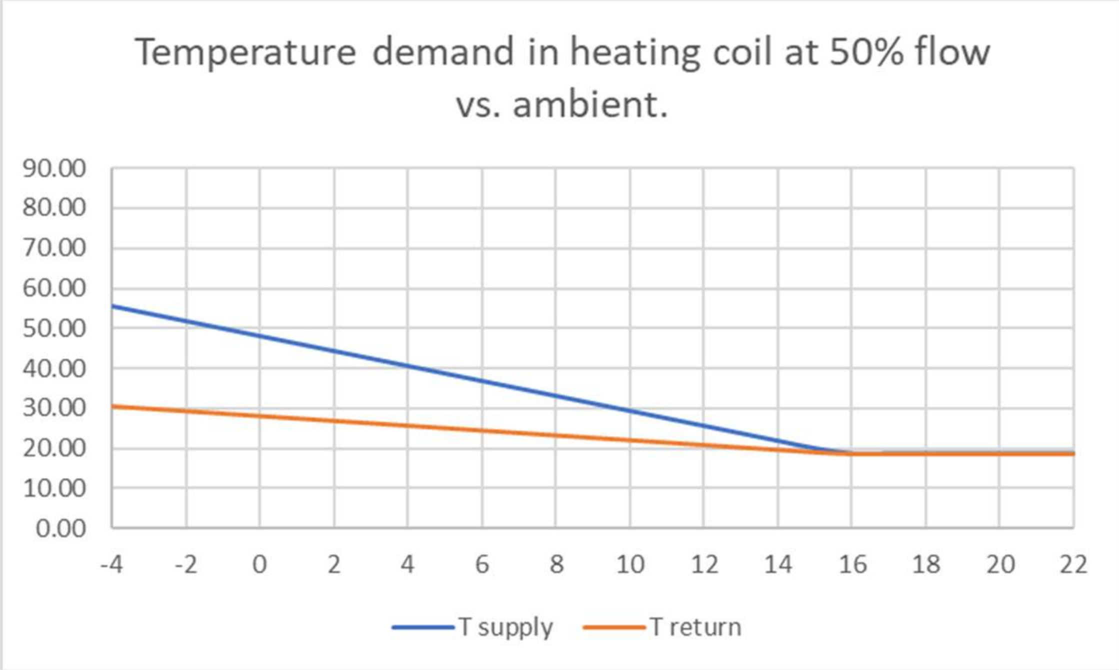


Actual heat and temperature demand ventilation heating

- Heating coil is designed for full flow, 170 000 m^3/h at -4°C ambient, recuperator temperature efficiency 60%, supply temperature into rooms 20°C, temperature lift from fans 2.1K.
- Heat demand : 362.5 kW.
- Temperature pair heat bearer : 80°C/40°C
- Actual max flow winter is 50% : 85 000 m^3/h.
- At actual winter flow the temperature lift is therefore 0.53K.
- Heat demand : 226.5 kW

New temperature demand for heating coil

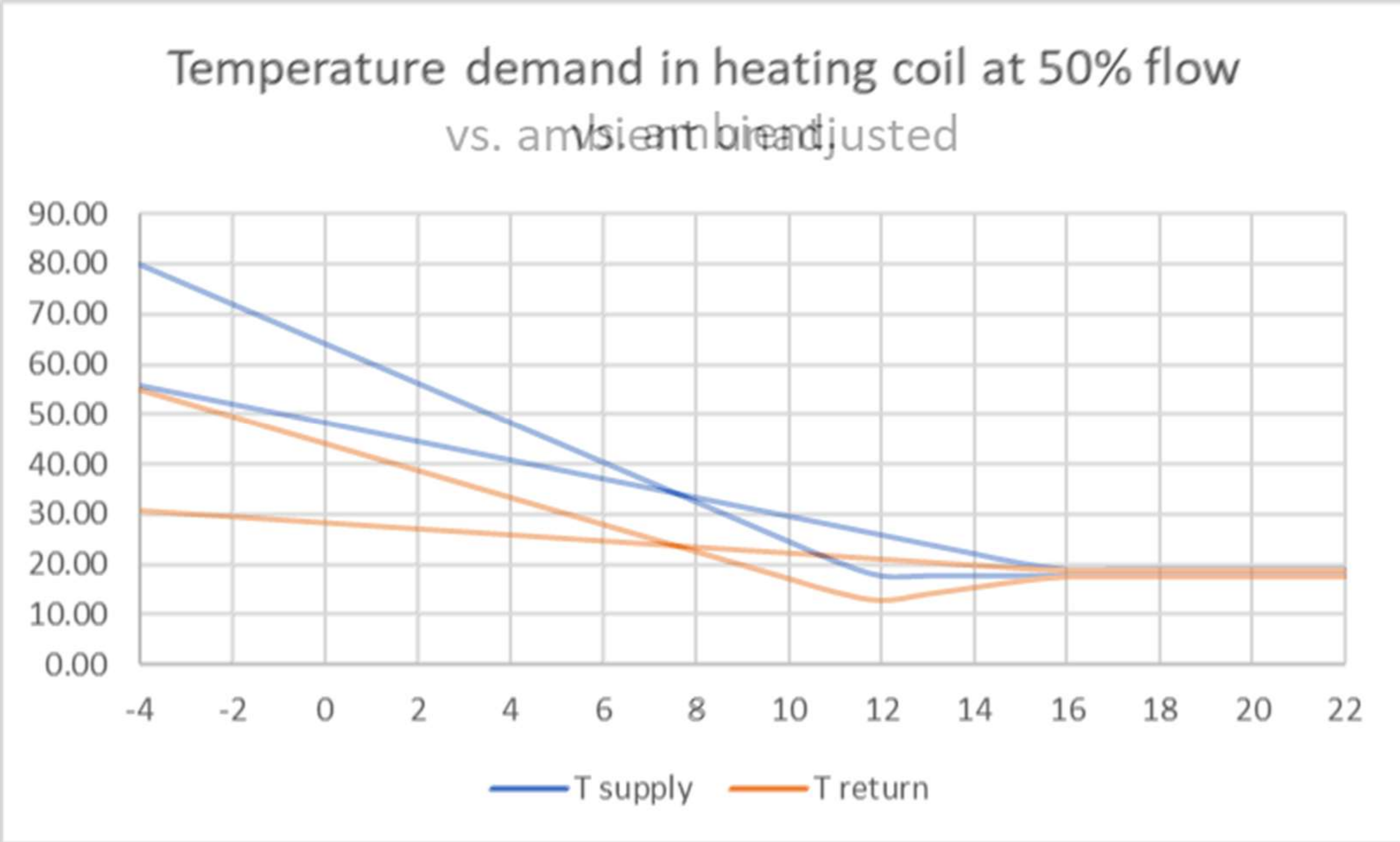




New temperature demand for heating coil

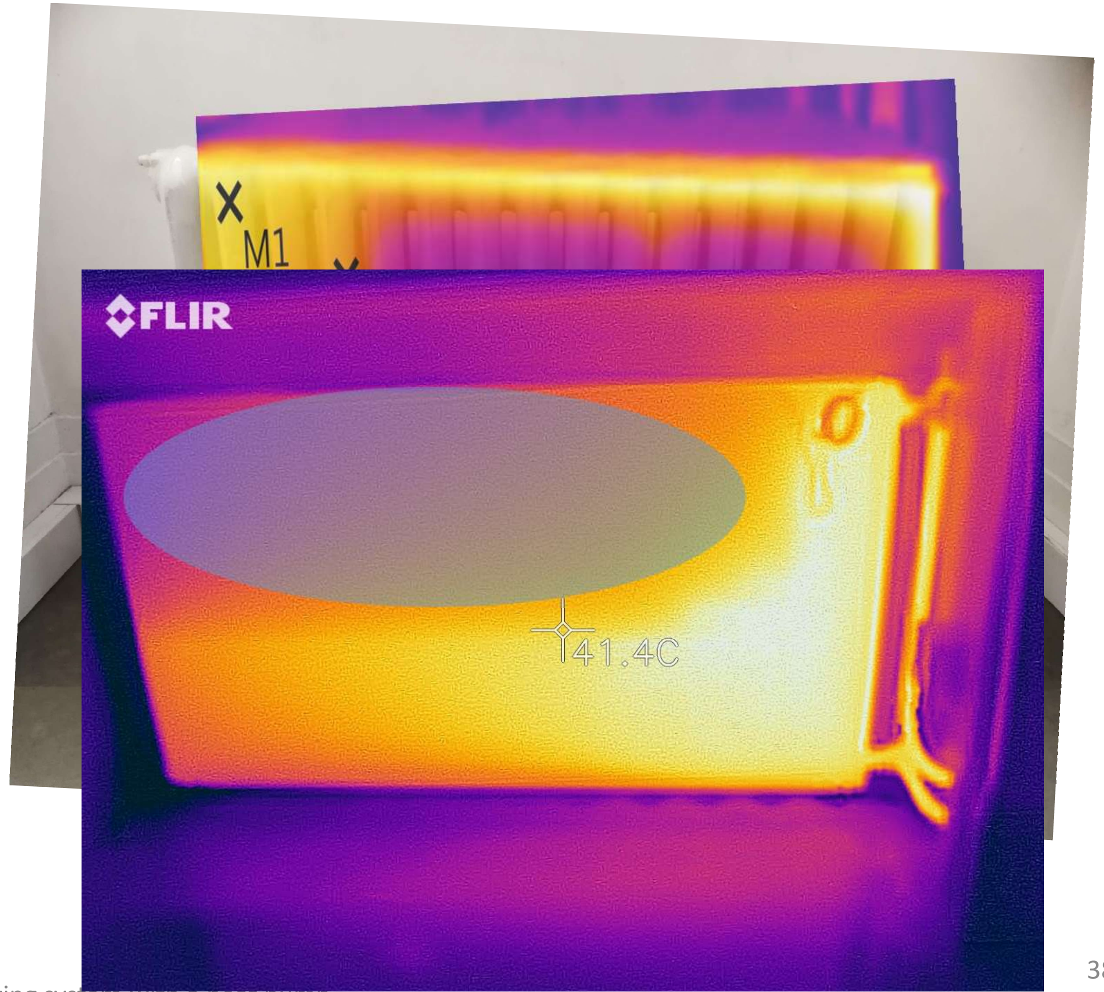
Nobody adjusted the settings

The return temperature is now as high as the supply temperature should have been at design conditions.

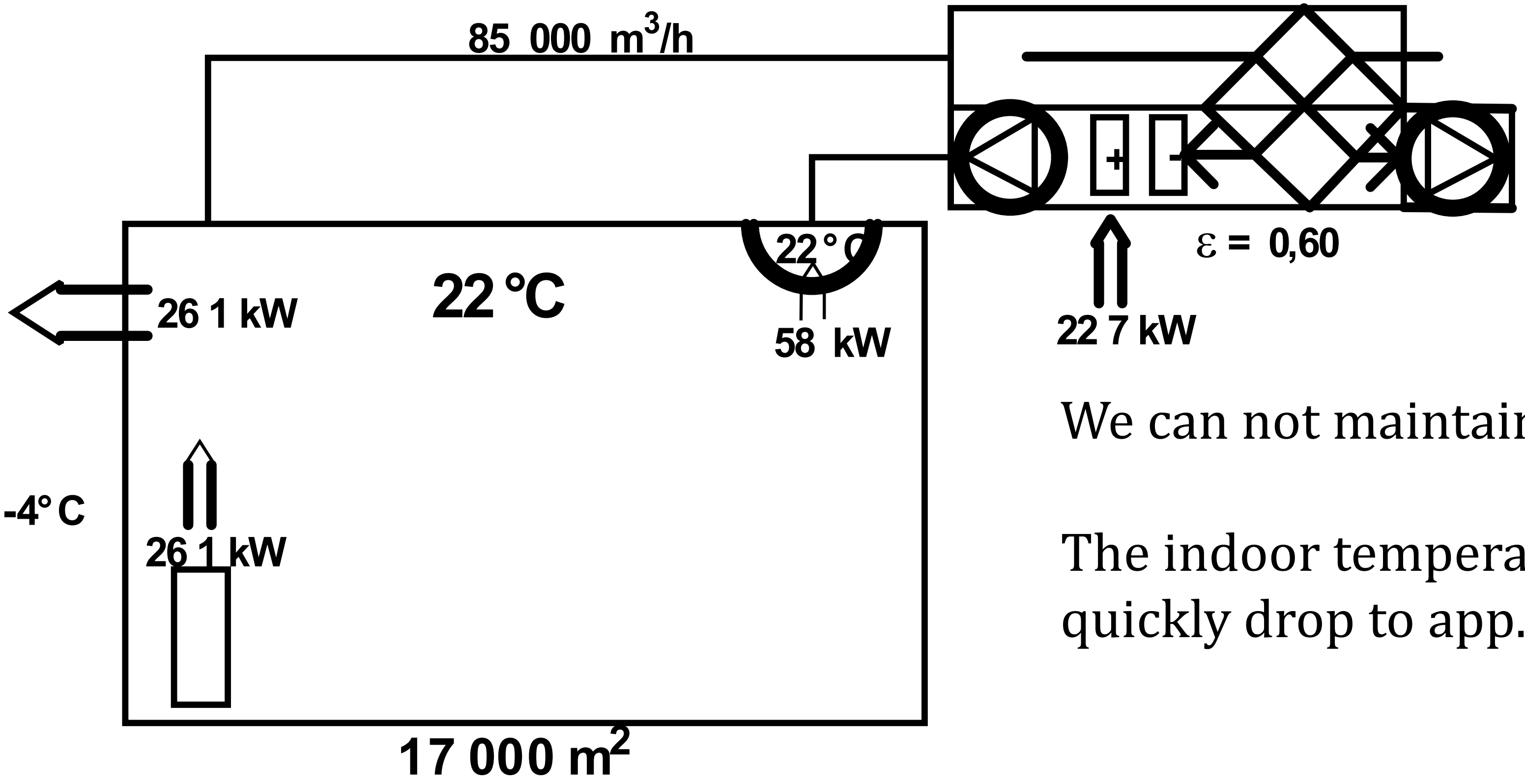


What has happened from building until today?

- Decay in efficiency of radiators.
- Poor control of water quality, sedimentation
- Air in radiators
- Large air pocket
- Leads to poor performance and higher temperature demand.
- This has to be adressed as well in the new design



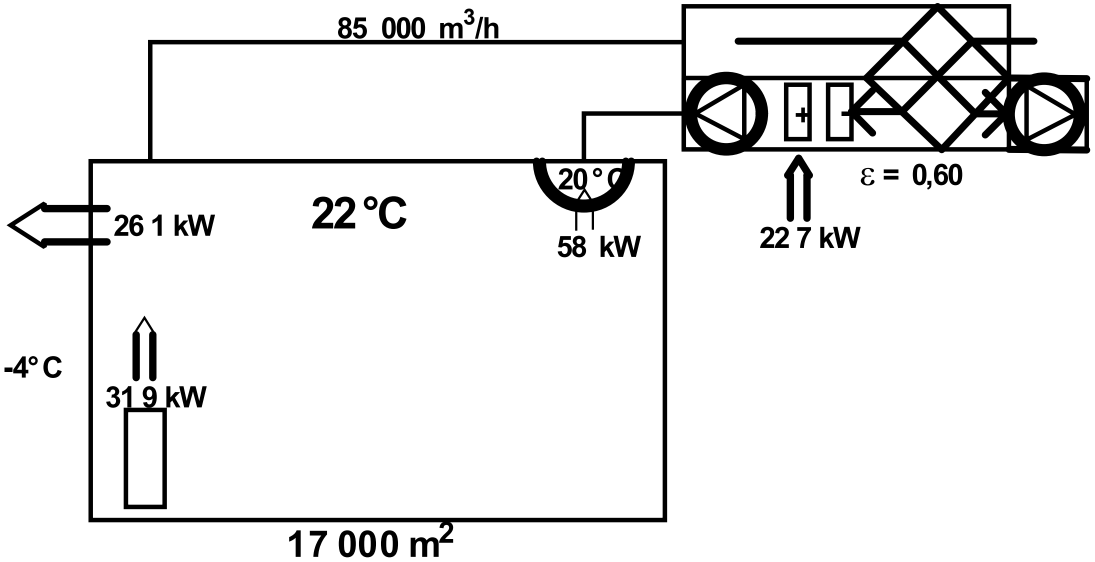
What happens indoor now?

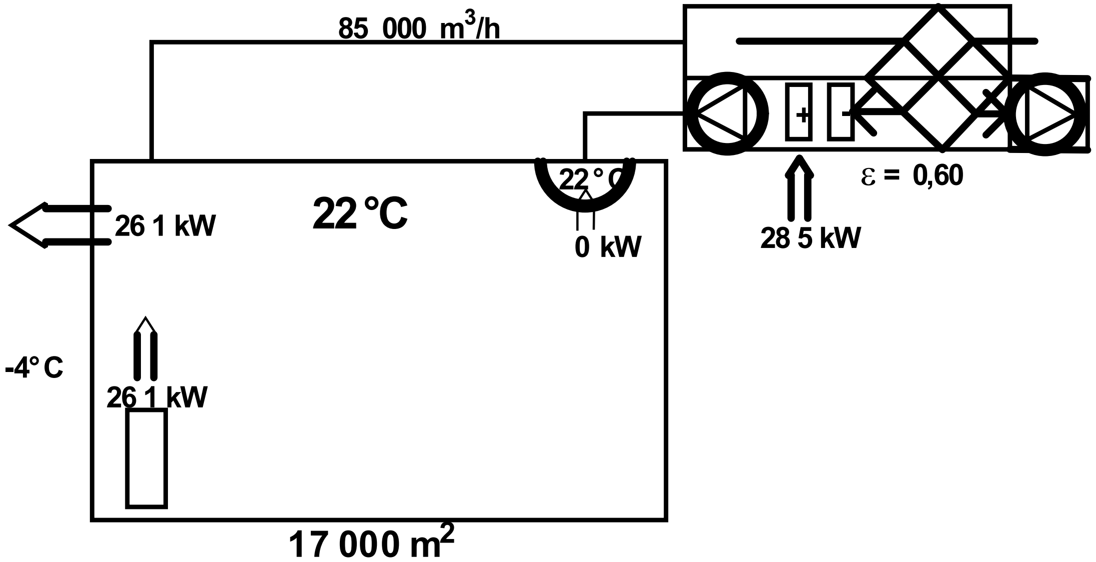


We can not maintain 22°C.

The indoor temperature will quickly drop to app. 20°C.

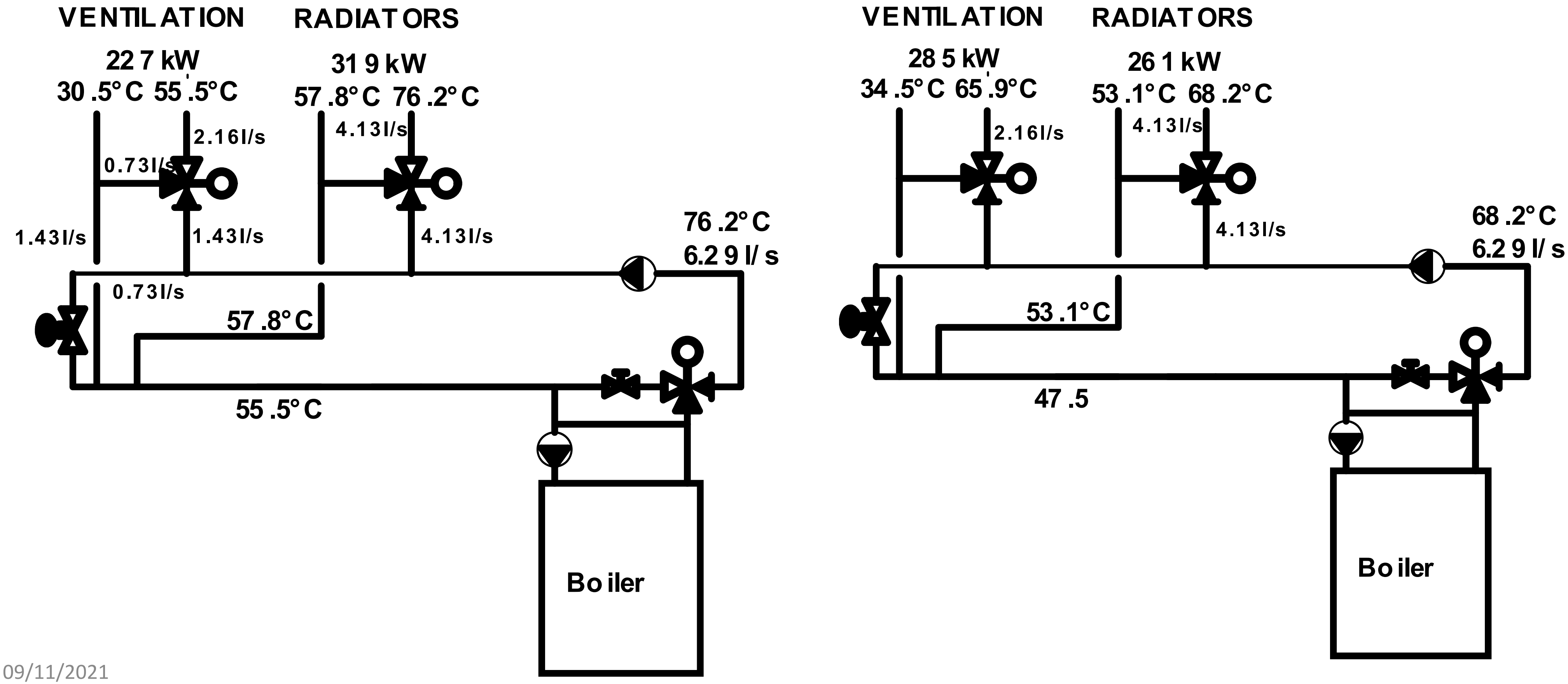
What happens indoor now?



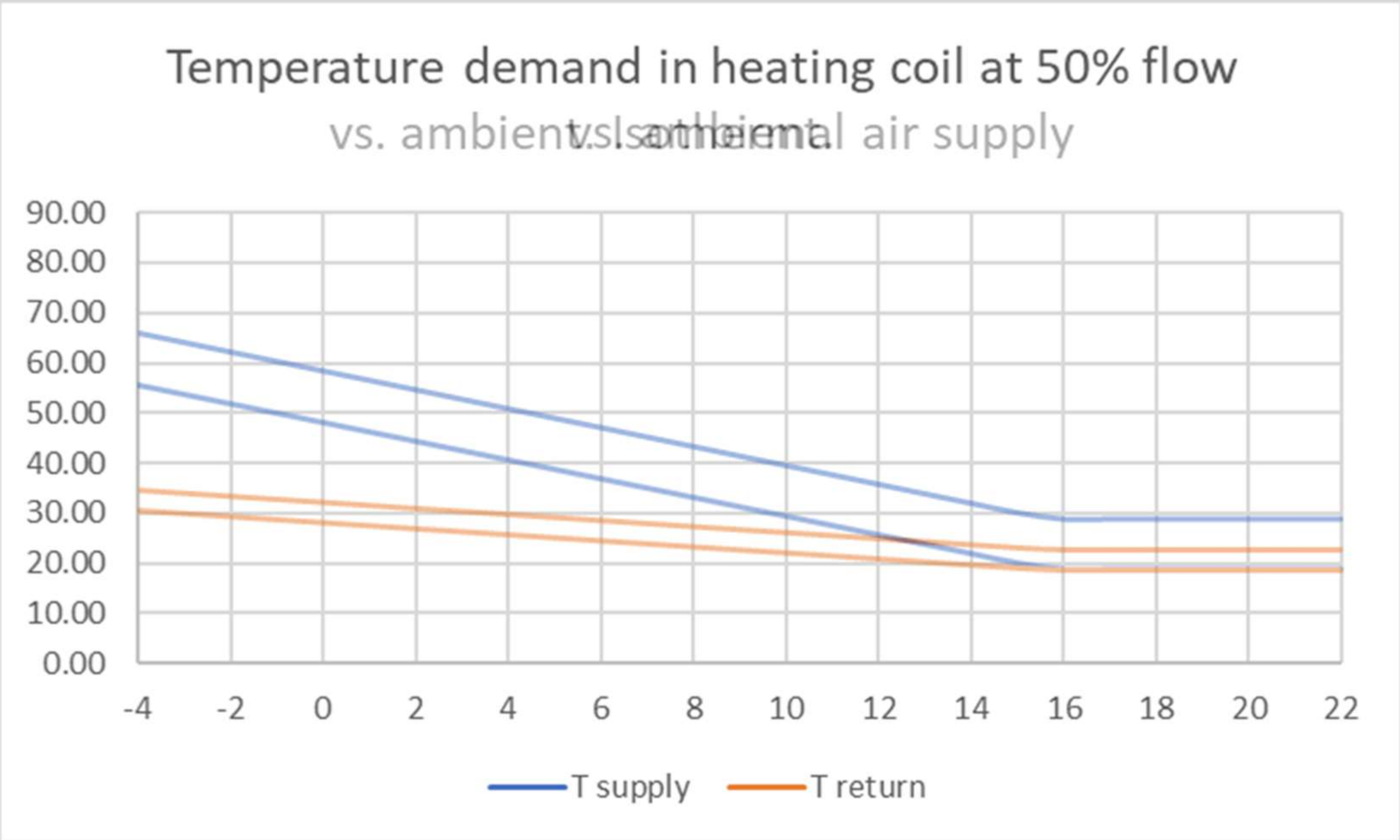


Should we increase the load on the radiators or the heating coils to compensate the 58 kW?
10 minutes.

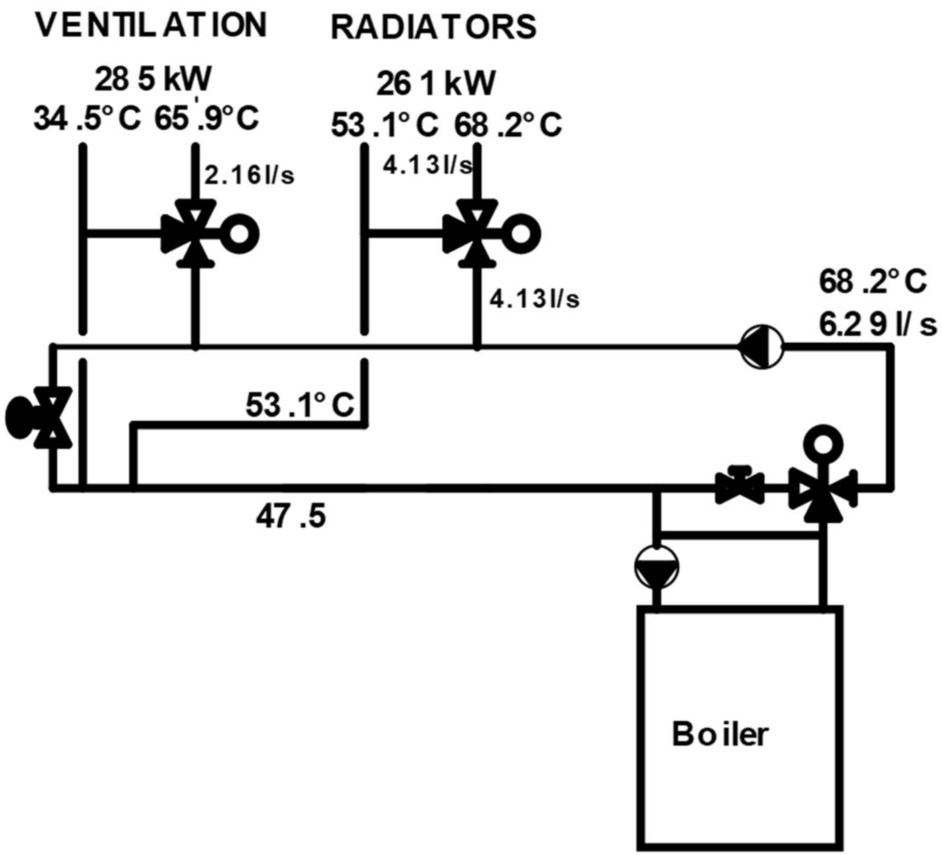
What to choose? Increase radiator or heating coil load?



Temperature demand ventilation. Isothermal air supply

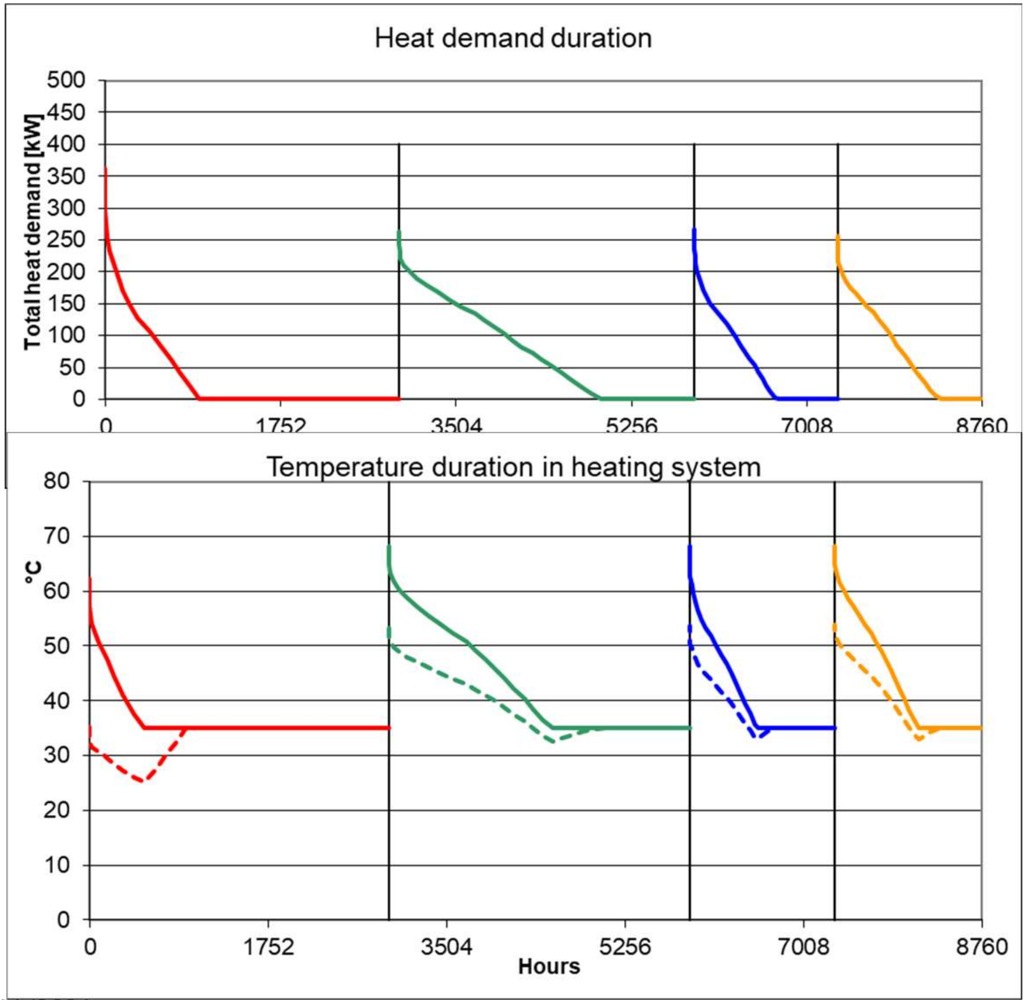


What happens with the system temperatures?

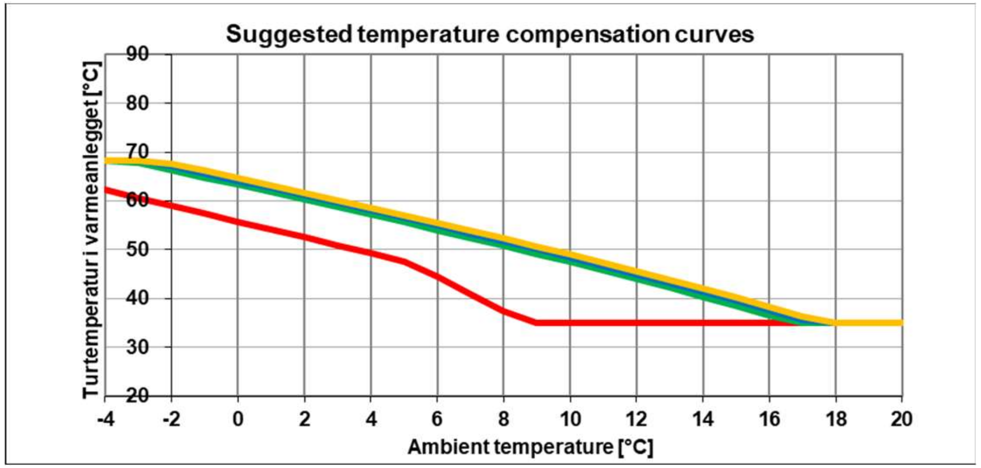


- The maximum design heat demand in the old building, before any retrofitting is 631 kW.
- With new windows it is 545 kW.
- With new windows, lights, computers etc. the annual heat demand is app. 676 MWh.

System temperature demands



- We want them as low as possible, makes the heat pump run better.
- With the changes already implemented, a heat pump will be able to give a meaningful contribution



Temperature demand reduction

- In retrofitting an old building with a heat pump, this is the major challenge.
- When changing the AHUs, we have at least two choices.
  - The design flow is found to remove all the internal loads at a ΔT of 6K.
  - 850 workspaces, occupancy 80%, each workstation has surplus heat of 100 W from people and 50W from equipment.
  - 17 000 m^2 5 W/m^2 from lights, 0,5 W/m^2 from misc.
  - Total internal design load : 195,5 kW.
  - Air flow design : 96 300 m^3/h (5,7 $m^3/h/m^2$).
  - This seems low according to my gut feeling, but I grew up when the lights were 10 W/m^2 and a PC was 150W.

What if nothing has changed?

- In a professional building you will most like have a chiller.
- If you have a chiller, you basically have a heat pump.
- If you have cooling of ventilation air, you most have a cooling coil.
- The thermal length of a cooling coil is much larger than that of the heating coil.

Cooling coil as a combi-coil

- The example from the start said
- Heat demand 362 kW.
- Air temperatures 11.6°C to 17.9°C
- Water temperatures 80°C to 40°C
- AMTD = (80+40)/2 –(11.6+17.9)/2 = 60 – 14.75 = 45.25 K
- UA = 362 / 45.25 = 8 kW/K

Cooling coil as a combi-coil

- Air flow 170 000 m^3/h
- Ambient 27°C/50%rH
- T of coil 17°C
- Cold bearer 7°C/12°C
- Cold demand 825 kW
- AMTD (27+17)/2 – (7+12)/2 = 22-10.5 = 11.5
- UA 825 / 11.5 = 71.7 kW/K

Cooling coil as a combi-coil

- UA 825 /11.5 = 71.7 kW/K
- Heat demand 285 kW
- AMTD = 285 / 71.7 = 4 K
- $T_{m,air}$ = 14.25°C
- $T_{m\ water}$ = 14.25 + 4 = 18.25°C.

- This is almost ridiculously low.
- The ΔT on the liquid side will be 285/825 * 5 = 1.73 K
- Meaning that the supply temperature will be 19.11°C and the return 17.38°C

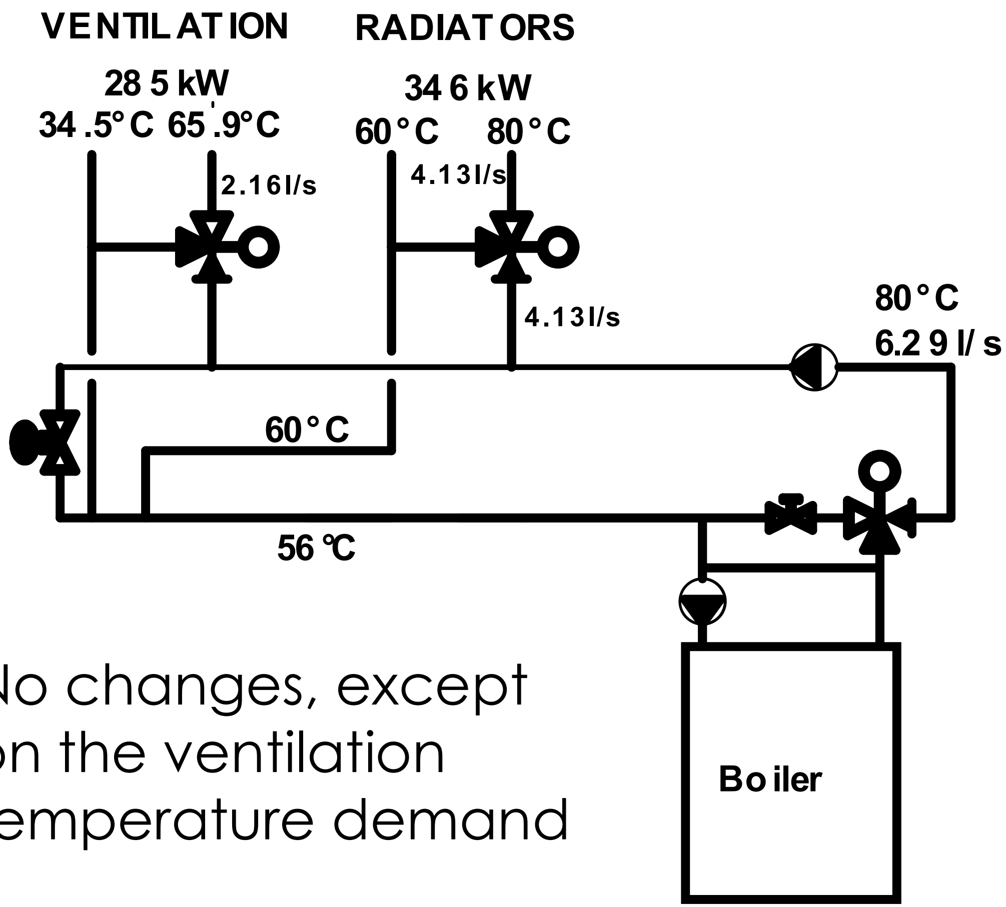
Cooling coil as a combi-coil

- Flow through the cooling coil :
- $\dot{m} = \frac{\dot{Q}}{c \times \Delta T} = \frac{825}{4.186\ x\ 5} = 39.4\frac{kg}{s} \approx 39.4\frac{l}{s}$
- Flow from header : 2.16 l/s
- A ΔT of 1.73 at the coil thereby becomes 31.56 at the header.
- Meaning that the minimum temperature at the header to the coil must be app. 49°C or above.

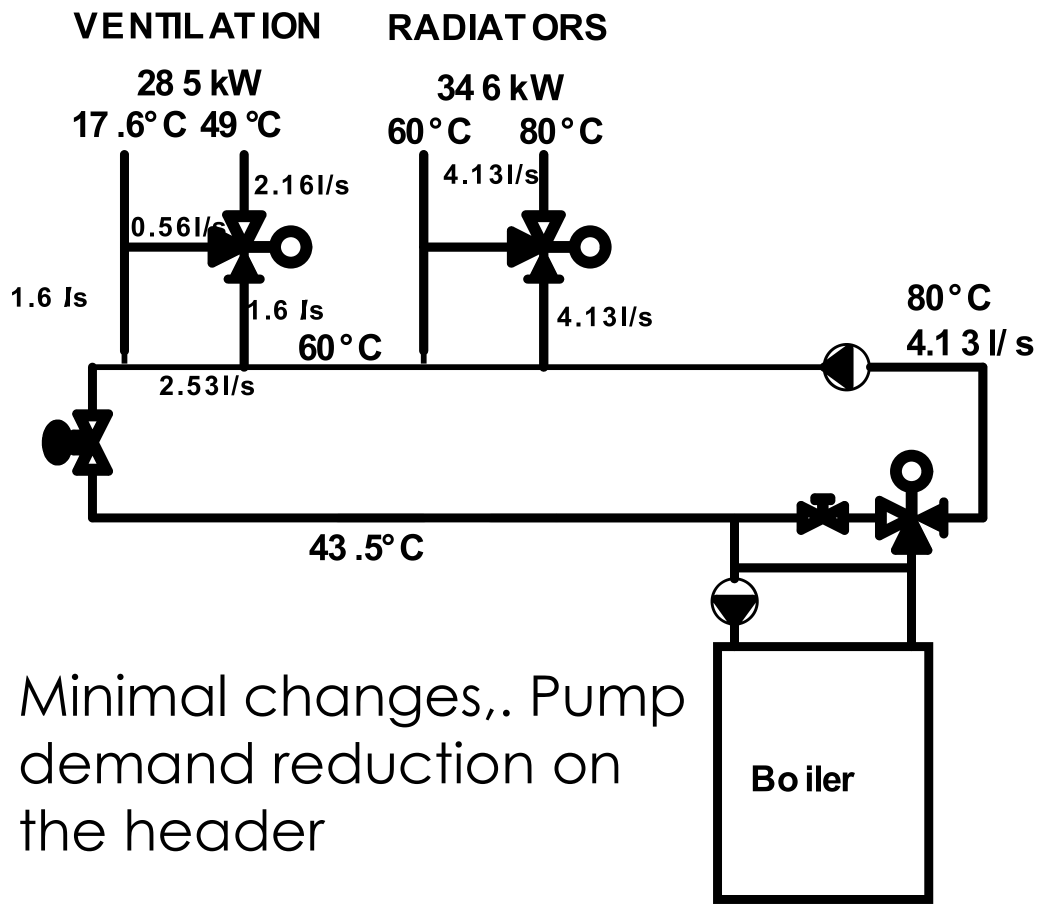
Why doing all this?

- If we want to implement the use of heat pumps, we have to bring the systems temperatures down.
- Cooling coil as heating coil => low temperature demand.
- No problems with serial connection of radiators and ventilation heat.

Why doing all this?

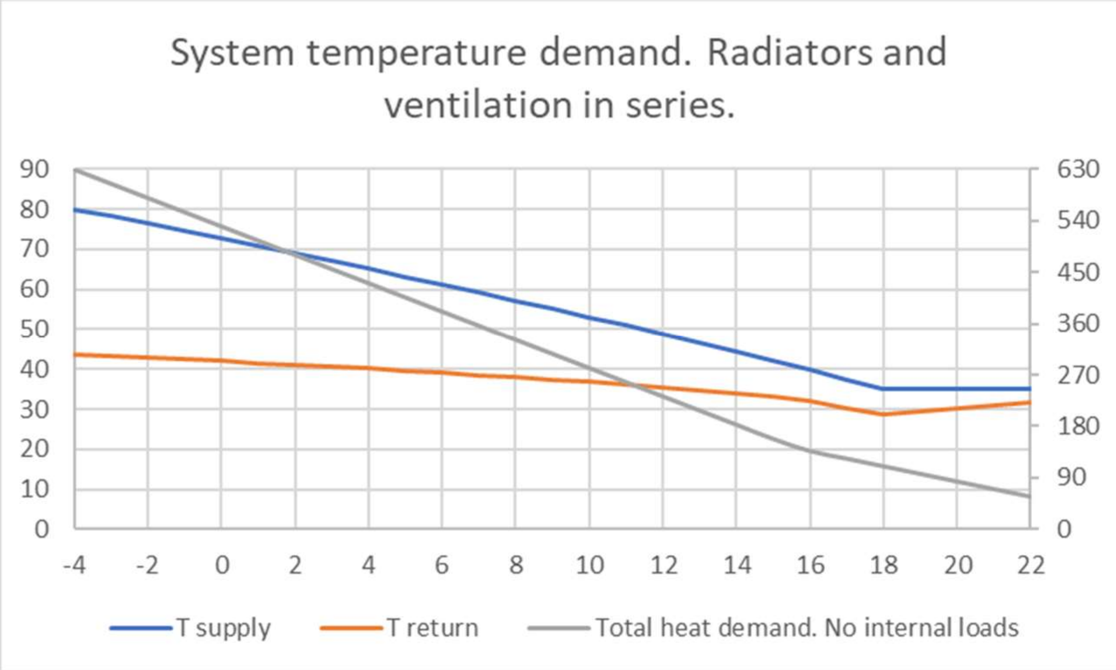


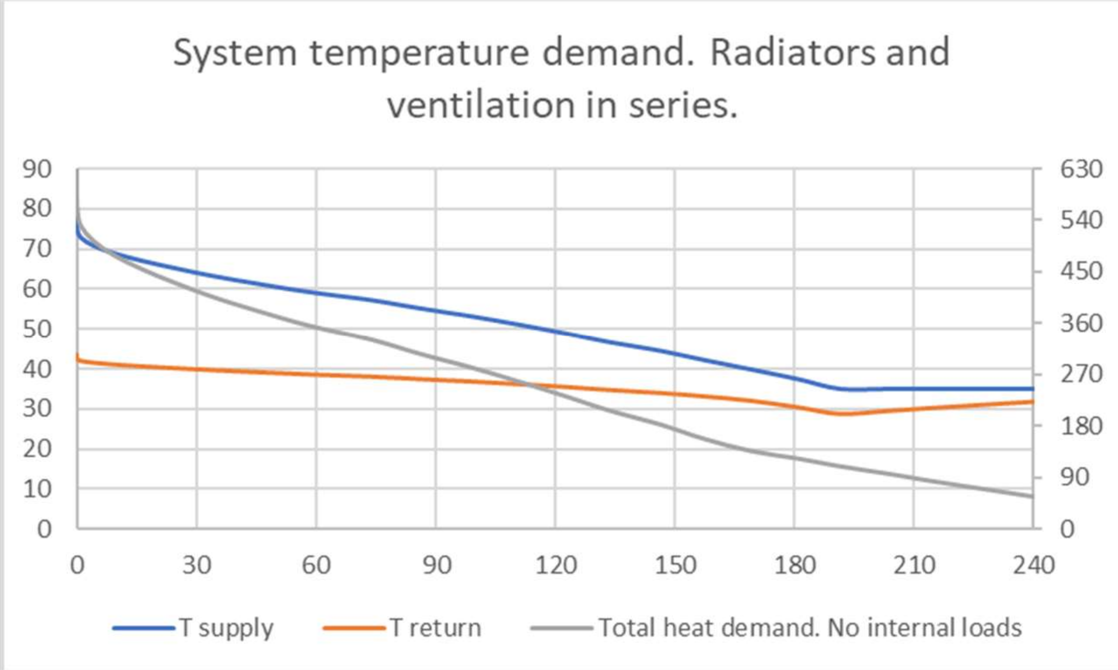
No changes, except on the ventilation temperature demand



Minimal changes,. Pump demand reduction on the header

Why doing all this?





Dwellings

- Basically, dwellings are easier to handle.
- An option always available is the air to air unit.
- The indoor part from my own home.
- When building new or refurbishing, the best option is underfloor heating with heat pump.