Designing a heating system with a heat pump in mind. New building

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A heat pump is not a boiler

- A heat pump in a larger building will typically be designed to cover 90% - 95% of the total annual heat demand.
- Therefore it is clear that the design point of the heating system as such is not the same as for the heat pump.
- In dwellings it will normally be OK to design for ~ 100% energy coverage, if the heat pump has frequency converter or inverter control of the compressor.

Remember

The most efficient cooling, is cooling you do not need.

Or in general

The most energy efficient is to reduce the demand.

Energy efficiency

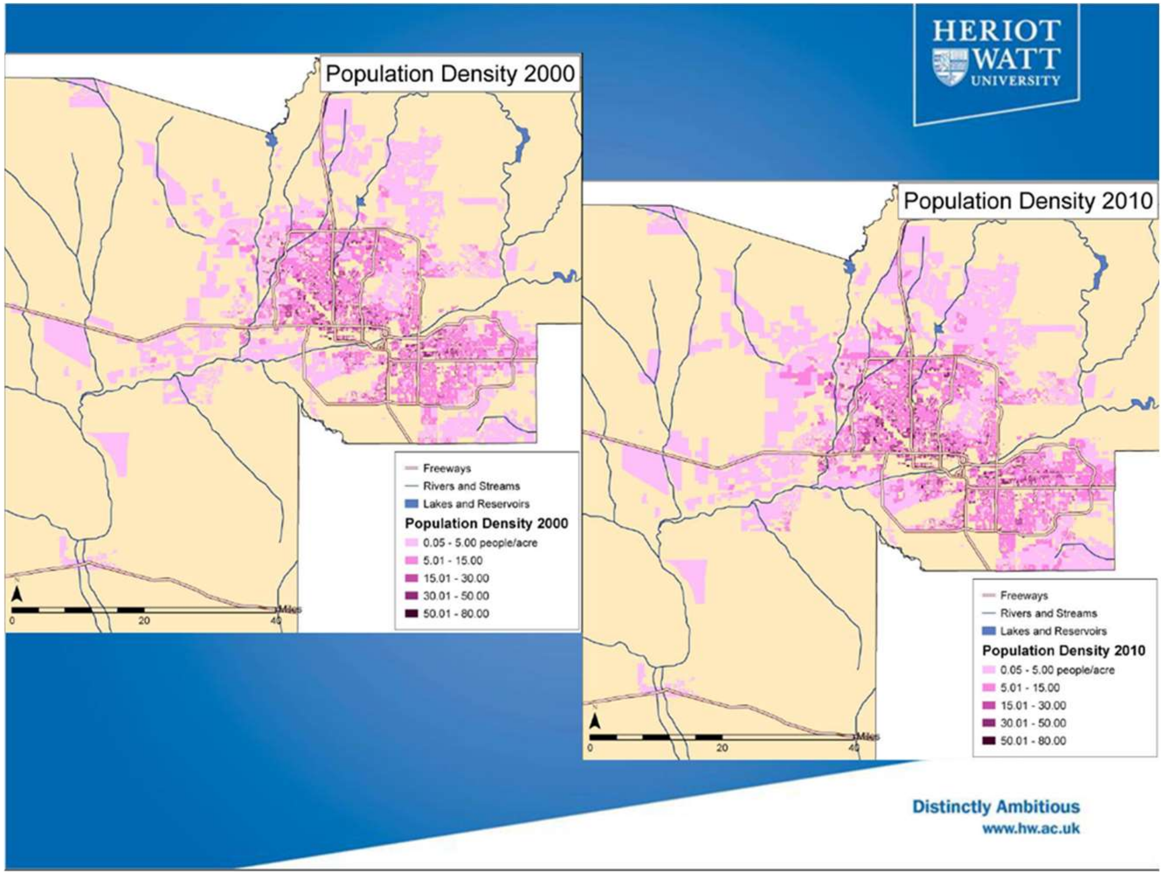
- The most important component, efficiency wise is the process or building that has to be either heated or cooled.
- First:
  A “tale” of what can happen when you don’t include energy efficiency in your design.
- And then we will apply ourselves to cover the demands with as little energy use as possible.

What happened in 2008

- This part of the presentation is inspired by a key-note presentation given by Sue Roaf at the ICR 2011 in Prague
- What happened in 2008?
- The credit crunch happened.
- The background cause for this was that the banking system in Arizona toppled.
- But banks just don't topple without reason
- What caused this?

What happened in Arizona?

- Large population increase



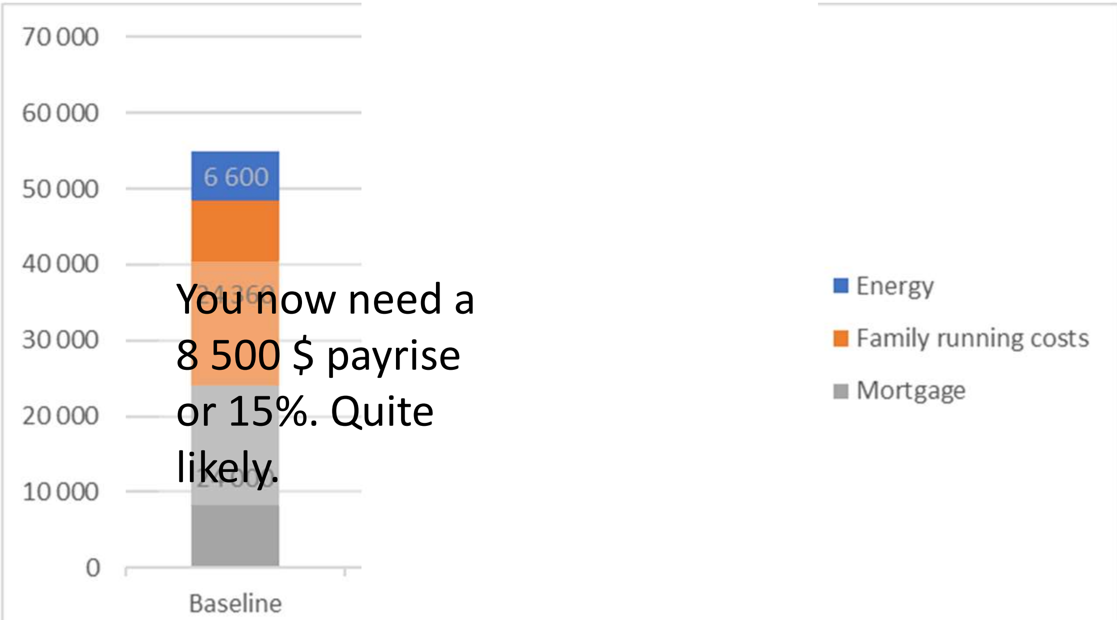
What happened in Arizona?

- Big housing developments
- Built by contractors for sale => short term profits
- Larger houses
  - Avg. 1975 140 m^2 (1 500 sqft)
  - Avg. 2007 370 m^2 (4 000 sqft)
- No insulation. No shading. No thermal mass
- Long distance from workplaces.
- These houses do NOT protect you from the heat

- A house like this is like a car in the desert sun.
- Without AC it is impossible to be indoors

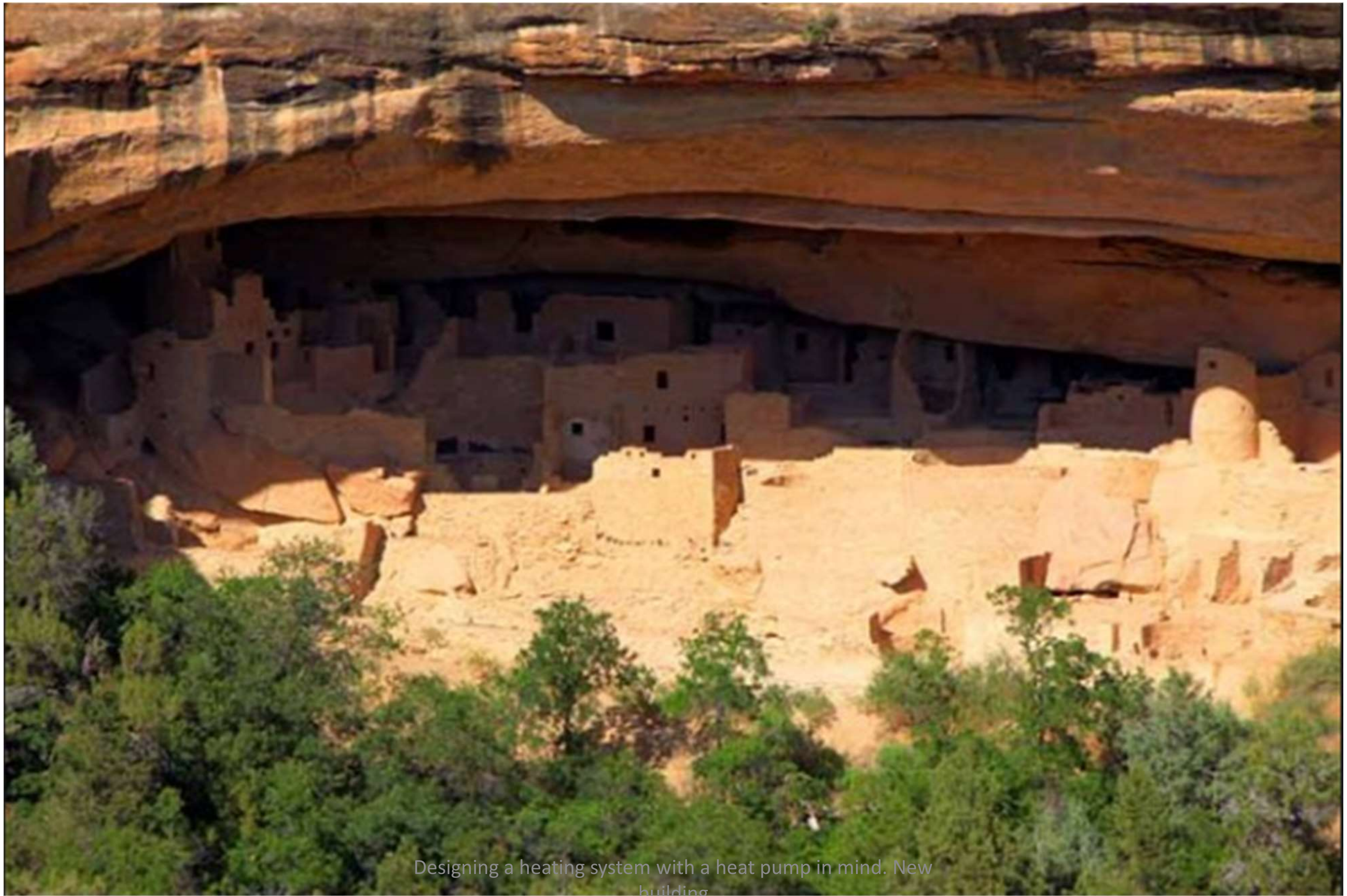
Family economy

- Oil price April 2007 $65 per barrel
- Oil price July 2007 $147 per barrel.
- You now have to choose : Pay the bank and die in your house or pay the electricity bills and survive.
- Result
- The US system makes it possible for people to let the house revert to the bank
- Banks filled up with unsaleable houses.



What should have been done

- Smaller houses of better quality
- Used solar energy. This is in the middle of a desert
- Built with shade.
- Built with thermal mass
- In short
- Looked at the original way of building



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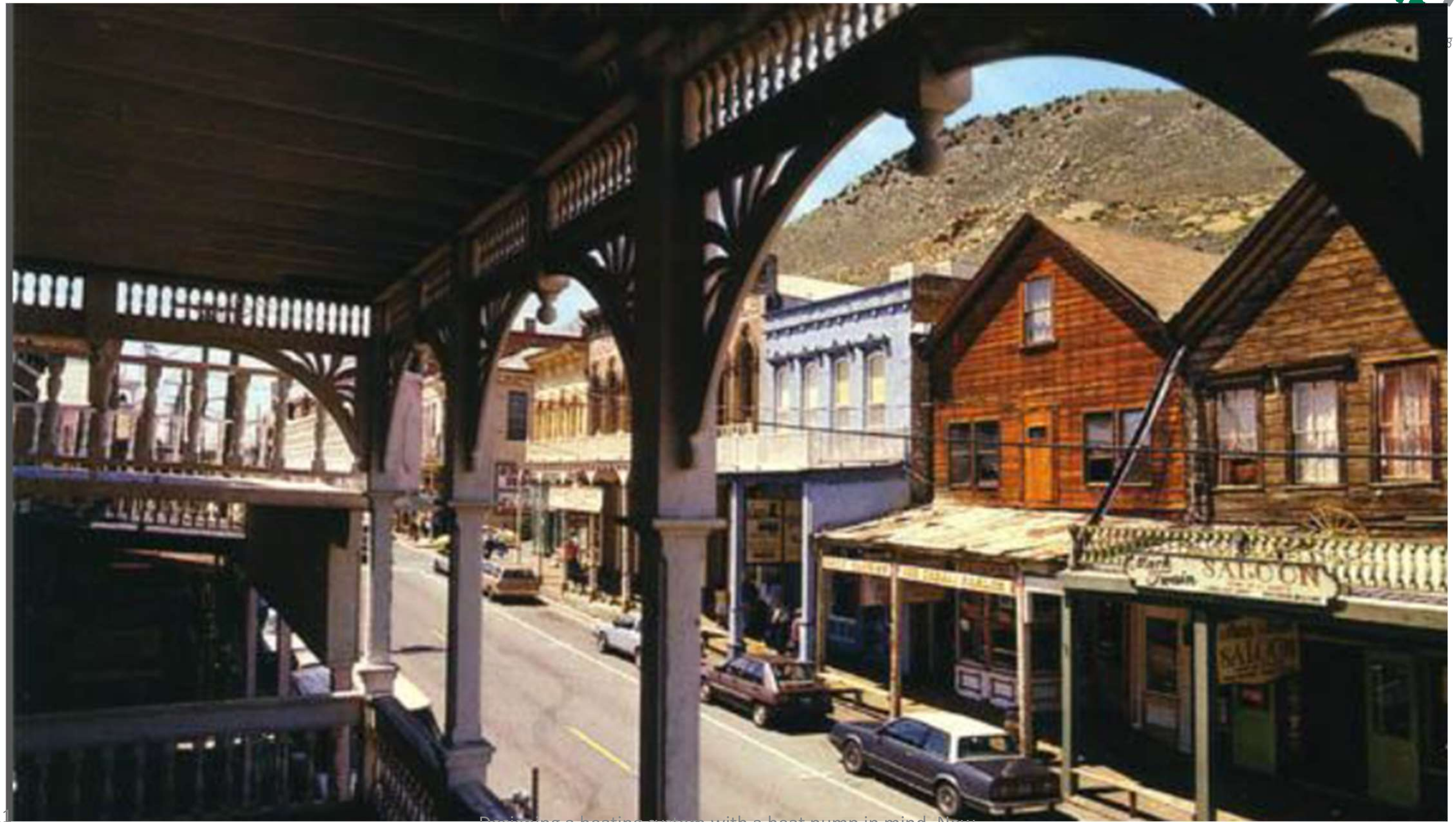
g the Big Picture



Conclusion this far

- As engineers and technicians we are too often not critical enough to the designs made by others.
- The building or the process we are to serve, is probably the most important part of an energy efficient system.

Determining the design heat demand

- Usually, when the project starts we don't know anything.
- Apart from
  - the purpose of the building,
  - the size of the building,
  - the number of people we have to squeeze in,
  - Sometimes the plot size.
- If a design heat demand covering transmission and infiltration losses, isn't available, we have to do it.
- HVAC-R. The dependables.

Assessing the design heat demand.

- Make use of the energy efficiency demands in the local building codes.
- Check the level of ambition of the home owner of developer.
- Find the minimum required ventilation rate of the building.
  - In Norway mechanical ventilation of new homes is required.
  - Is that a requirement in the UK?
- Design ambient temperature is a very important decision.
- Might require local knowledge.

Design Ambient Temperature

	ASHRAE fundamentals 2017	
	99 %	99.60 %
Edinburgh	-3.2	-5.2
Aberdeen	-2.4	-4.6
London City	-0.9	-1.9
Plymouth	-0.1	-1.4
Stornoway	0	-1.1
Cardiff	-1.1	-2.3
Bergen Airport	-6.4	-7.1
Rørås (inland Norway)	-28.9	-32.4

- The UK is not cold in a heat pump matter of speaking.
- Air will probably prove a very good heat source.
- ASHRAE uses the 99% threshold as Design Outdoor Temperature.
- What would you normally use?

Design ambient temperature

- The Norwegian definition
- The average temperature of the coldest 72 hour periode in the latest 30 year period.

- NOT a common occurence

- The Norwegian Design Ambient Temperature (DAT) for Røros is -40°C.
- Lowest recorded is -50.4°C.
- Bergen DAT : -10°C
- That is center.
- Many places where it is app. 5°C lower.

Design Ambient Temperature

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Røràs (inland Norway)	-28.9	-32.4

- ASHRAE uses the 99% threshold as Design Outdoor Temperature.
- I would use the 99.6%.

Assessing the design heat demand.

Assesment of heat demand covering transmision and infiltration losses									Minimum demands from building code	TEK17	
Floor space	17 000	m2	Hygienic minimum ventilation rate, building	2.5	m3/h/m2	Maximum air leakage from building codes	1.5		U floor	0.1	W/m2K
Occupance design	850		Hygienic minimum ventilation rate, people	26	m3/h/pers				U window	0.8	W/m2K
			Total hygienic minimum ventilation rate	3.80	m3/h/m2				U wall	0.18	W/m2K
T soil. Set to annual mean temperature	10	°C	Actual minimum ventilation rate (1.2)	4.55	m3/h/m2				U roof	0.13	W/m2K
T Indoor	22	°C	Efficiency recuperator in AHU	80 %		Air change due to infiltration	0.105	per hour	leakage number at 50 Pa	1.5	per hour
Design Ambient temperature	-5.2	°C	ΔT supply air / room temperature	0	K				Recuperatorefficiency	80 %	
			ΔT supply air from fan power	0	K						
Length of the building	125	m	Transmision			Infiltration			Ventilation		
Width	17	m	U floor	0.1	W/m2K	Volume of the building	51 000	m3	Total air flow	77 350	m3/h
Number of storages	8	stk	U window	0.8	W/m2K	Air change	0.105	per hour	Supply air temperature	22	C
Storage hight	3	m	U wall	0.18	W/m2K	Air flow	5 355	m3/h			
Window share of building envelope	30 %		U roof	0.13	W/m2K				Supply air temperature after recuperator	16.56	C
Incline roof	12	°	Heat loss floor	2 550	W				Supply air temperature after heating coil	22	C
Roof width	17.38	m							ΔT heating coil	5.44	K
			Heat loss windows	44 495	W						
Area floor to ground (footprint)	2 125	m2	Heat loss walls	23 510	W				Heat demand heating coil	142 365	W
Area building fasades	6 816	m2	Heat loss roof	7 682	W						
Area windows	2 045	m2									
Wall area from gable/roof incline	30.7	m2	**Total transmision heat loss**	**78 237**	**W**	**Q infiltrasjon**	**49 280**	**W**	Heat demand from subtemperature suplly air	0	W
Area wall	4 802	m2									
Area roof	2 172	m2	**Q trans og inf.**	***127 517***	**W**						
			Q tot, design building heating	**127 517**	W						
			Q tot, design, heating system	**269 882**	W		**269.9**	kW			
			q trans&inf	7.5	W/m2						
			q vent	8.4	W/m2						
			q tot des	15.9	W/m2						

Assessing the design heat demand.

- This was set up for the Norwegian building codes, regarding energy efficiency.
- Lets play a bit with the spread sheet, and see what happens.
- I hope that you have received a copy of the spread sheet.

- C:\Users\gertm\OneDrive\Skrivebord\Beregningsprogrammer\Egenutviklet\Heat demand assement.xlsx

Building basic design and design heat demand

- Building length 125 m
- Building width 17 m
- Storages 8
- Storage hight 3 m
- Window share 30%
- Roof incline 12°
- Use minimum demands from the Norwegian TEK17.
- Building located in London City

- Occupancy 850
- Minimum hygienic ventilation rate 6 l/s/person
- Safety factor ventilation 1.2
- Isothermal ventilation.
- Indoor temperature 22°C

- Determine building and ventilation design heat demand, using the spead sheet.

Design heat demand. Solution

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Seeing the Big Picture

Assesment of heat demand covering transmision and infiltration losses									Minimum demands from building code	TEK17	
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Occupance design	850		Hygienic minimum ventilation rate, people	21.6	m3/h/pers				U window	0.8	W/m2K
			Total hygienic minimum ventilation rate	1.08	m3/h/m2				U wall	0.18	W/m2K
T soil. Set to annual mean temperature	12	°C	Actual minimum ventilation rate (1.2)	1.3	m3/h/m2				U roof	0.13	W/m2K
T Indoor	22	°C	Efficiency recuperator in AHU	80 %		Air change due to infiltration	0.105	per hour	leakage number at 50 Pa	1.5	per hour
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Length of the building	125	m	Transmision			Infiltration			Ventilation		
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Incline roof	12	°	Heat loss floor	2 125	W				Supply air temperature after heating coil	22	C
Roof width	17.38	m							ΔT heating coil	4.78	K
			Heat loss windows	39 097	W						
Area floor to ground (footprint)	2 125	m2	Heat loss walls	20 658	W				Heat demand heating coil	35 741	W
Area building fasades	6 816	m2	Heat loss roof	6 750	W						
Area windows	2 045	m2									
Wall area from gable/roof incline	30.7	m2	**Total transmision heat loss**	**68 629**	**W**	**Q infiltrasjon**	**43 301**	**W**	Heat demand from subtemperature suplly air	0	W
Area wall	4 802	m2									
Area roof	2 172	m2	**Q trans og inf.**	***111 931***	**W**						
			Q tot, design building heating	**111 931**	W						
			Q tot, design, heating system	**147 672**	W		**147.7**	kW			
			q trans&inf	6.6	W/m2						
			q vent	2.1	W/m2						
			q tot des	8.7	W/m2						

Design flow

- Building heating, radiators, designed for 60°C/40°C
- Heating coils designed for 60°C/30°C
- Determine the flow to radiators, heating coils, total flow, and resulting return temperature.

Design flow. Solution

- Radiators
- Heat demand : 111.9 kW.
- $\dot{Q} = \dot{m}\ x\ c\ x\ \Delta T \Rightarrow\ \dot{m} = \frac{\dot{Q}}{c\ x\ \Delta T} = \frac{111.9}{4.186\ x\ 20} = 1.337\frac{kg}{s} = 4.81\ m^3/h$
- Heating coils
- Heat demand : 35.7 kW
- $\dot{Q} = \dot{m}\ x\ c\ x\ \Delta T \Rightarrow\ \dot{m} = \frac{\dot{Q}}{c\ x\ \Delta T} = \frac{35.7}{4.186\ x\ 30} = 0.284\frac{kg}{s} = 1.02m^3/h$
- Total header flow : 1.621 l/s = 5.83 m^3/h.
- Combined return temperature:
- $\dot{Q} = \dot{m}\ x\ c\ x\ \Delta T \Rightarrow\ \Delta T = \frac{\dot{Q}}{c\ x\ \dot{m}} = \frac{147.6}{4.186\ x\ 1.621} = 21.75\ K \Rightarrow T_{Return} = 38.25°C$

Design flow. Solution

- Heat pump systems should be run at the lowest possible temperatures.
- Therefore in my assessments, I lock the flows, so that it is either ful flow or standstill.

- But what happens during a work day, when people are in, the lights are on and the coffee is brewing.

Internal loads

- 850 work spaces. (Nobody says anything about how many that actually works)
- 100 W heat loss per person.
- Each person uses a laptop with attached screen. Total heat load of 50 W/person.
- Lights 5 W/m^2.
- Miscellaneous 0.5 W/m^2
- Occupancy 80% => Heat load work day = 0.8*850*(100+50) + 17 000*(5+0.5) = 195 500 W
- Supply air temperature 16°C. Indoor temperature to be maintained at 22°C.
- Necessary air flow to remove surplus heat : 31.9 kg/s = 98 200 m3/h at 27°C/50%rH or 95 400 m3/h through duct work at 16°C/80%rH
- Parasittical load of 1K from fans.
- Temperature of cooling coil 15°C

Hang on, hang on.

- Did you notice the internal loads?
- 195 500 W.
- Did you notice the transmission- and infiltration design heat demand?
- 111 931 W.
- This building will NOT experience building heat demand during workdays until the ambient temperature drops below -19°C.
- As a result of this, it basically wont have ventilation heat demand, other than the few hours in the morning where ventilation starts before people arrive

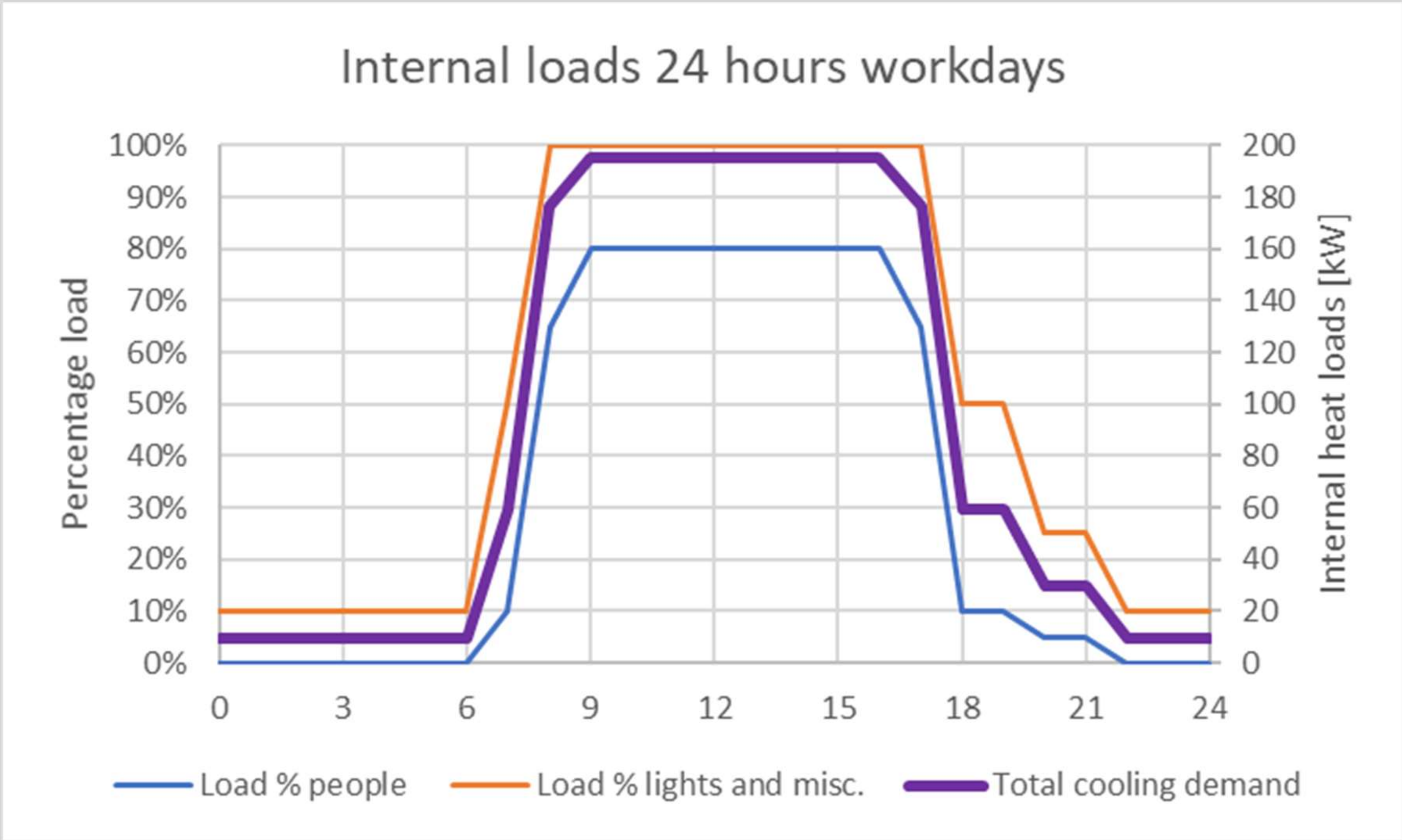
Is a radiator system the good solution?

- If we design the ventilation system for supllying air at 27°C, an air flow of 66 200 m3/h will cover the design building heat demand.
- It is a question of economical and energy analysis to decide whether or not an airborne heating system is to be preferred.

Variation in internal loads

The variations in internal loads are usually very consistent during the work week.

We can also see that the internal loads are larger than the building heat demand.



Example. 25th and 26th of January 2005

Ambient variation

Heat loss variation

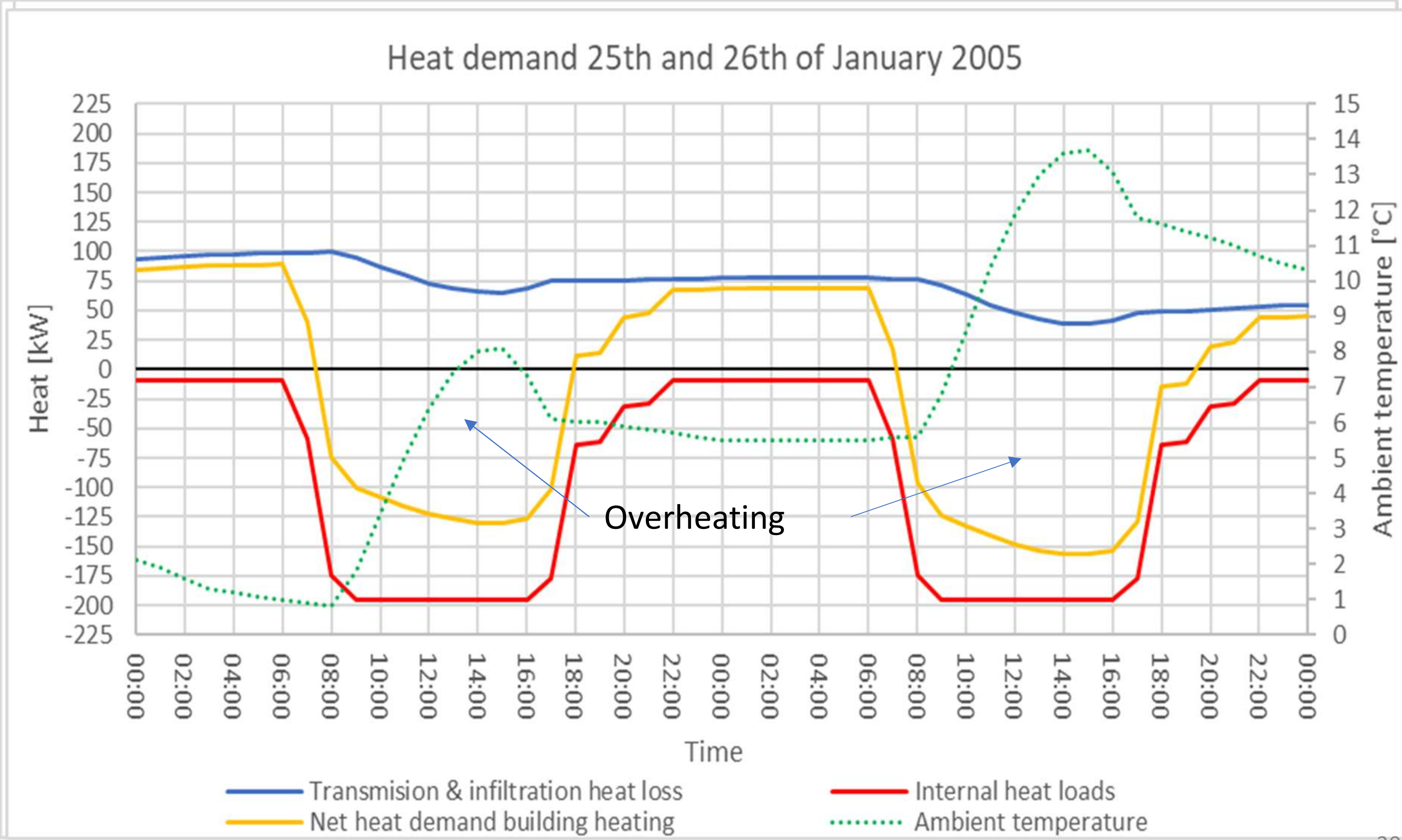
Internal loads

Net building heat demand.

At 2°C ambient the building starts to overheat if we don't do something.

Reduce supply air temperature.

Next step increase air flow.



Example. 25th and 26th of January 2005

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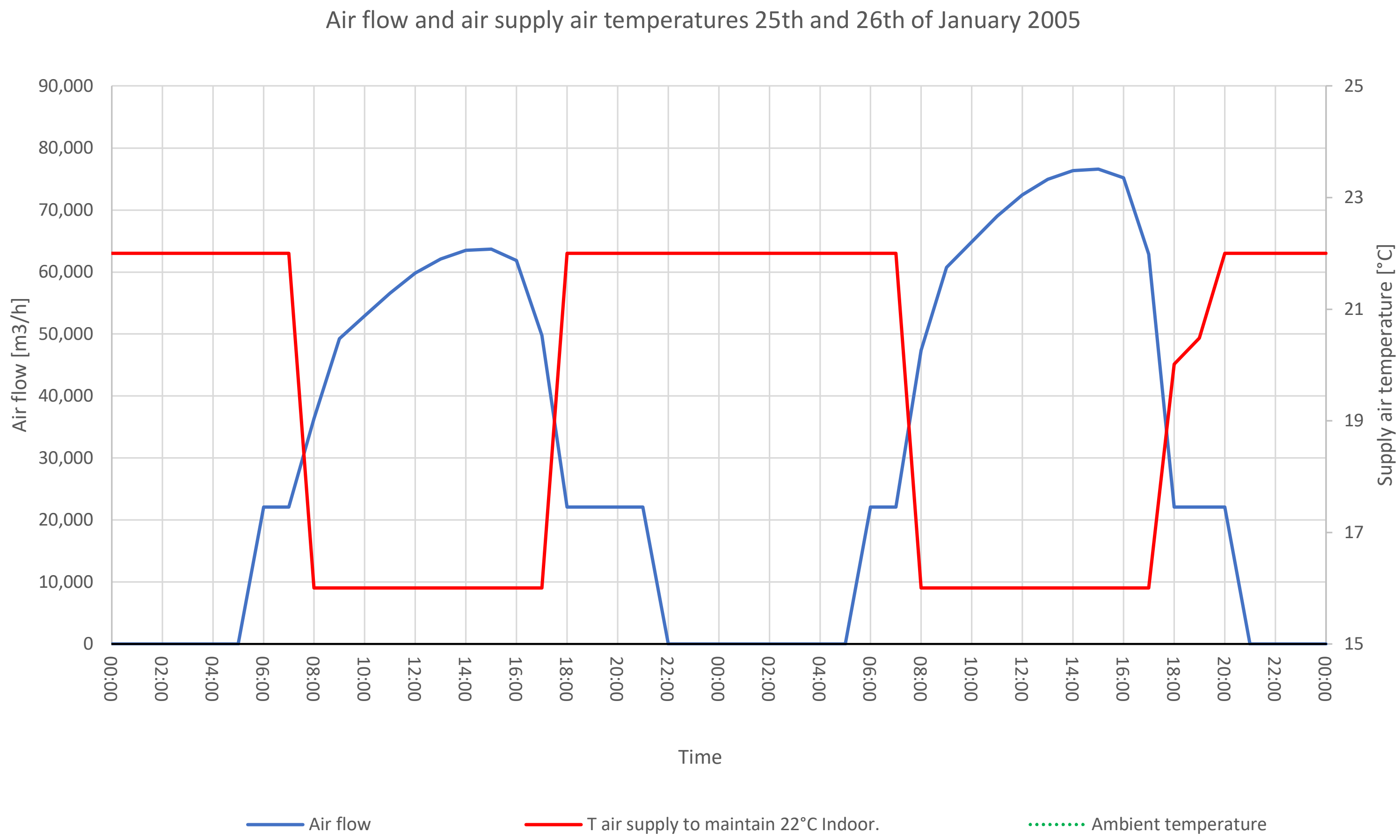
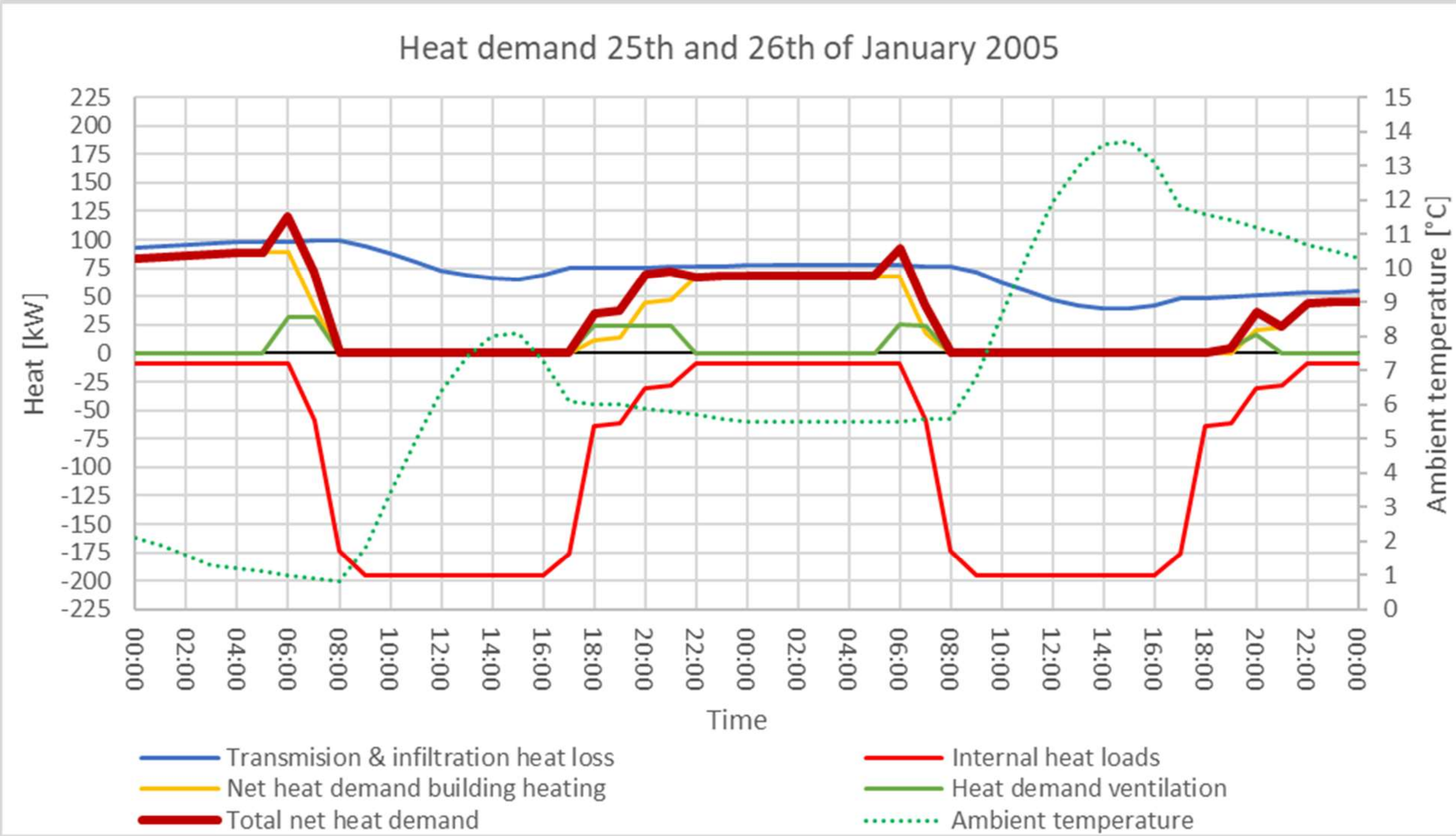


Example. 25th and 26th of January 2005

Ventilation air heat demand.

Total net heat demand

Challenging to be the heating system and maintaining 22°C indoor.

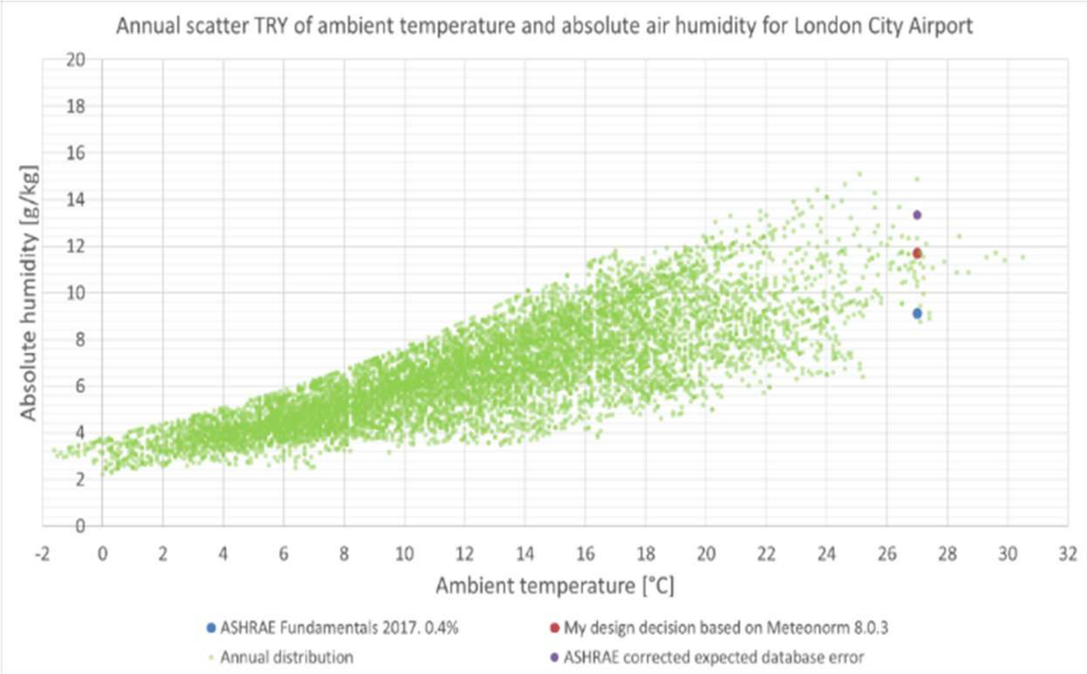


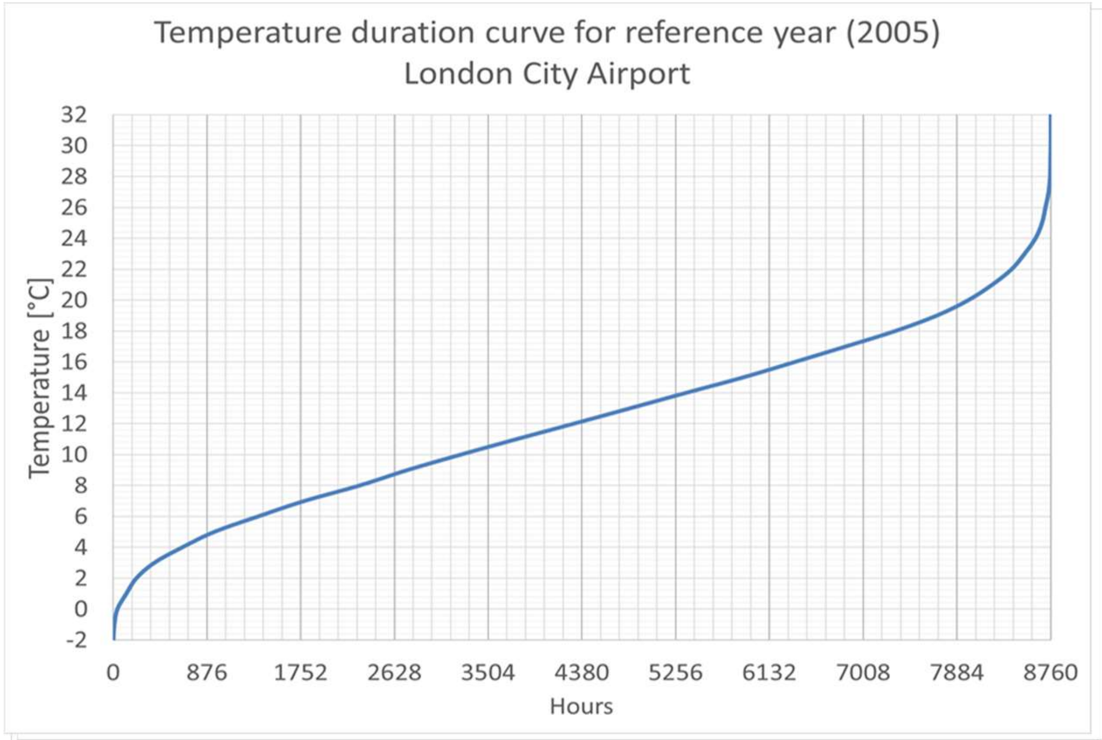
Background data. Climate

- In order to find the total annual heat demand, we need to know how the ambient temperature varies.
- If no data are easily available I use Meteonorm 8 to generate hourly data for a reference year.
- Instead of calculating hour by hour, I calculate degree by degree.
- Not exact, but correct enough to give good guidance.

Annual ambient conditions. Necessary for heat pump design

Data from London City Airport. 8760 datapoints, 2005



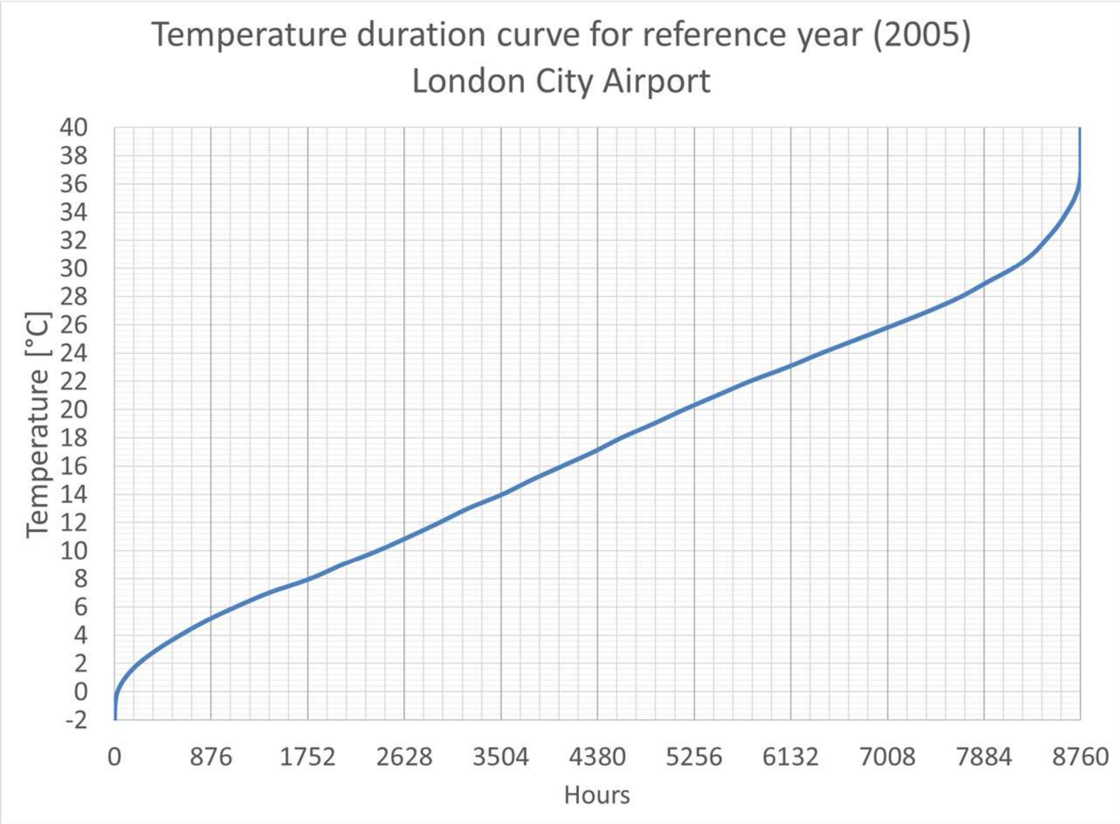


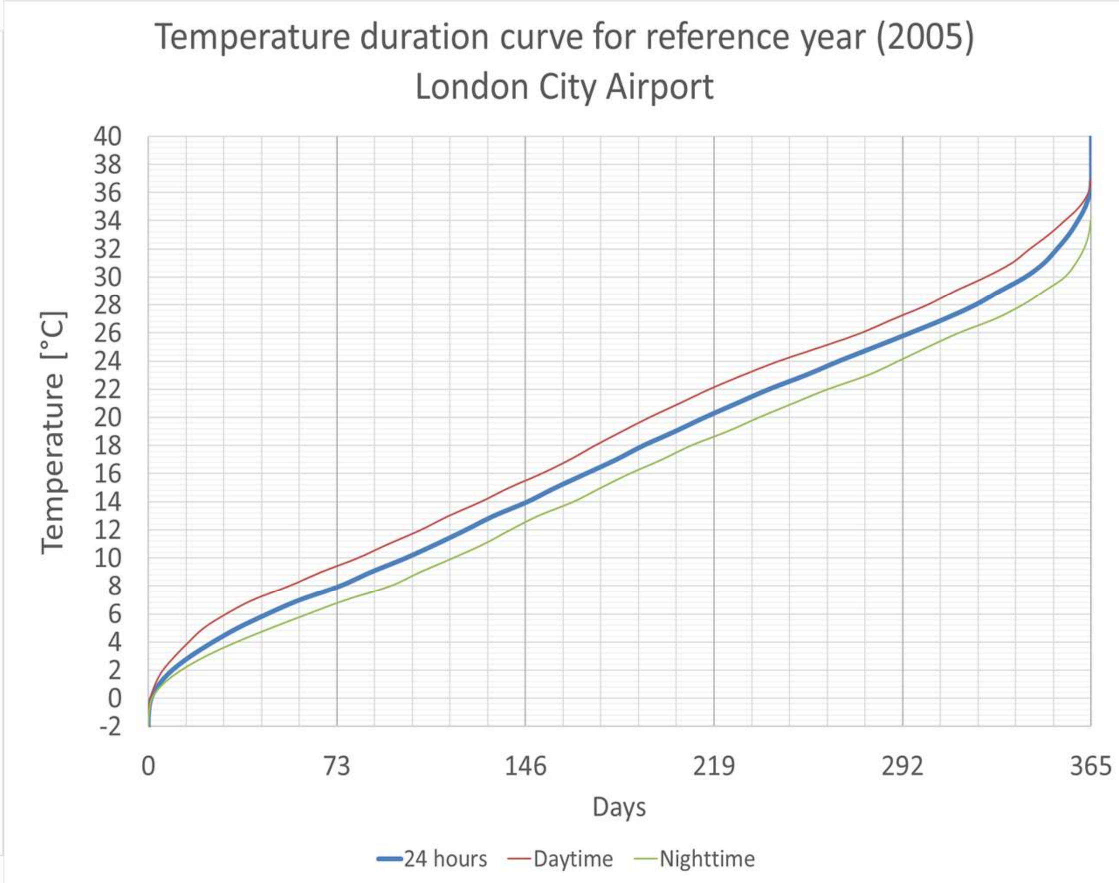
- Winter design ambient temperature -2°C
- Summer design ambient condition 27°C/50%rH

Background data. Climate

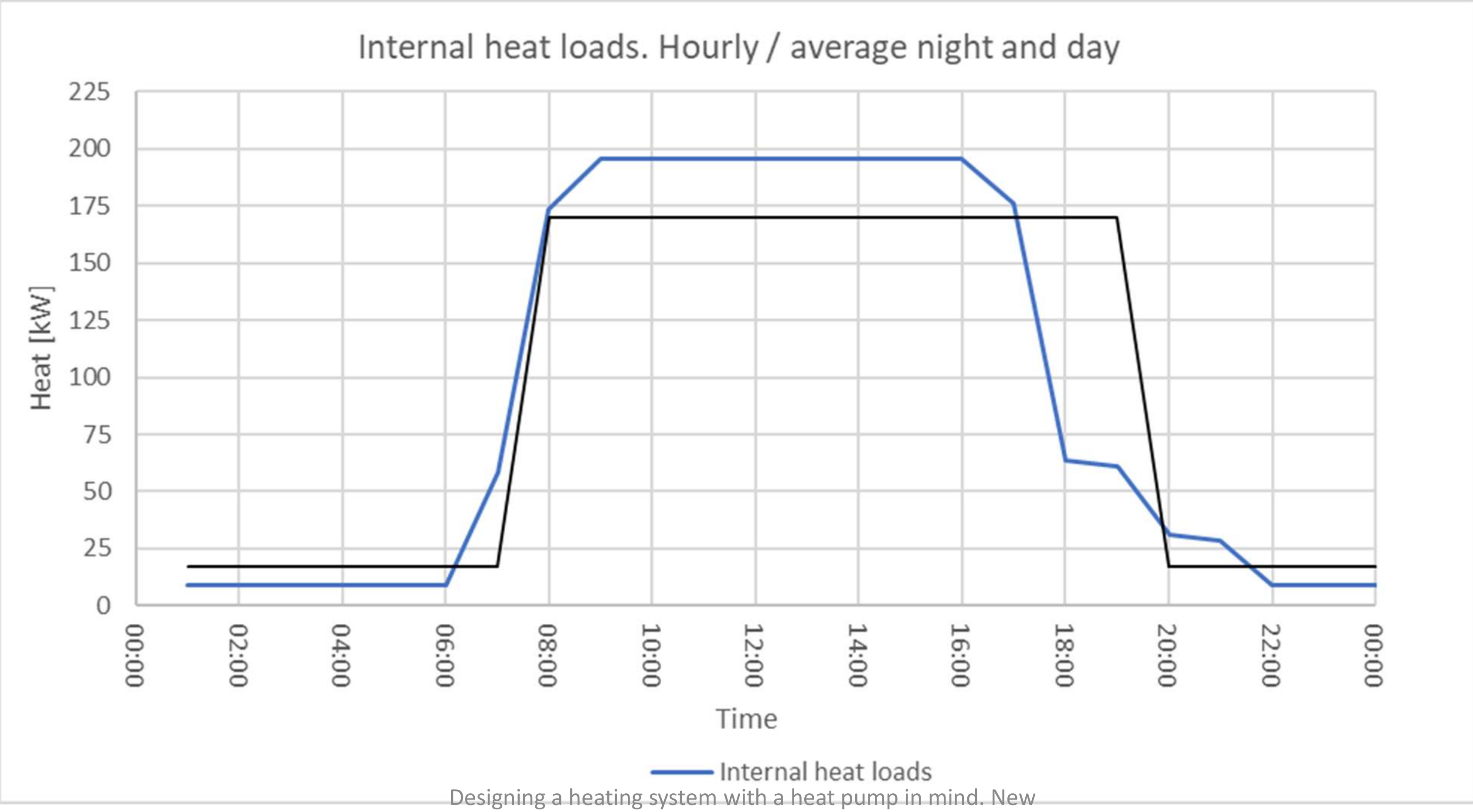
- When calculating to determine heat pump performance in dwellings, we basically don't have to take into account the internal load variations, as they are small.
- However as we saw on the 25th and 26th of January 2005, the internal loads in an office building are quite larger, and varies greatly.
- Furthermore, we saw earlier that the normal internal heat load is greater than the transmission and infiltration losses.
- I use 4 situations, daytime workdays, night time workday, daytime weekends and night time weekends.
- This requires that the climate data are split up.

Background data. Climate

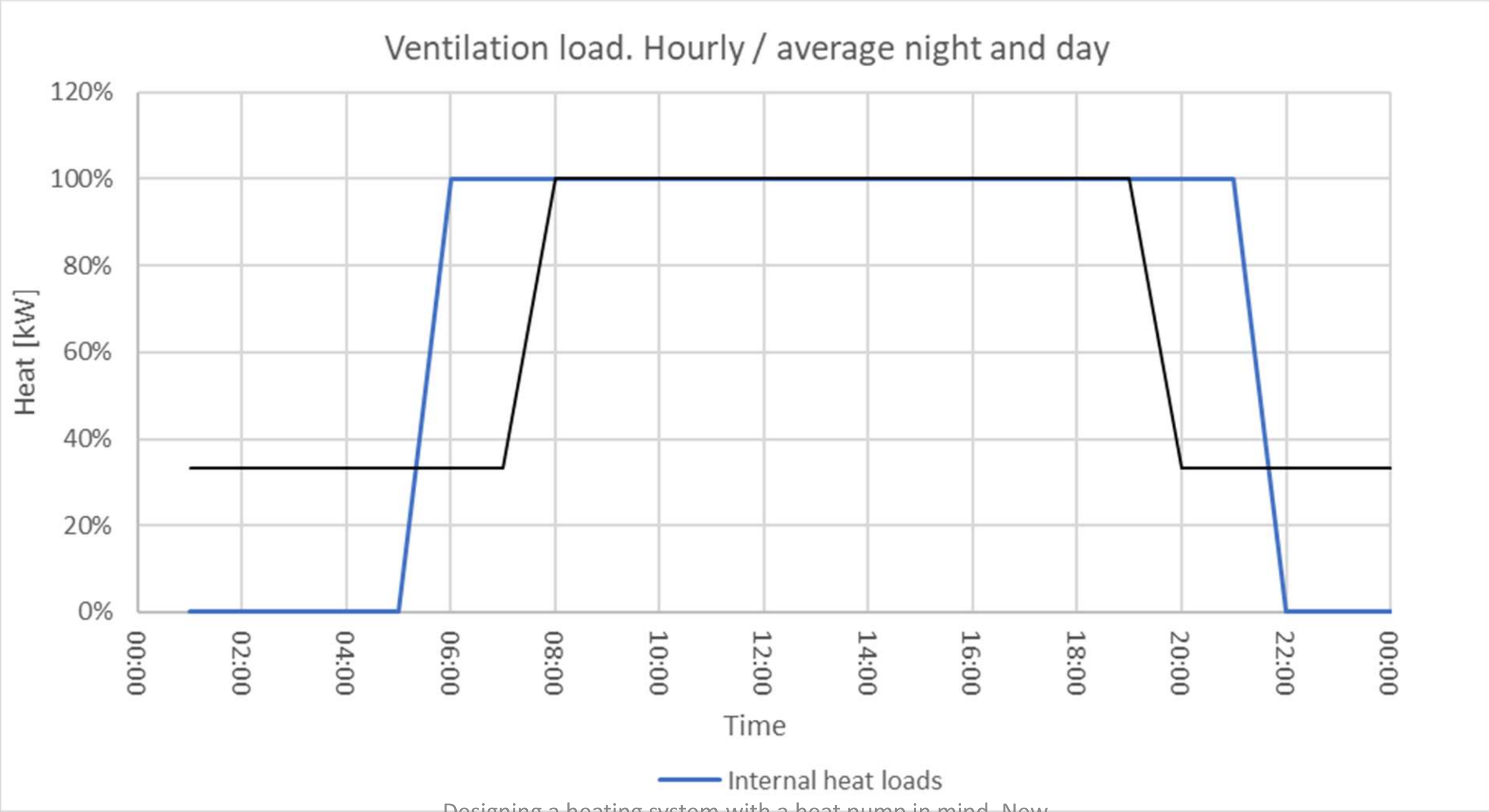




Background data. Internal heat loads



Background data. Ventilation intensity



Work a bit

- Ambient temperature is 6°C.
- Determine the transmission- and infiltration heat loss.
- Night ventilation average is 33% of winter design flow (22 100 m^3/h). Air supply temperature is 22°C, recuperator efficiency is 80%, air extract temperature is 22°C
- Determine the ventilation heat demand.

- 5 minutes

Solution

- Transmission- and infiltration heat demand at 6°C.
- $\dot{Q}_{RAD,DES} = 112\ kW, \Delta T = 22 - (-1.9) = 23.9 \Rightarrow \ \dot{q} = \frac{112}{23.9} = 4.68\ kW/K$
- $\dot{Q}_{RAD,ACT} = 4.68 \frac{kW}{K} x\ (22\ - 6) = 4.68\ x\ 16 = 75\ kW$

- Ventilation heat demand at 6°C
- $T_{ON\ COIL} = \ \varepsilon_{RECUP}\ (T_{INDOOR} - T_{AMB}) + T_{AMB} = 0.8x(22 - 6) + 6 = 18.8°C$
- $\dot{Q}_{COIL,ACT} = \ \dot{m}_{AIR}\ x\ c_{AIR}\ (T_{INDOOR} - T_{ON\ COIL}) = 7.36\text{x}\ 0.33\ \text{x}\ 1.015\ \text{x}\ 3.2 =$ 7.9 kW

Converting heat demand to temperature demand.

$$\dot{Q}_{RAD} = K1 \times \Delta T_{M,RAD}^{1,3} \Rightarrow K1 = \frac{\dot{Q}_{RAD,DES}}{\Delta T_{M,RAD,DES}^{1,3}} = \frac{\dot{Q}_{RAD,ACT}}{\Delta T_{M,RAD,ACT}^{1,3}} \Rightarrow$$

$$\Delta T_{M,RAD,ACT} = \left(\frac{\dot{Q}_{RAD,ACT}}{\dot{Q}_{RAD,DES}}\right)^{\frac{1}{1,3}} \times \Delta T_{M,RAD,DES}; \Delta T_{M,RAD} = \frac{T_{SUPPLY} + T_{RETURN}}{2} - T_{ROOM}$$

$$\dot{Q}_{COIL} = K2 \times \Delta T_{M,COIL} \Rightarrow K2 = \frac{\dot{Q}_{COIL,DES}}{\Delta T_{M,COIL,DES}} = \frac{\dot{Q}_{COIL,ACT}}{\Delta T_{M,COIL,ACT}} \Rightarrow$$

$$\Delta T_{M,COIL,ACT} = \left(\frac{\dot{Q}_{COIL,ACT}}{\dot{Q}_{COIL,DES}}\right) \times \Delta T_{M,COIL,DES};$$

$$\Delta T_{M,COIL} = \frac{T_{SUPPLY,WATER} + T_{RETURN,WATER}}{2} - \frac{T_{AIR,ON} + T_{AIR,OFF}}{2}$$

Convert the heat demands to temperature demand.

- Design conditions for the radiators are
  - Q_{DES} = 111.9 kW
  - T supply, design = 60°C, T return, design = 40°C
  - T room = 22°C
- Design conditions for the heating coil is
  - Q_{DES} = 35.7 kW
  - T supply, water, design = 60°C, T return, water, design = 30°C
  - T air on, design = 17.22°C, T air off = 22°C

- Determine the actual temperature demand for the radiators and the heating coil.
  - 10 minutes

Solution

- $\Delta T_{M,RAD,ACT} = (\frac{75}{111.9})^{\frac{1}{1,3}} \times 28 = 20.6K; \Delta T_{M,RAD,DES} = \frac{60+40}{2} - 22 = 28K$
- $T_{M,RAD,ACT} = \Delta T_{M,RAD,ACT} + T_{ROOM} = 20.6 + 22 = 42.6°C$
- $\Delta T_{WATER,RAD,ACT} = \frac{75}{111.9}\ x\ (60 - 40) = 13.4K$
- $T_{WATER,SUPPLY} = \frac{13.4}{2} + 42.6 = 49.3°C$; $T_{WATER,RETURN} = 49.3 - 13.4 = 35.9°C$

- $\Delta T_{M,COIL,DES} = \frac{60+30}{2} - \frac{17.2+22}{2} = 45 - 19.6 = 25.4K$
- $\Delta T_{M,COIL,ACT} = (\frac{7.9}{35.7}) \times 25.4 = 5.6K \Rightarrow T_{WATER,MEAN} = \frac{18.8+2}{2} + 5.6 = 26°C$
- $\Delta T_{WATER} = \frac{7.9}{35.7} x\ (60 - 30) = 6.64K$
- $T_{WATER,COIL,SUPPLY} = \frac{6.64}{2} + 26 = 29.3°C$; $T_{WATER,RETURN} = 29.3 - 6.64 = 22.7°C$

Compare an old 80°C/60°C system to a new 60°C/40°C

- Some might wonder how much bigger a radiator system you need when going from 80/60 to 60/40.
- An older building would have a radiator heat design demand of 230 kW on 80/60.
- The new building with a heat demand of 112 kW, would it need a bigger radiatorsystem?

- 5 minutes

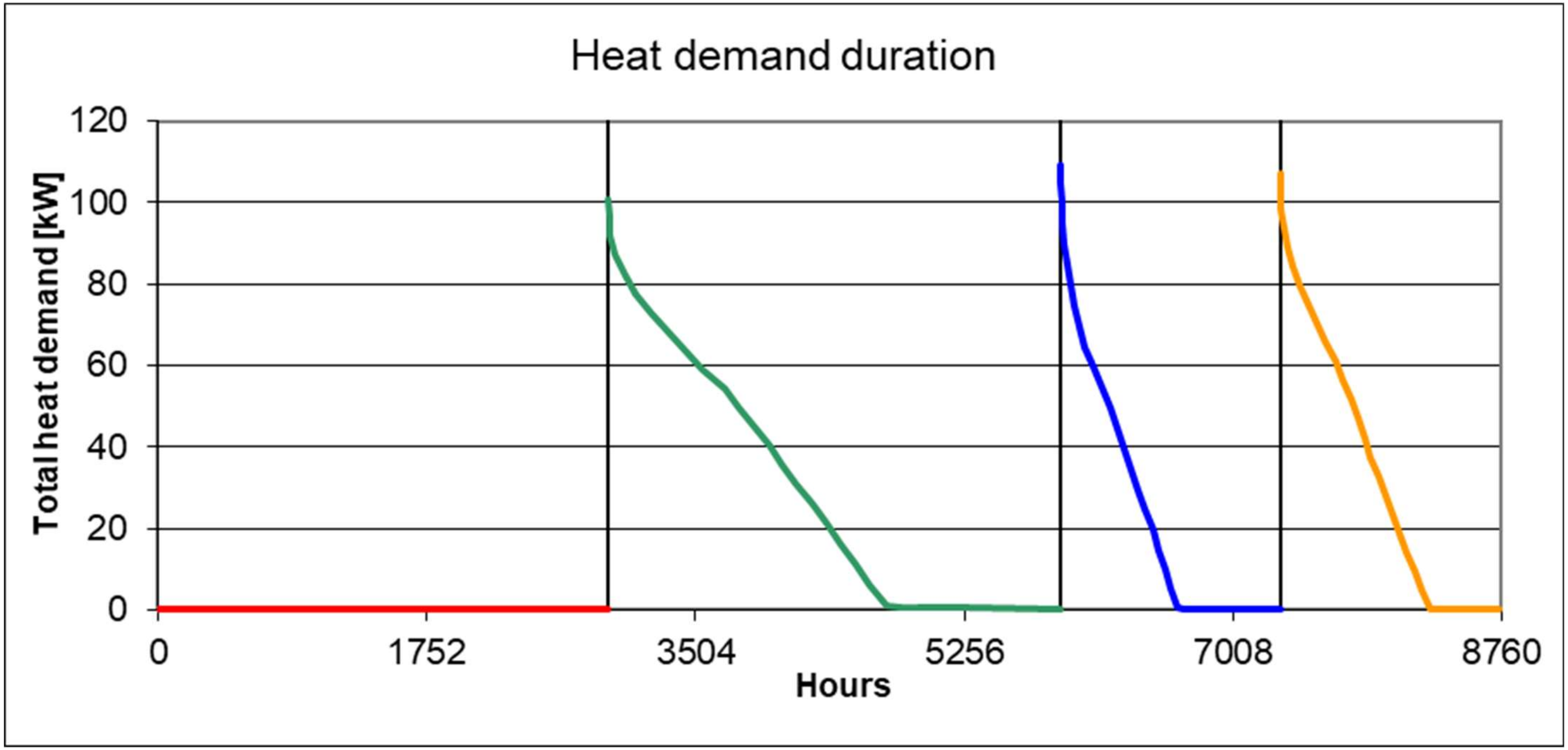
Solution

- $\Delta T_{M,RAD,ACT} = (\frac{\dot{Q}_{RAD,ACT}}{\dot{Q}_{RAD,DES}})^{\frac{1}{1,3}} \times \Delta T_{M,RAD,DES}$; $\Delta T_{M,RAD} = \frac{T_{SUPPLY}+T_{RET}}{2} - T_{ROOM}$
- $\Delta T_{M,RAD,DES} = \frac{80+60}{2} - 22 = 48$
- $\Delta T_{M,RAD,ACT} = (\frac{111,9}{230})^{\frac{1}{1,3}} \times 48 = 27.6K \Rightarrow T_{M,RAD,ACT} = 27.6 + 22 = 49.6K$
- Surface mean temperature in a 60/40 system is 50°C.
- Same system as the old building.

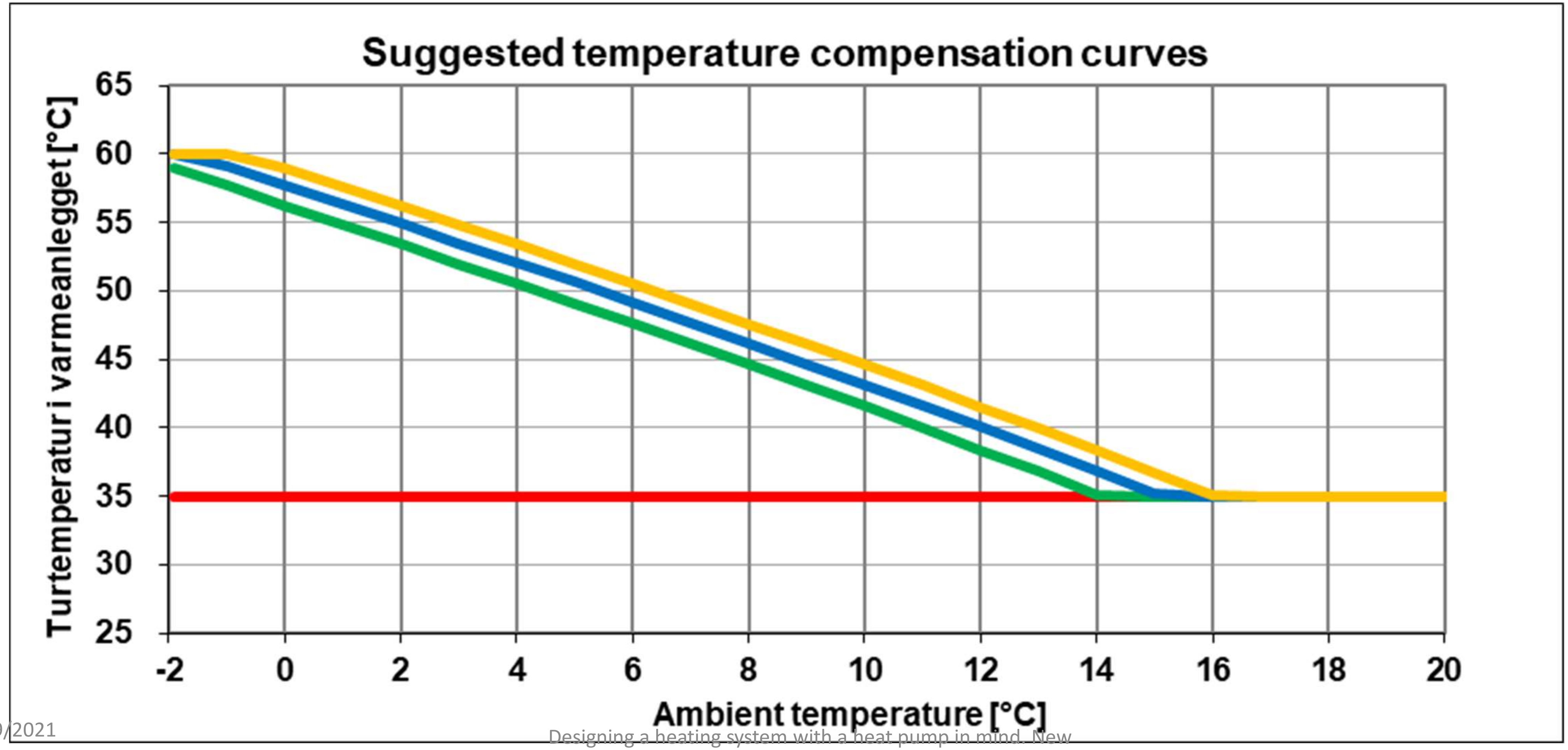
Simulation

- The hard way is to perform this calculations per hour, that means 8 760 calculations.
- The slightly easier way is to calculate 4 situations in steps or 1K. App 4 x 60 calculations.
- I haven't found of the shelf programmes that can perform this, so it is up to you.

Simulation results



Simulation results



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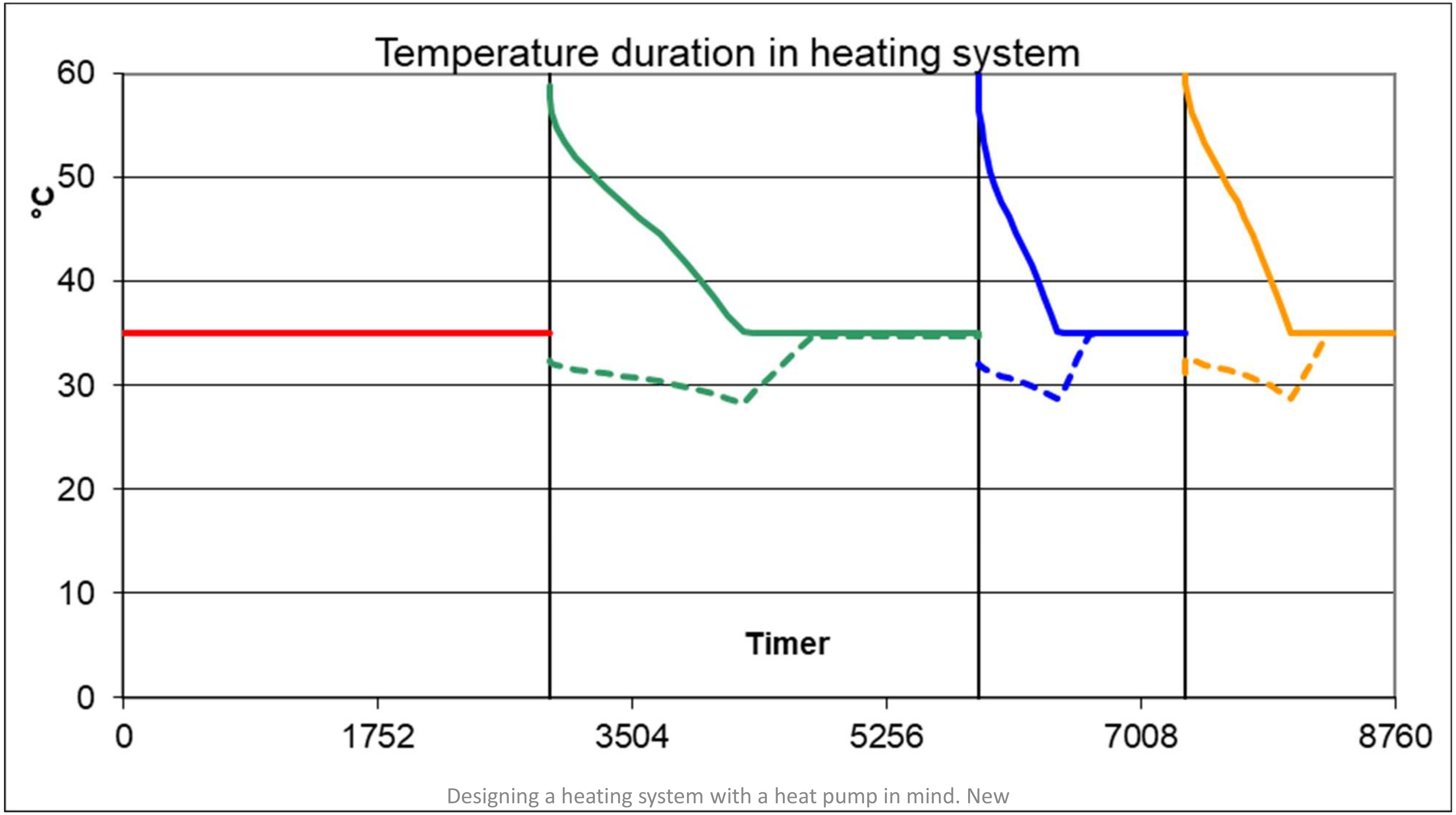
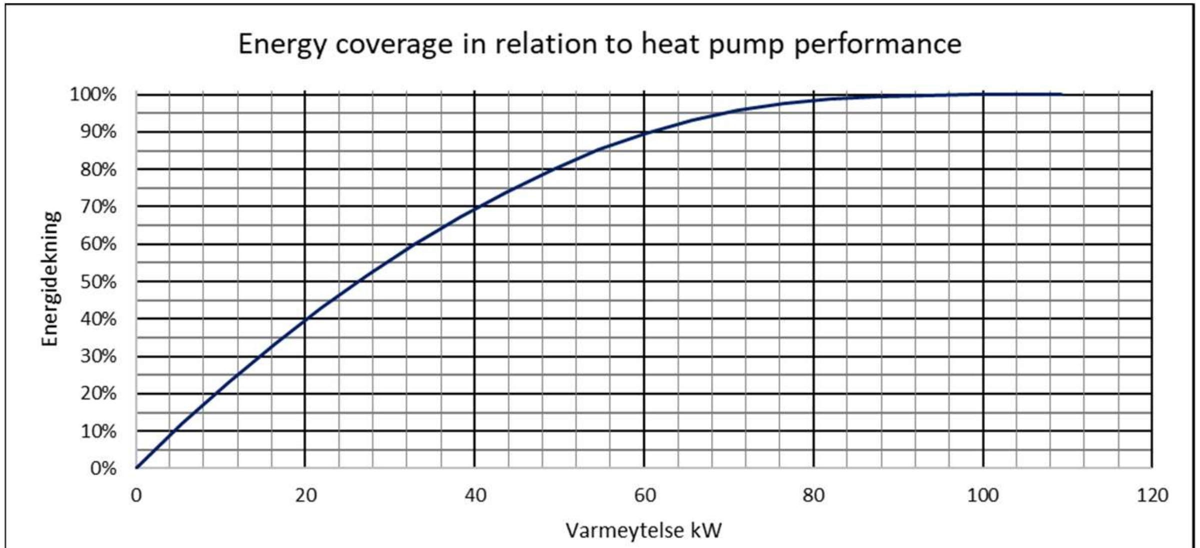


Simulation results

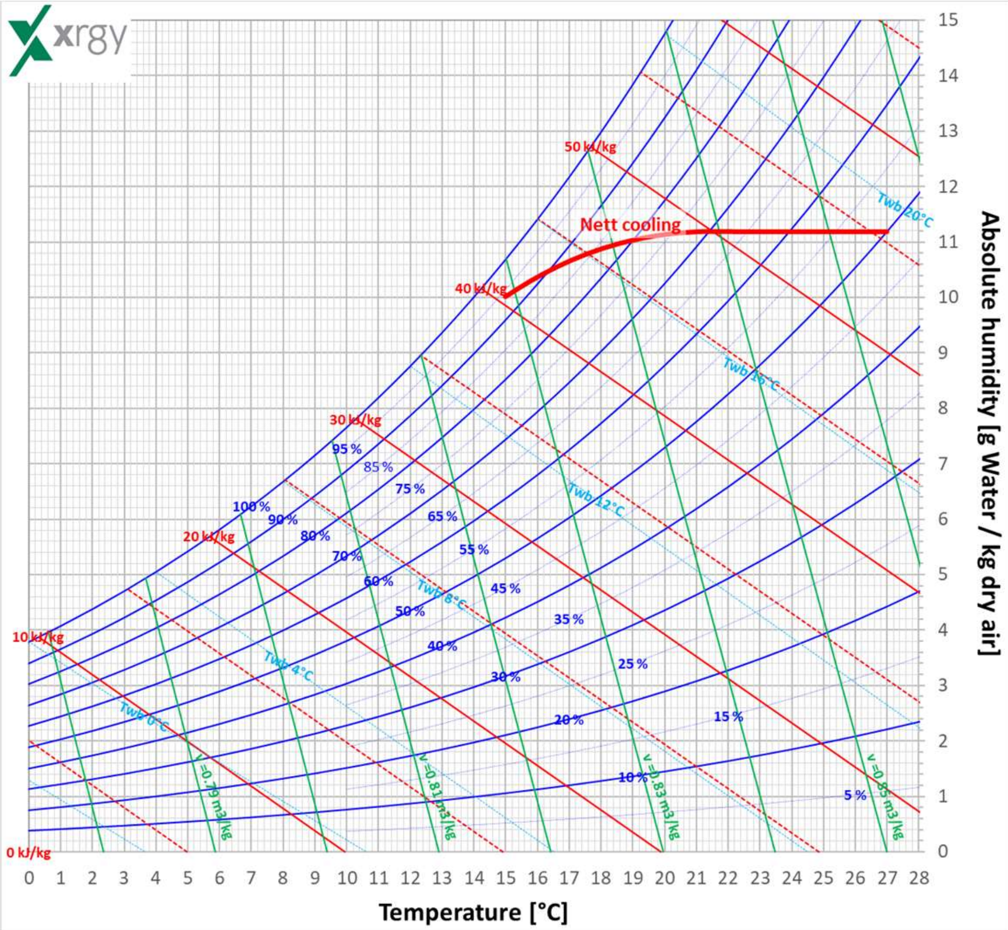
- Annual heat demand 161 700 kWh
- Heat pump coverage 95%
- Suggested heat pump performance 70 kW
- Annual run time 2 200 h

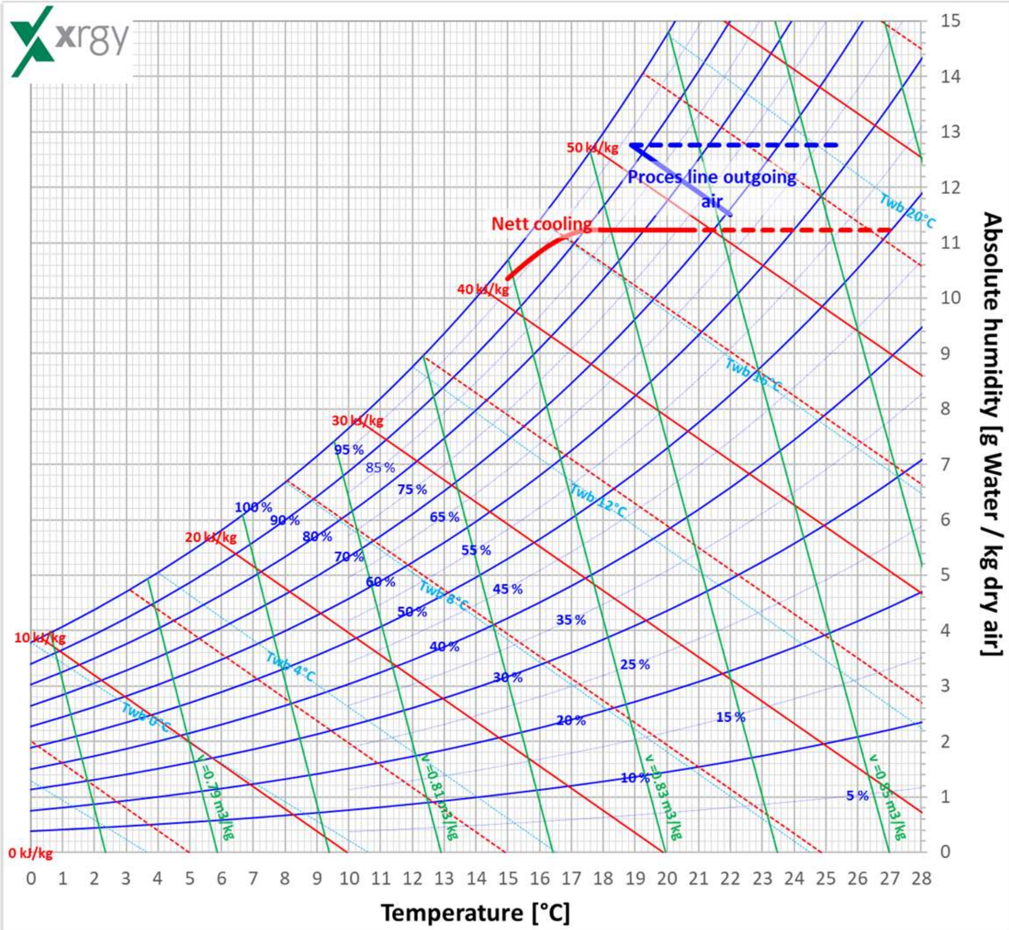


Cold demand.

- Why look at that?
- If done correctly the chillers can be used as heat pumps.
- Cooling ambient air from 27°C/50%rH to 15°C
- Using hydronic system running at 12°C/17°C.
- Cold demand : 489 kW.
- Using evaporative precooling...
- Cold demand : 252 kW
- The machinery is of ample size to cover the heat demand.

Cold demand


xrgy
Nett cooling
50 kJ/kg
40 kJ/kg
30 kJ/kg
20 kJ/kg
10 kJ/kg
0 kJ/kg
100 %
95 %
90 %
85 %
80 %
75 %
70 %
65 %
60 %
55 %
50 %
45 %
40 %
35 %
30 %
25 %
20 %
15 %
10 %
5 %
Twb 0°C
Twb 4°C
Twb 8°C
Twb 12°C
Twb 16°C
Twb 20°C
v =0.79 m3/kg
v =0.81 m3/kg
v =0.83 m3/kg
v =0.85 m3/kg
Temperature [°C]
Absolute humidity [g Water / kg dry air]


xrgy
Proces line outgoing air
Nett cooling
50 kJ/kg
40 kJ/kg
30 kJ/kg
20 kJ/kg
10 kJ/kg
0 kJ/kg
100 %
95 %
90 %
85 %
80 %
75 %
70 %
65 %
60 %
55 %
50 %
45 %
40 %
35 %
30 %
25 %
20 %
15 %
10 %
5 %
Twb 0°C
Twb 4°C
Twb 8°C
Twb 12°C
Twb 16°C
Twb 20°C
v =0.79 m3/kg
v =0.81 m3/kg
v =0.83 m3/kg
v =0.85 m3/kg
Temperature [°C]
Absolute humidity [g Water / kg dry air]

Generel system considerations

- In the machinery room the heat pump must ALWAYS be the first source of heat.
- Normally a heat pump will be put in series with a boiler or any other back up unit.
- The supply from the back up unit has to be VERY slow to start.
- It is essential that the heat pump has sufficient water to work against, preferably tanks.
- A Norwegian rule of thumb says that you should have 20 l of tank volume per kW of minimum performance.

Generel system considerations

- Use natural refrigerants to future proof your installations.
- In new systems, control the temperature in the heating circuit from the opening of the radiator valves in the area with the highest demand.
- Typically the opening should be 90%-95%
- If you can avoid it, do not use circulation pumps with frequency converters. They usually mask errors in the temperature settings.

Thank you

- Thank you for taking part in this, and I would very much like to get some feed back from you.

- I hope you found this interesting, I got a few surprises when working on it, especially when applying the Norwegian building codes in a climate as warm as the UK.