Cold water shafts in buildings

Comparison of simple thermal model to detailed models and lab-experiments

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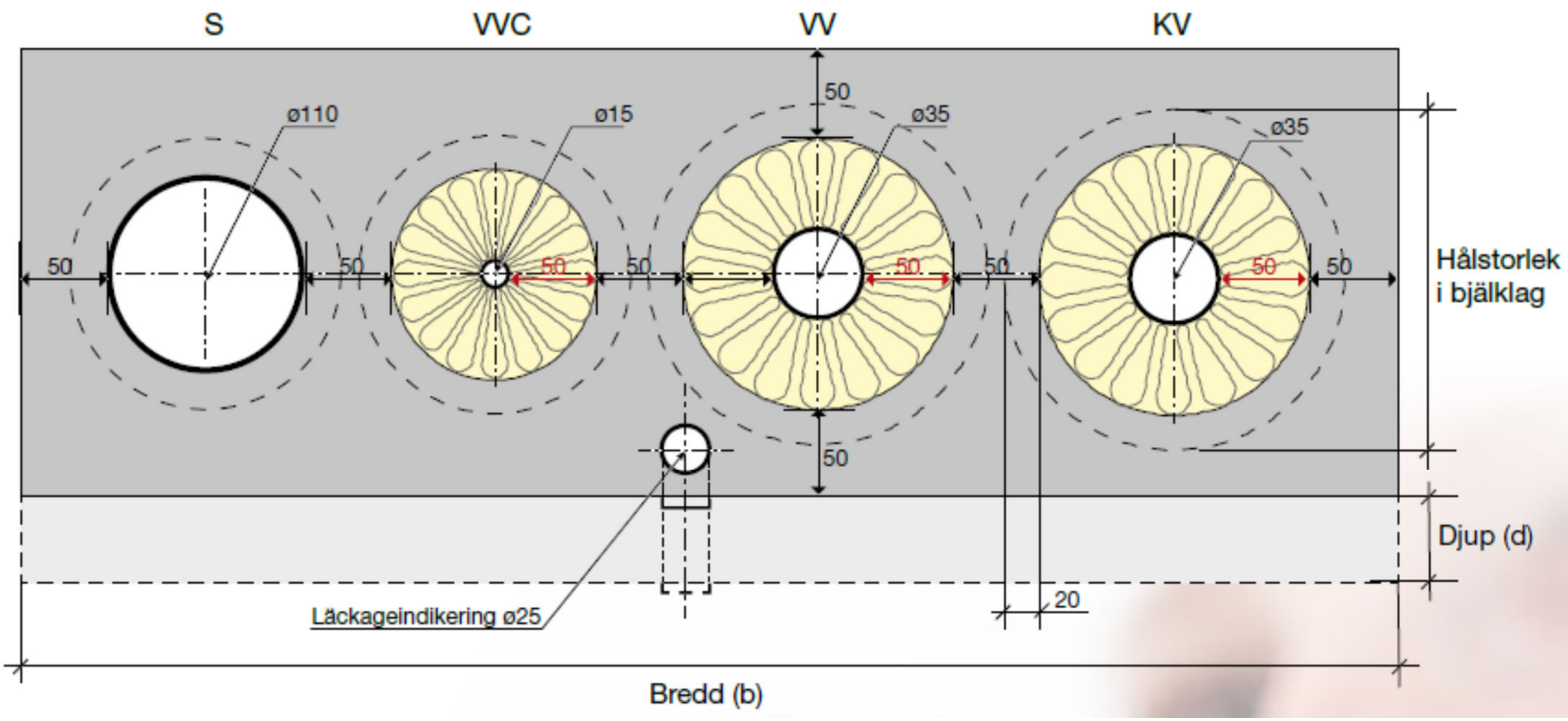
Regulation (<24°C / 8hrs)

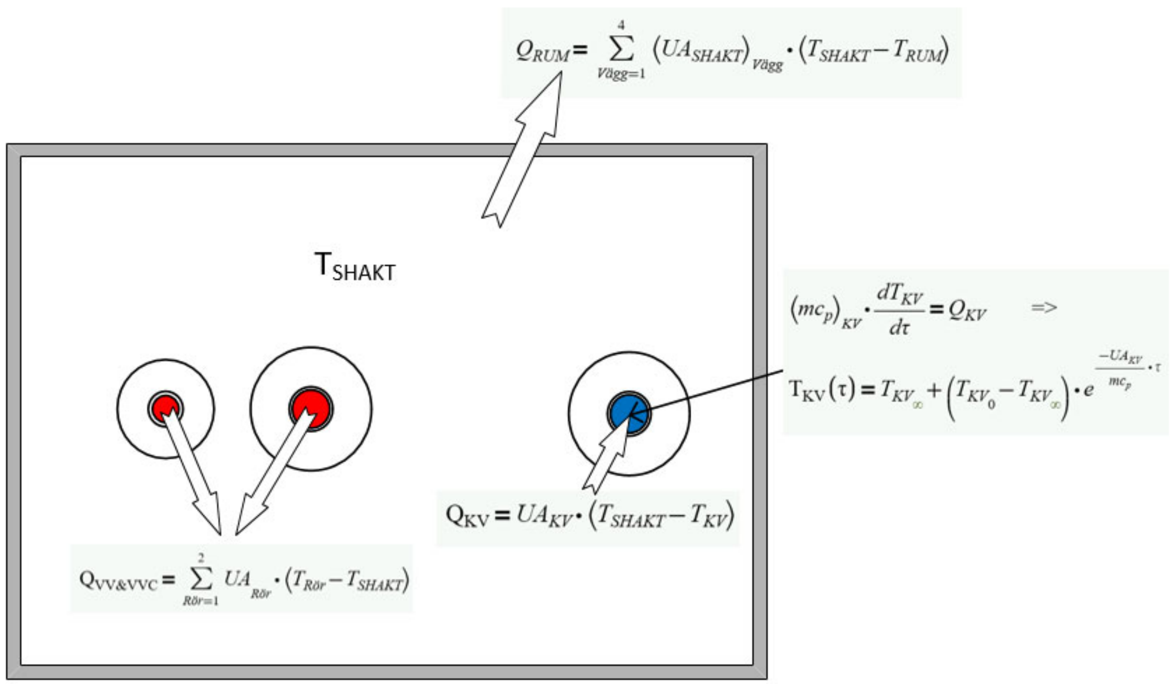
”..tappkallvatteninstallationer bör inte placeras… …i varma schakt eller varma golv, i vilka installationer för t.ex. tappvarmvatten, tappvarmvattencirkulation och radiatorer är förlagda. Om det är omöjligt att undvika att placera tappkallvatteninstallationer på sådana ställen så… …bör installationernas utformning och isolering dimensioneras så att tappkallvattnet kan vara stillastående i 8 timmar utan att temperaturen på tappkallvattnet överstiger 24 °C.”

Standard layout



Model proposed by Säker Vatten

- Based on Lumped Capacity methodology, transient 0D
- Simplified, as shaft temperature assumed constant



Limitations with the proposed model

- Does not account for varied shaft temperatures over time
- Does not account for storage effects in other parts of the shaft
- Does not account for air movement within the shaft
- Does it matter?

More comprehensive models (0D, 2D, 3D)

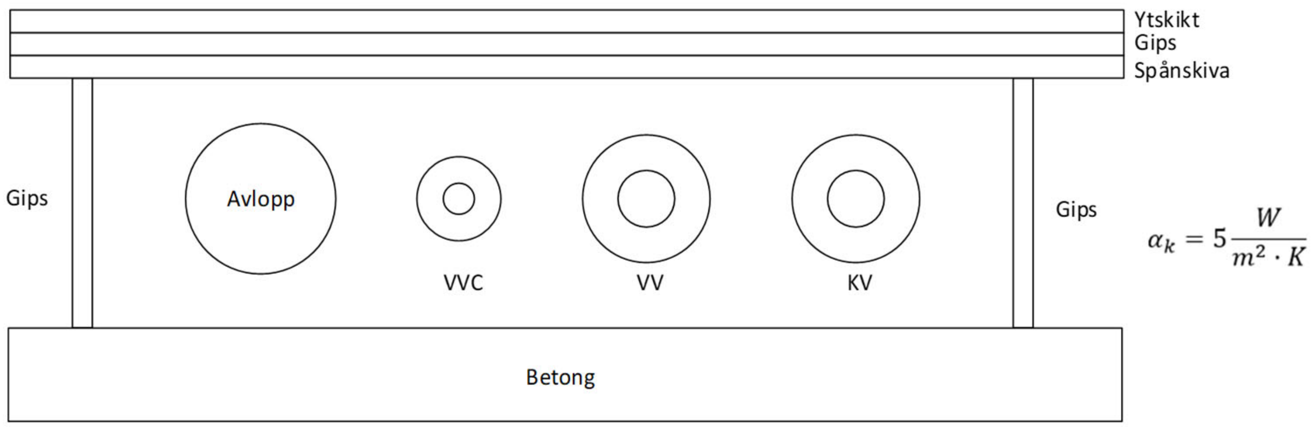
- 0D, Coupled Lumped Capacity,
  - Account for storage effects in most of the materials and components in the shaft
  - Assume no spatial temperature gradients within the shaft air

- 2D-FEM,
  - Assume no spatial temperature gradients within the shaft air

- 3D-FEM

Geometry and assumptions used

$\alpha_k = 5 \frac{W}{m^2 \cdot K}$ $t_{badrum} = 23°C$ or 24°C (for 0D)



$\alpha_k = 5 \frac{W}{m^2 \cdot K}$

Dimension	Värde
VV-rör	28 mm
VVC-rör	15 mm
KV-rör	28 mm
Avloppsrör	110 mm
Isolertjocklek	50 mm
Minsta inre avstånd	50 mm

Material	Densitet $\frac{kg}{m^3}$	Värmelednings-förmåga $\frac{W}{m \cdot K}$	Värme-kapacitet $\frac{J}{kg \cdot K}$
Isolering	206.77	0.036 till 0.052	11 – 24
Spånskiva	619	0.1672	1 552
Betong	2 300	1.8	880
Gipsskiva	570	0.19 (torr)	1 100
Ytskikt	180	0.9 (torr)	850
Vatten	980 – 1000	0.56 – 0.65	4 180 – 4 200

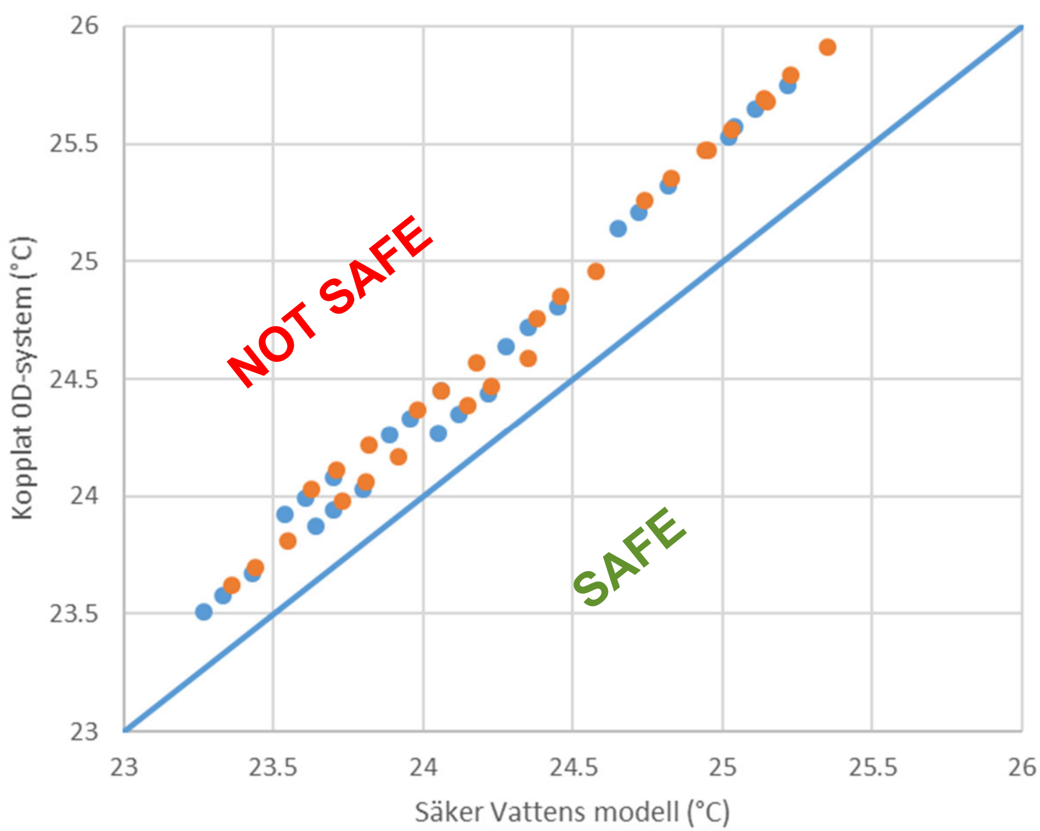
System of 0D-models

$$(m \cdot c_p)_{AVL} \cdot \frac{dT_{AVL}}{d\tau} = UA_{AVL} \cdot (T_{SHAKT} - T_{AVL})$$

$$(m \cdot c_p)_{KV} \cdot \frac{dT_{KV}}{d\tau} = UA_{KV} \cdot (T_{SHAKT} - T_{KV})$$

$$(m \cdot c_p)_{SV} \cdot \frac{dT_{SV}}{d\tau} = UA_{i_{SV}} \cdot (T_{SHAKT} - T_{SV}) + UA_{y_{SV}} \cdot (T_{rum} - T_{SV})$$

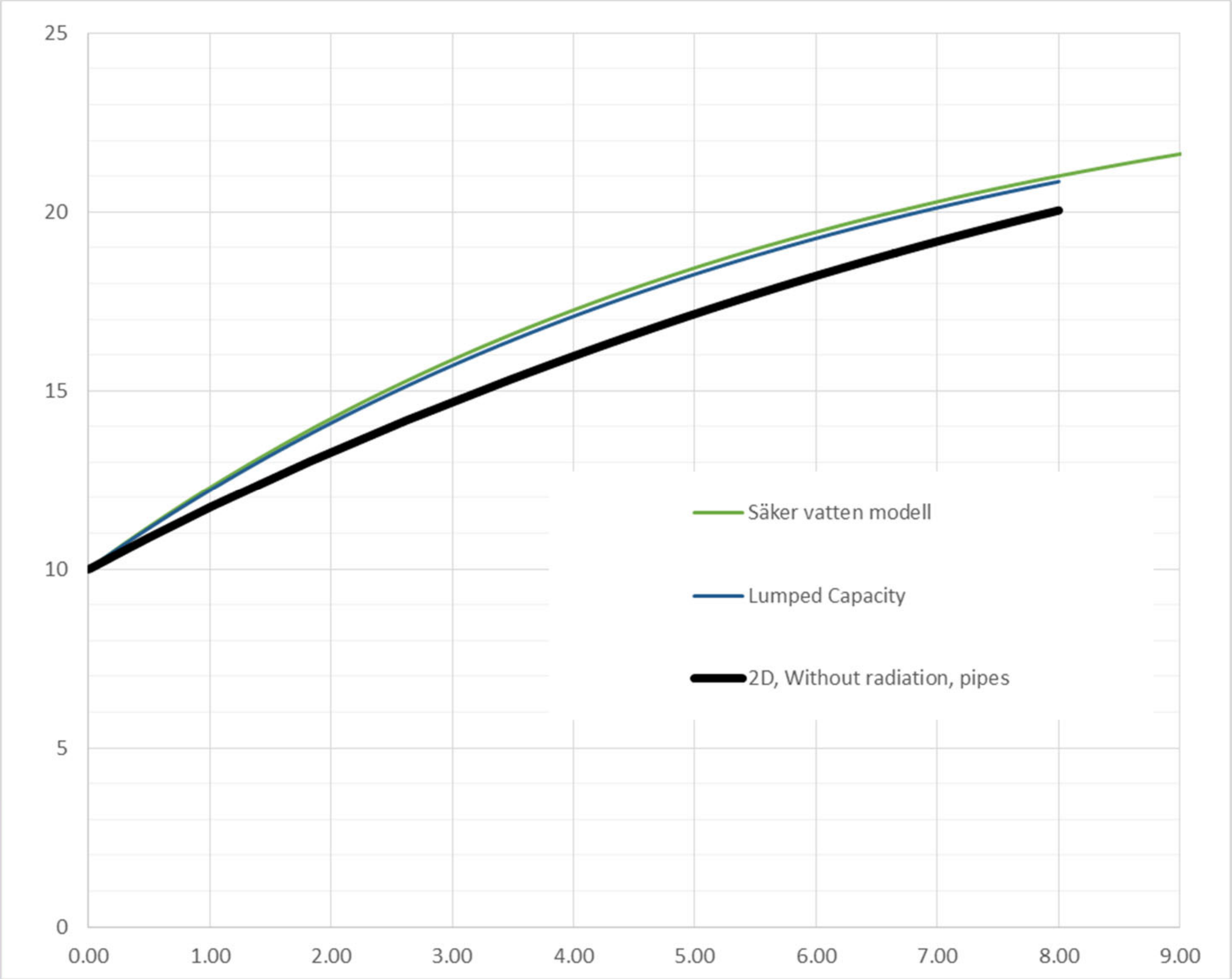
$$(m \cdot c_p)_{SHAKT} \cdot \frac{dT_{SHAKT}}{d\tau} = UA_{AVL} \cdot (T_{AVL} - T_{SHAKT}) + UA_{VV} \cdot (T_{VV} - T_{SHAKT}) + UA_{VVC} \cdot (T_{VVC} - T_{SHAKT}) + UA_{KV} \cdot (T_{KV} - T_{SHAKT}) + UA_{i_{SV}} \cdot (T_{SV} - T_{SHAKT})$$



Conclusion:
More details alter the results, approximately 0.5 K to the **UNSAFE** side.

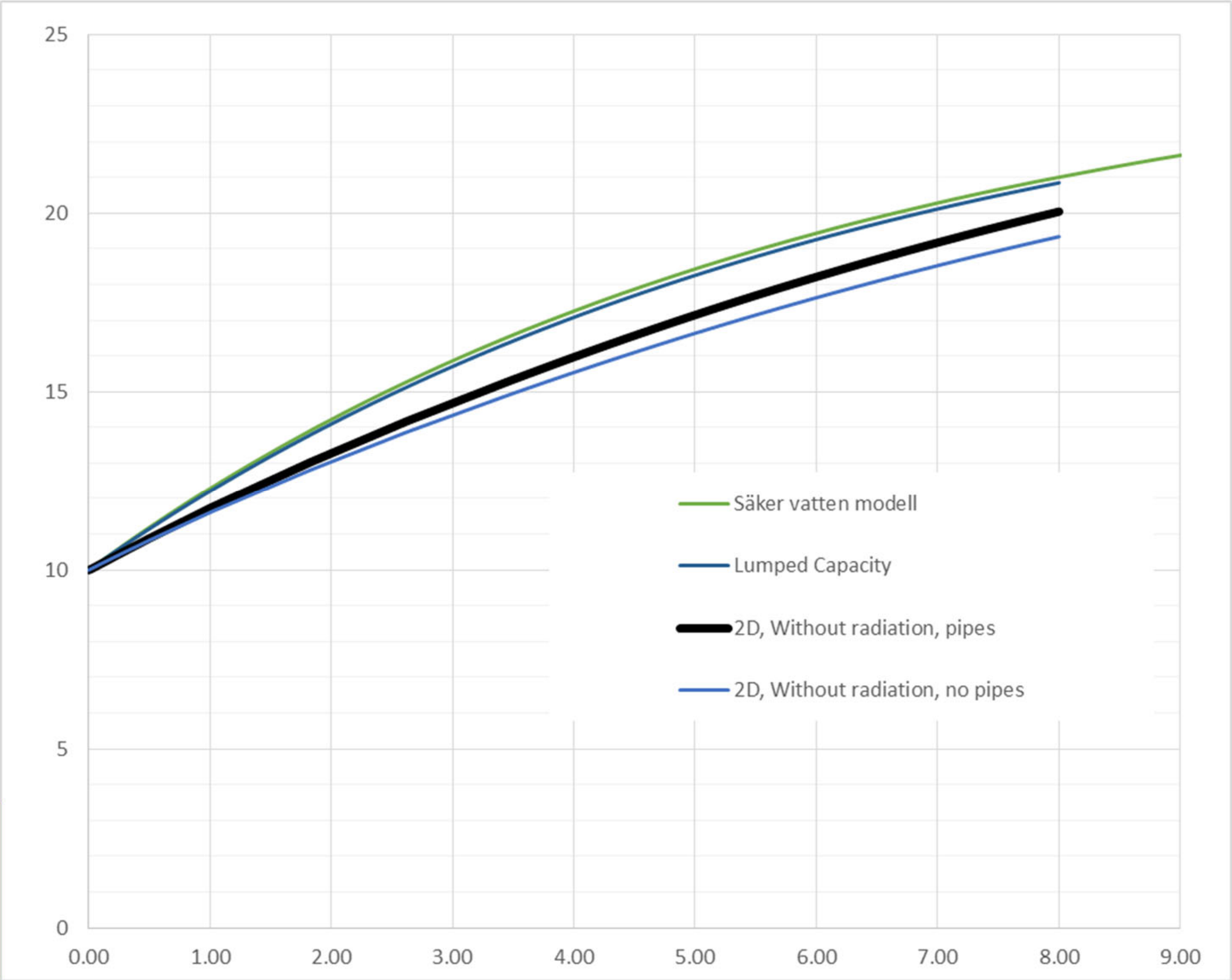
Transient 2D

- Physical dimensions and storage capacities are accounted for, no radiation heat transfer assumed



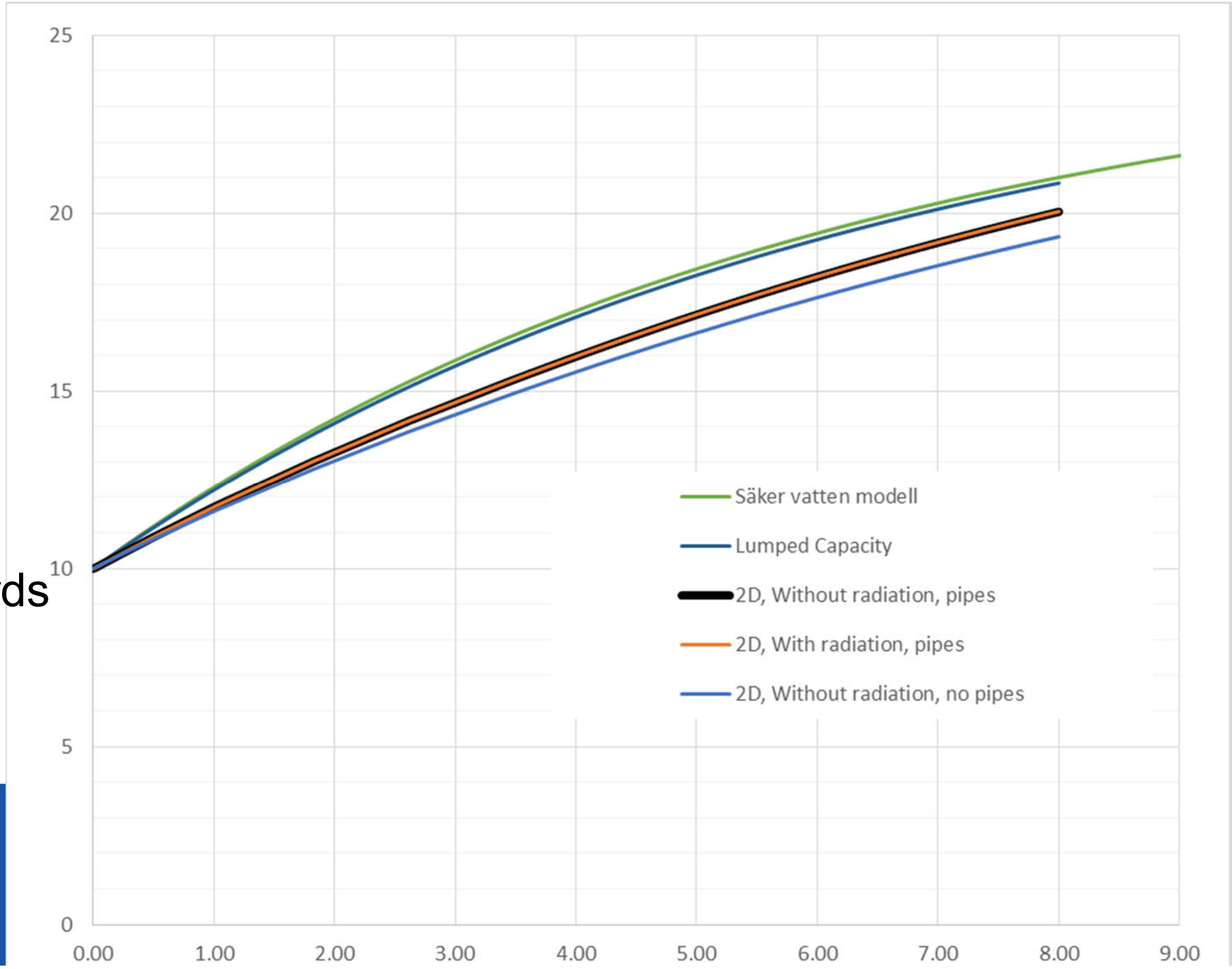
Transient 2D, No Pipes (just water…)

- Pipe volume is replaced with water



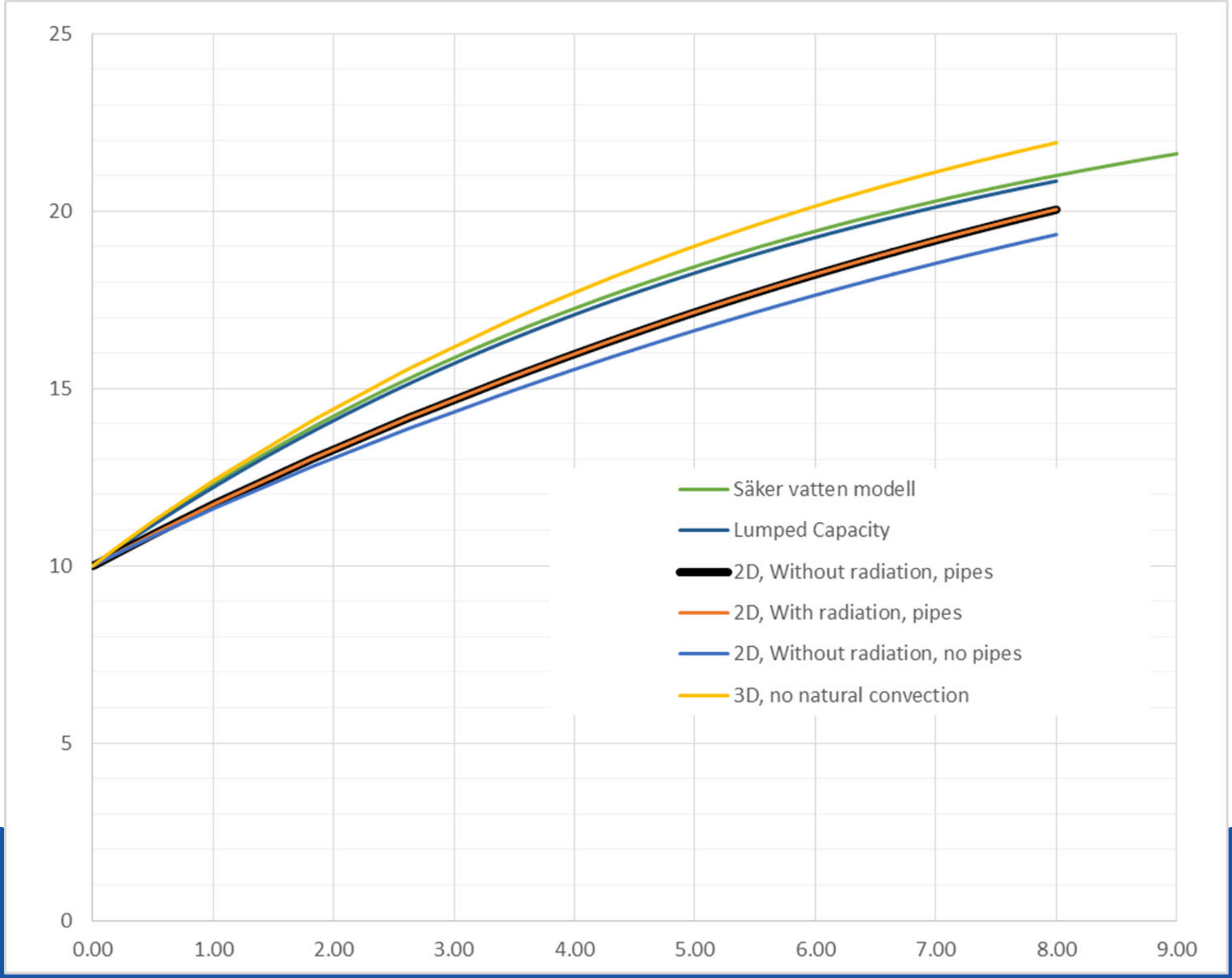
2D, pipes and radiation

Radiation does not seem to have any impact on the result



Conclusion:
2D alter the results, and towards the **SAFE** side

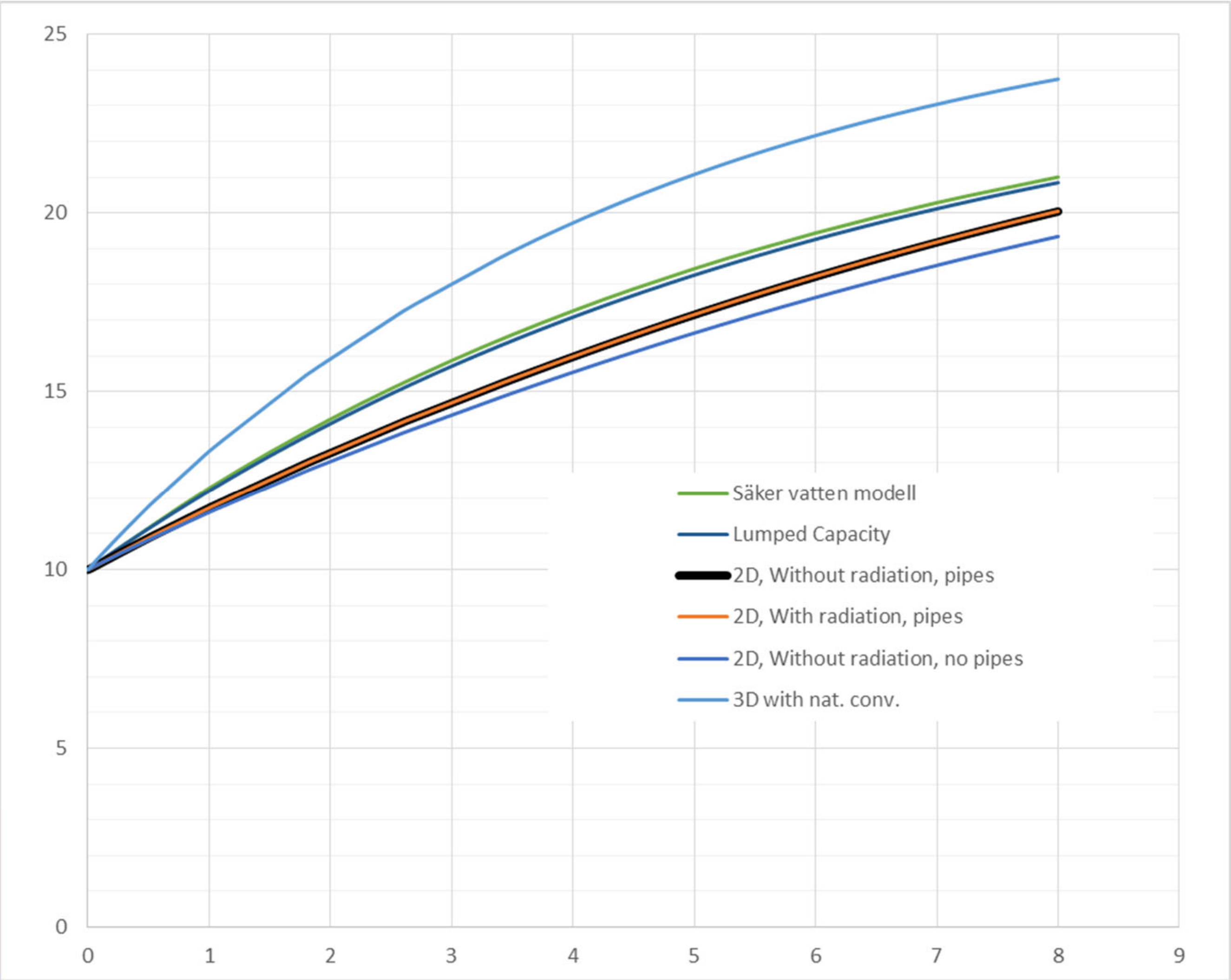
3D, no air movement accounted for



3D, with air movement accounted for

Including 3D and buoyancy both increase the heat transfer to the Cold Water Pipe

Conclusion:
3D alter the results, and towards the **UNSAFE** side



Model uncertainty

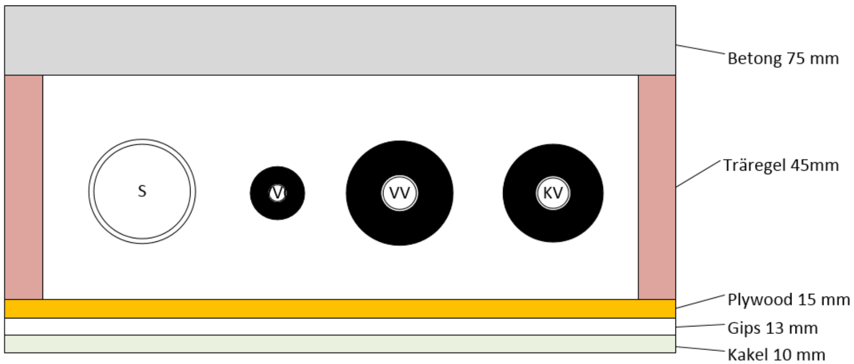
What is the most critical parameters in the model by Säker Vatten:

- Cold Water volume and properties (storage capacity)
- Heat transfer resistance between the shaft air and the surrounding room air
- Surrounding room temperatures
- Incoming Cold Water temperature
- Insulation thickness of the cold water pipe way more important than the insulation on the hot water pipes

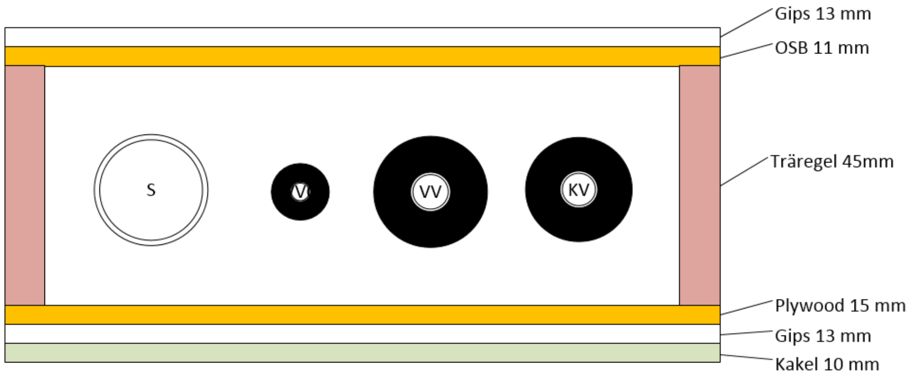
Next phase – check response of different configurations

Since the 3-D model seemed to indicate that the Cold Water temperature increase faster than the simple 0D model, can the simplistic model still be used?

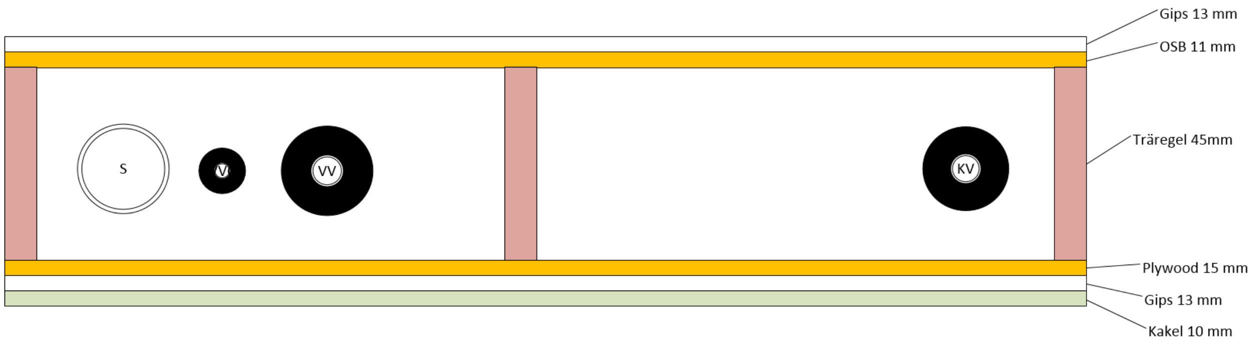
Phase 3 – 3 different types



Schakt #1



Schakt #2



Schakt #3

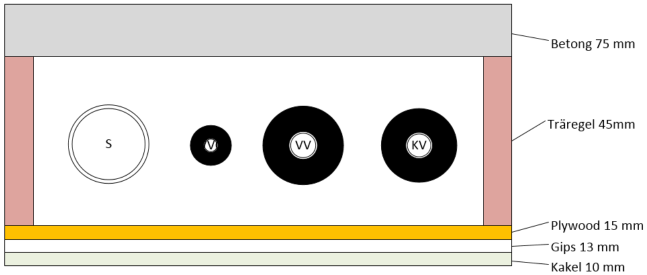
Thermal properties and boundary conditions

Lambdavärden		
Trä		0.14
Betong		1.7
Gipsskiva		0.25
Plywood		0.14
Spånskiva		0.14
Tegel		0.6
Kakel	ca	1.5

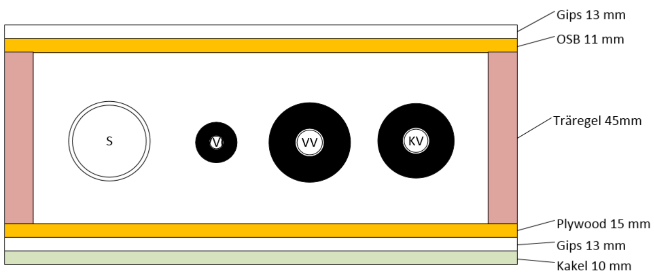
Rörmaterial		Dy	h	Di
Koppar		15	1	13
small		22	1	20
large		28	1.2	25.6
very large		35	1.5	32
PP		16	2.7	10.6
small		20	2.8	14.4
large		25	3.5	18
very large		32	3.6	24.8

- Cold water temperature is initially 10°C.
- Circulated Hot water temperature is 60°C
- Surrounding room temperature is 23°C

Results



Schakt #1

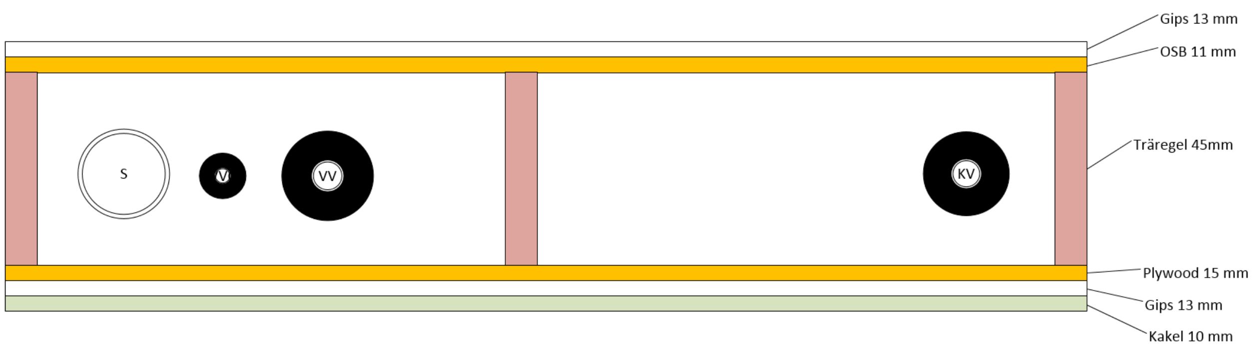


Schakt #2

					Temperatur efter 8 hr		
Testcase	Schakttyp	Rörtyp	Rörstorlek	Isolering	Olle KV-temp (VVC = 55°C)	Olle KV-temp (VVC = 60°C)	3D-simulering (VVC = 60°C)
1	Betong	Cu	Small	40	24.3	24.6	25.4
2	Betong	Cu	Small	50	23.9	24.2	25.1
3	Betong	Cu	Small	60	23.6	23.9	24.8
4	Betong	Cu	Large	40	23.5	23.8	23.7
5	Betong	Cu	Large	50	22.9	23.1	23.3
6	Betong	Cu	Large	60	22.4	22.7	23.1
7	Betong	PP	Small	40	ej aktuell	ej	26.4
8	Betong	PP	Small	50	ej aktuell	ej	26.1
9	Betong	PP	Small	60	ej aktuell	ej	25.9
10a	Betong	PP	Large	40	24.7	25.0	25.8
11a	Betong	PP	Large	50	24.4	24.7	25.4
12a	Betong	PP	Large	60	24.2	24.5	25.2
10b	Betong	PP	Very Large	40	24.0	24.3	23.9
11b	Betong	PP	Very Large	50	23.4	23.7	23.5
12b	Betong	PP	Very Large	60	23.0	23.3	23.3
13	OSB GIPS	Cu	Small	40	25.1	25.5	25.6
14	OSB GIPS	Cu	Small	50	24.6	25.0	25.3
15	OSB GIPS	Cu	Small	60	24.3	24.9	25.0
16	OSB GIPS	Cu	Large	40	24.2	24.7	23.8
17	OSB GIPS	Cu	Large	50	23.6	24.0	23.5
18	OSB GIPS	Cu	Large	60	23.0	23.4	23.3
19	OSB GIPS	PP	Small	40	ej aktuell	ej	26.7
20	OSB GIPS	PP	Small	50	ej aktuell	ej	26.3
21	OSB GIPS	PP	Small	60	ej aktuell	ej	26.1
22a	OSB GIPS	PP	Large	40	25.5	26.0	26.0
23a	OSB GIPS	PP	Large	50	25.2	25.6	25.6
24a	OSB GIPS	PP	Large	60	24.9	25.3	25.4
22b	OSB GIPS	PP	Very Large	40	24.8	25.3	24.1
23b	OSB GIPS	PP	Very Large	50	24.2	24.6	23.7
24b	OSB GIPS	PP	Very Large	60	23.7	24.0	23.4

Results

All testad combinations yields less than 24°C after 8 hrs



Schakt #3

Comparison of "Standard Model" (Säker Vatten)" and "Detailed Model" (3D)

Mean Average Deviation, norm being 3D model, is 0.04 °C.

Absolute Mean Average Deviation is 0.45 °C

Sample Standard Deviation between Standard Model and Detailed Model is 0.58 °C

Standard Model uncertainty (Student's t), compared to 3D:

Uncertainty 68% confidence level	0.12°C
Uncertainty 95.45% confidence level	0.25°C
Uncertainty 99.73% confidence level	0.40°C

Safety factor:

The simple model may be corrected accounting for uncertainty of the model.

The model may be corrected according to:

$$0.04 + 0.40 \approx 0.44\ K.$$

(Mean deviation + Uncertainty @ 99.73%)

Experimental investigation

Student bachelor project (kandidatexamensarbete), spring 2019

Värmeöverföring till kallvatten i flerbostadshus

(Heat transfer behavior of cold water in multi-family houses)

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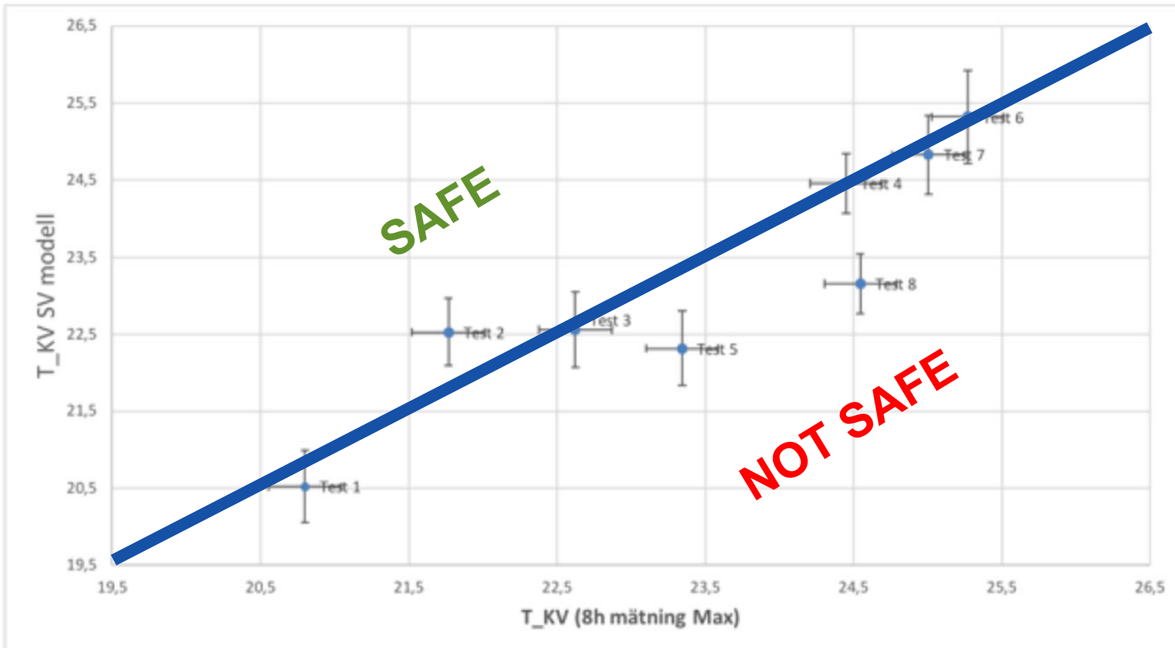
Handledare: Joachim Claesson

14 juni 2019

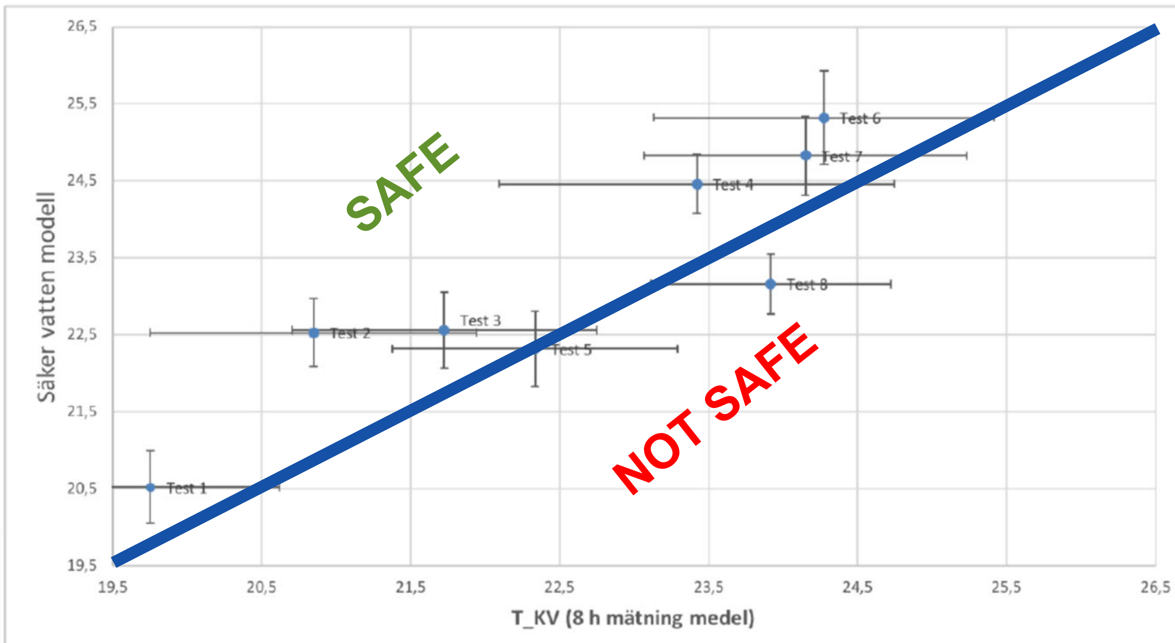
Kandidatexamensarbete
KTH – Skolan för Industriell Teknik och Management
Energiteknik EGI-2019
TRITA-ITM-EX 2019:333
SE-100 44 STOCKHOLM

Resultat

- Measurement seems to agree fairly to the model used by Säker Vatten, and hence with the Detailed Model



Figur 18: Osäkerhet för högst uppmätta temperatur av termoelementen på KV



Figur 19: Osäkerhet för medeltemperaturen av termoelementen på KV

Guidlines for thermal design of cold water shafts

- Maximize heat transfer though shaft walls towards surrounding room.
- Maximize **time constant** of Cold Water (i.e. increase insulation thickness and pipe dimensions).
- Minimize How Water dimensions (decrease heat transfer area) while maintaining insulation thickness

$$\frac{dT_{KV}}{d\tau} = \frac{UA_{KV}}{(m \cdot c_p)_{KV}} \cdot (T_{SH} - T_{KV})$$

$$(m \cdot c_p)_{AVL} \cdot \frac{dT_{AVL}}{d\tau} = UA_{AVL} \cdot (T_{SH} - T_{AVL})$$

$$(m \cdot c_p)_{SV} \cdot \frac{dT_{SV}}{d\tau} = UA_{i_{SV}} \cdot (T_{SH} - T_{SV}) + UA_{y_{SV}} \cdot (T_{rum} - T_{SV})$$

$$(m \cdot c_p)_{SH} \cdot \frac{dT_{SH}}{d\tau} = UA_{AVL} \cdot (T_{AVL} - T_{SH}) + UA_{VV} \cdot (T_{VV} - T_{SH}) + UA_{VVC} \cdot (T_{VVC} - T_{SH}) + UA_{KV} \cdot (T_{KV} - T_{SH}) + UA_{i_{SV}} \cdot (T_{SV} - T_{SH})$$

Conclusions

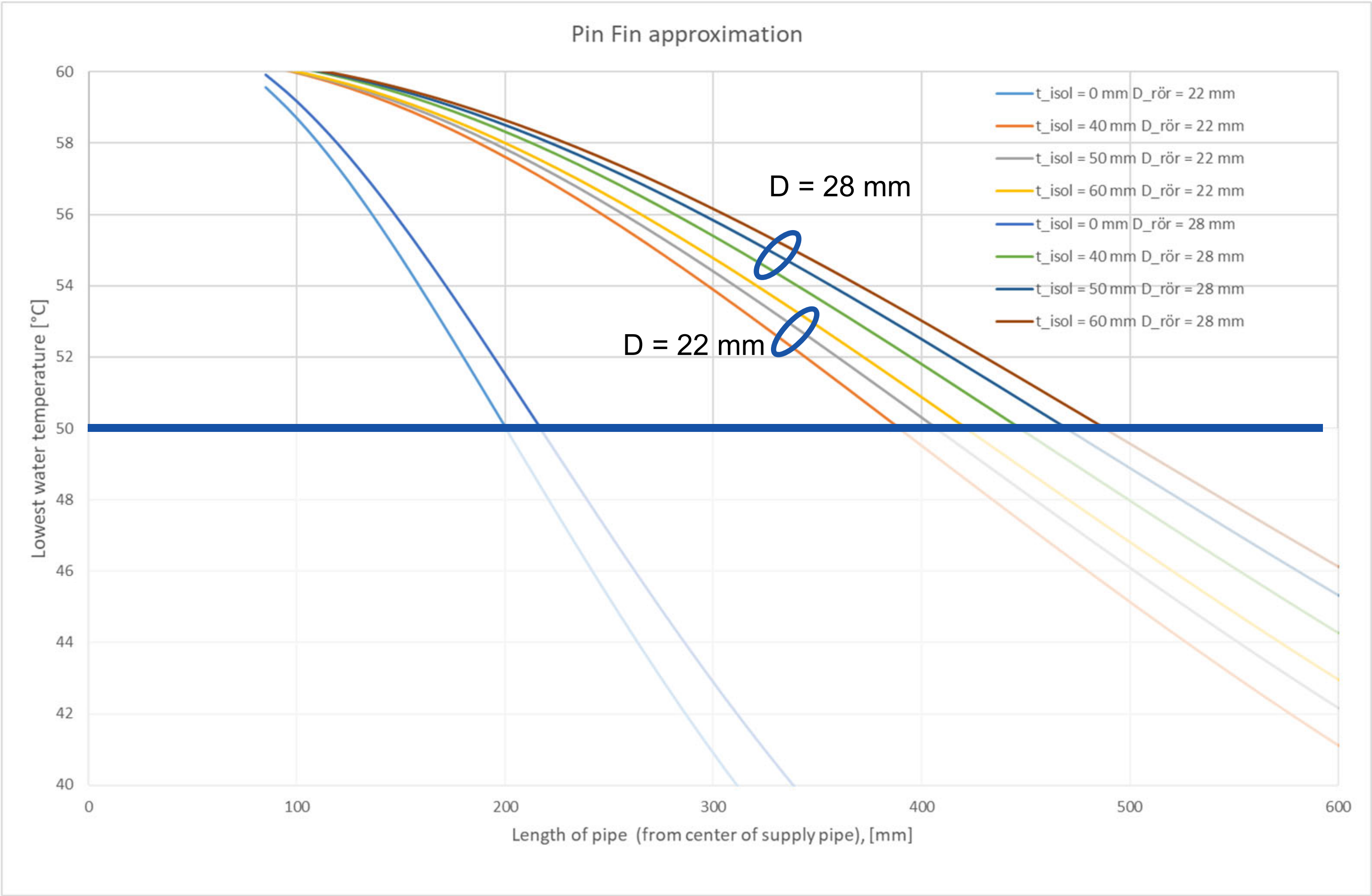
- With implement safety margin (+0.44 K), the Standard Model implemented by Säker Vatten may be used to evaluate the standard shafts

- Supported by detailed simulations and experiments

Additional studies

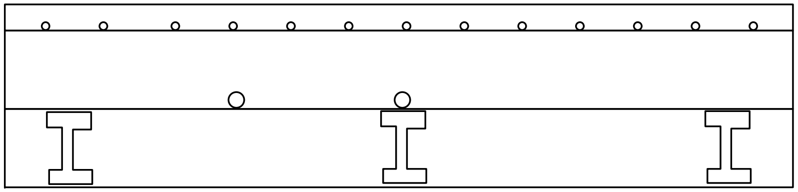
- Floor heating
- Unused, plugged, pipelines

Unused, plugged, pipelines

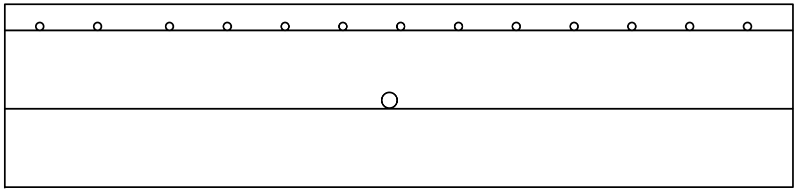


Impact from floor heating

Cases:



May work (24 °C after 8hrs), refined studies required…



Does not work (24 °C within 8hrs)

Probably doesn’t work (24 °C within 8hrs), refined studies required…

Questions?