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The importance of the concrete in thermal pile behaviour

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Outline

- Introduction & traditional approach
- A transient approach to pile concrete
- Numerical study using real heat pump temperatures
- Initial site data
- Concrete thermal properties
- Conclusions

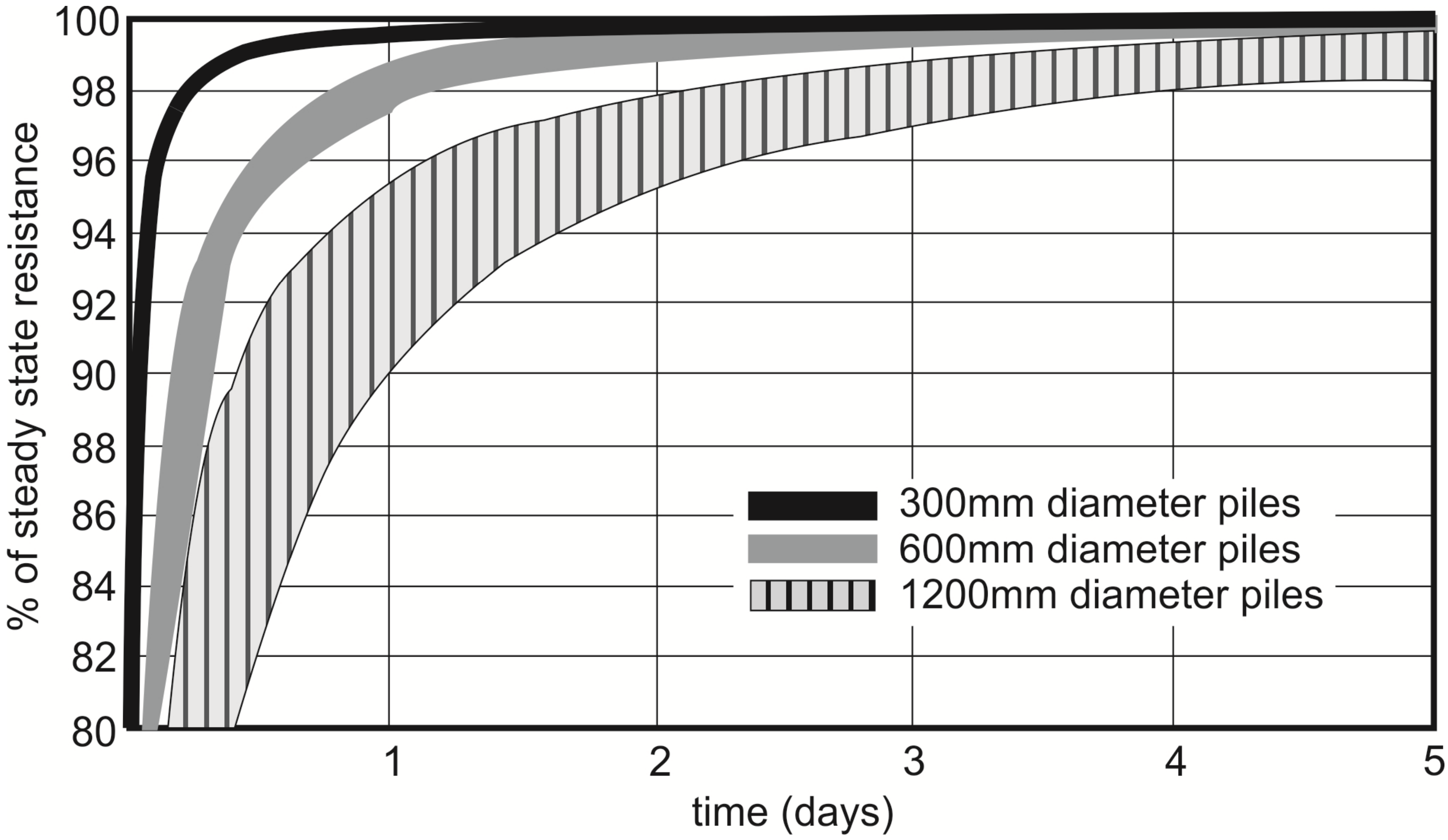
Pile Thermal Resistance

- Temperature change across concrete usually captured using a (steady state) resistance term

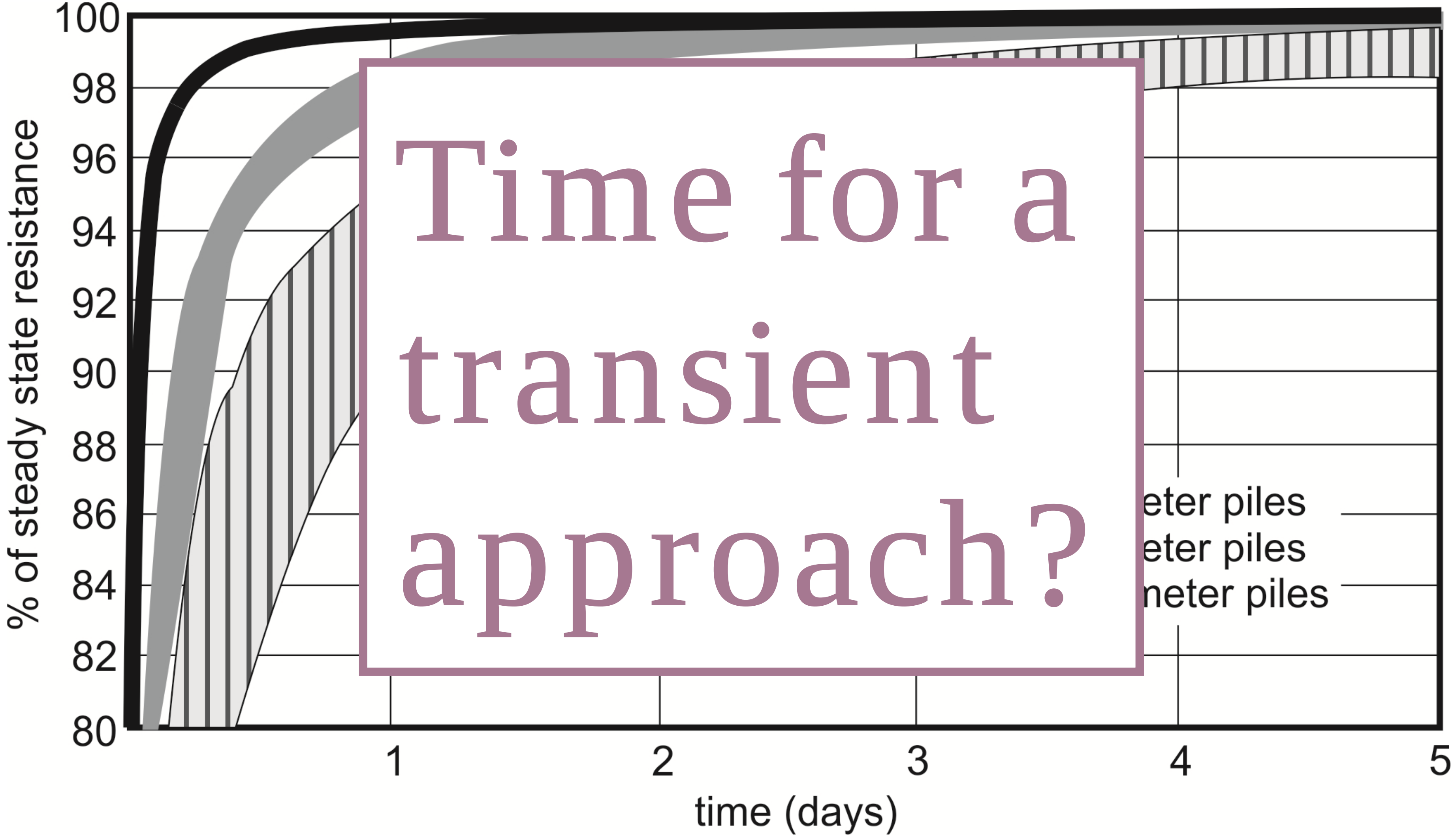
$$R_b = R_{pconv} + R_{pcond} + R_c$$

- Empirical database of experience is absent
- R_{pconv} & R_{pcond} relatively “easy” to calculate
- R_c is often largest part of resistance due to volume of concrete
- Depends on pipe arrangements and thermal conductivity of concrete

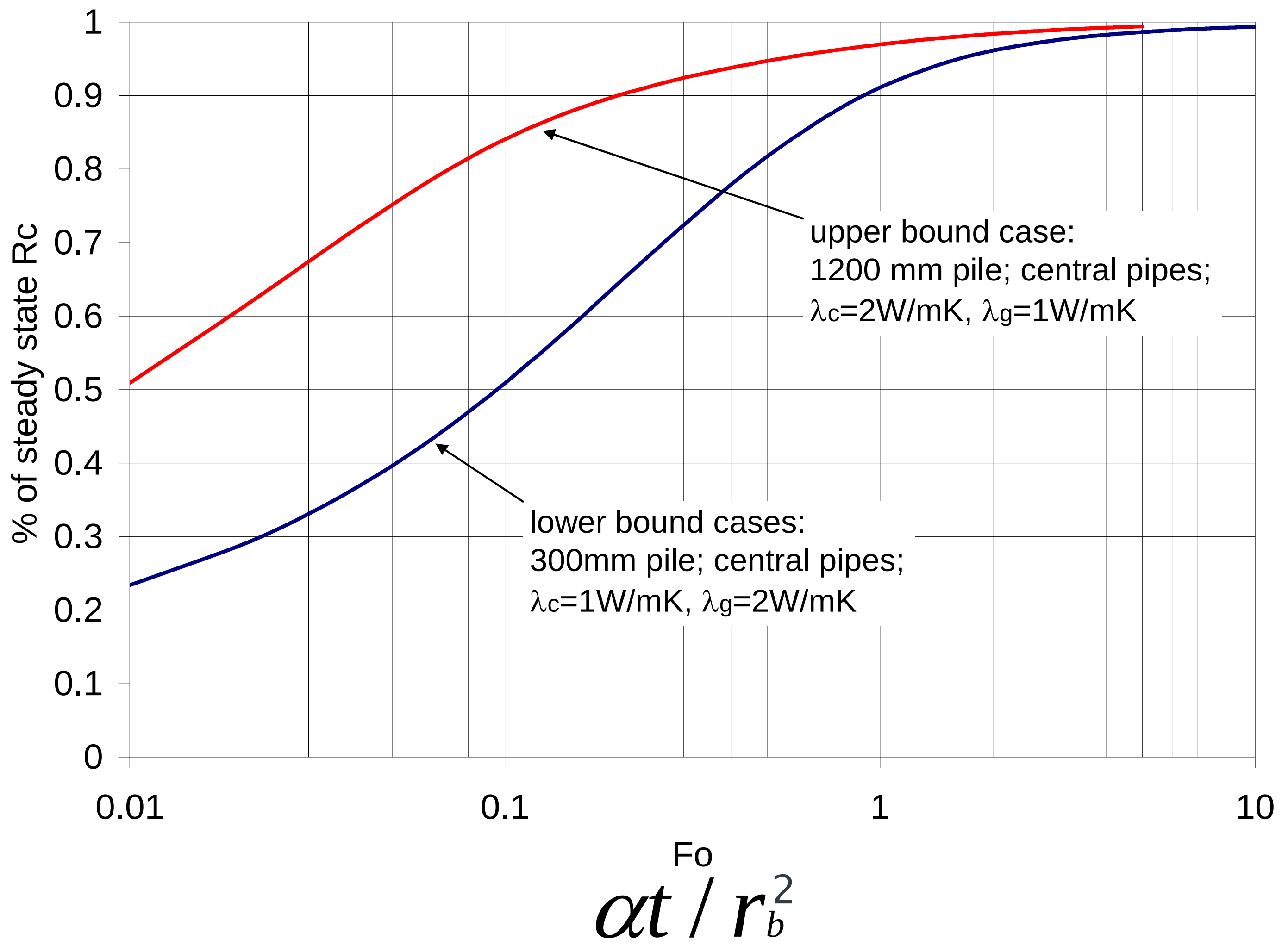
Time to Approach Steady State



Time to Approach Steady State



Piles with Centrally Placed Pipes



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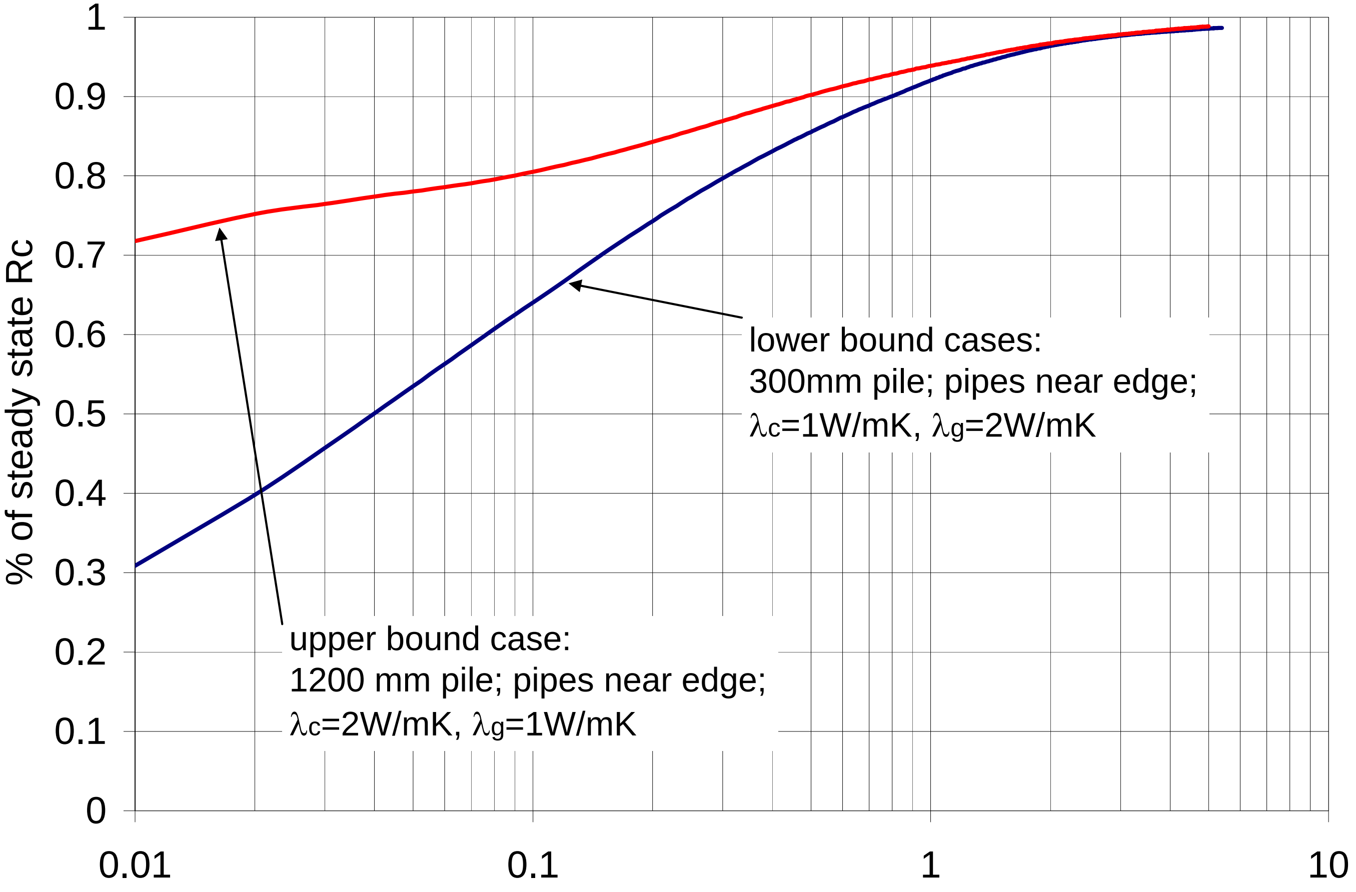
Piles with Pipes near the Edge



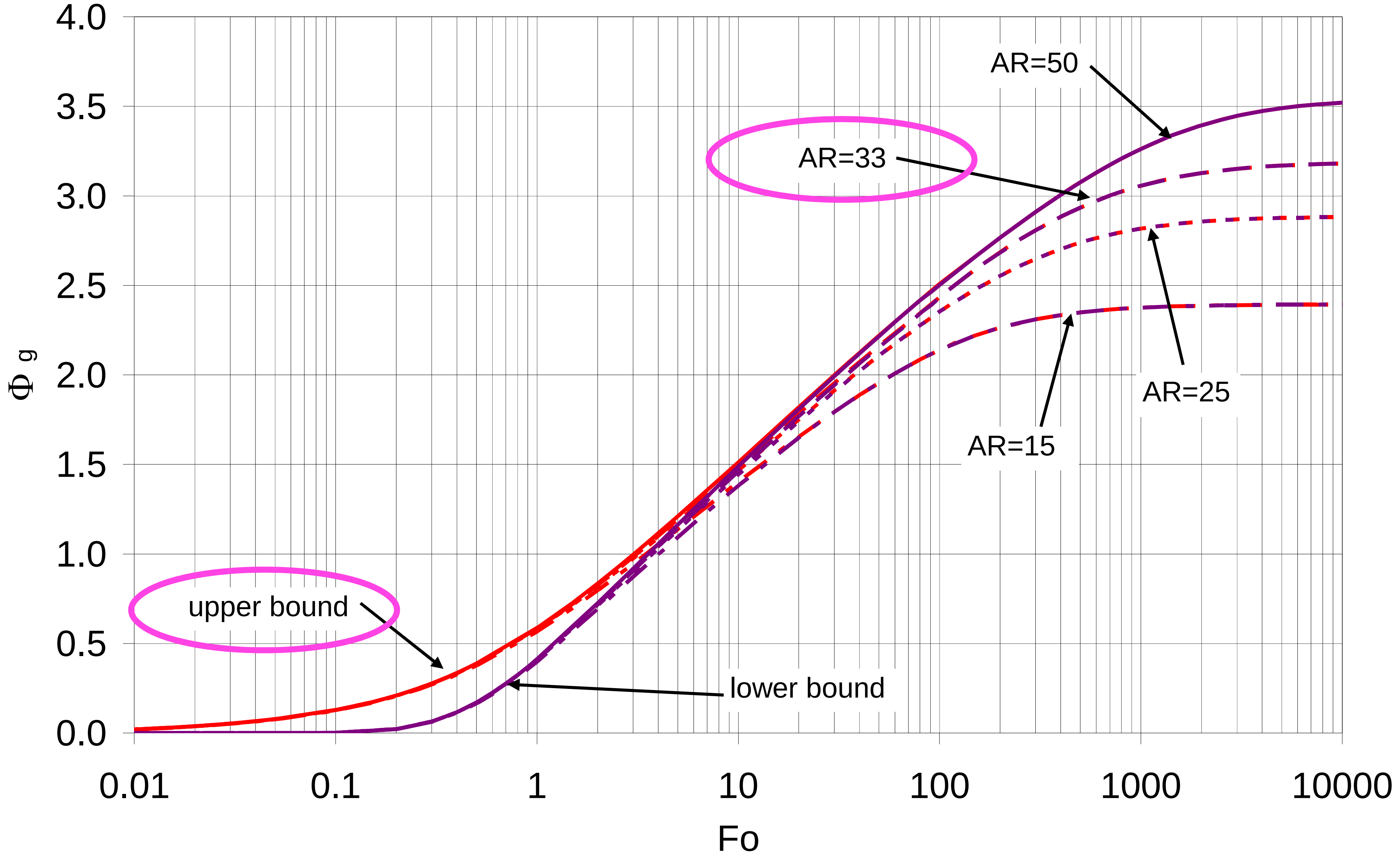
$$\alpha t / r_b^2$$

Example: Steady State vs Transient

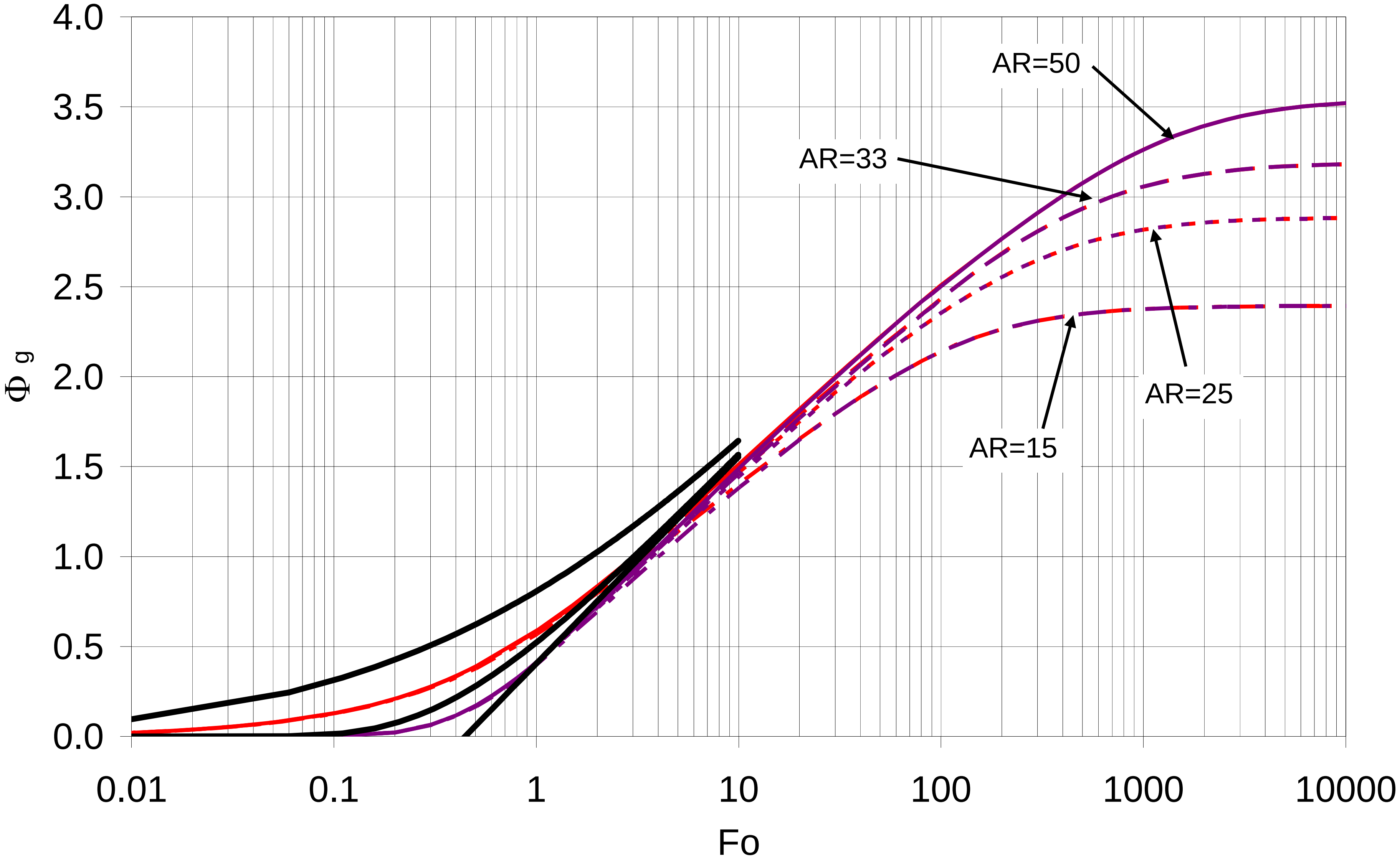
$$\Delta T_f = qR_p + qR_c G_c + \frac{q}{2\pi\lambda_g} G_g$$

- Assumptions:
  - Transient G function for ground temperature changes
  - Transient G function for pile concrete (as % of steady Rc)
  - Steady state heat transfer within and across pipes
  - 600mm dia pile, 20m long (AR=33.3); 4 pipes near the edge
- λ_c=1W/mK; λ_g=2W/mK; α_g=1E-6m2/s
- Rc=0.075mK/W; Rp=0.025mK/W

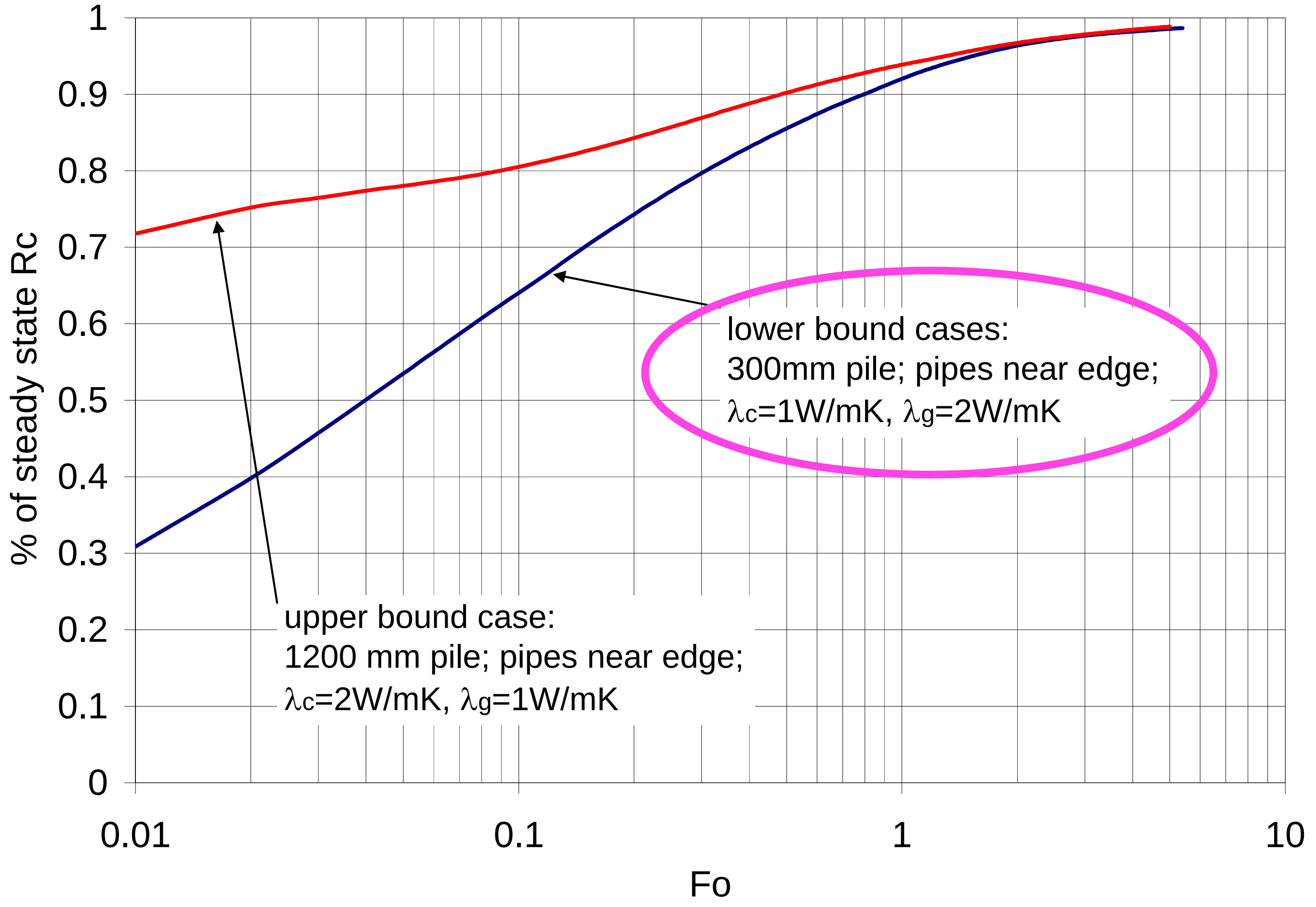
Thermal Pile G-function



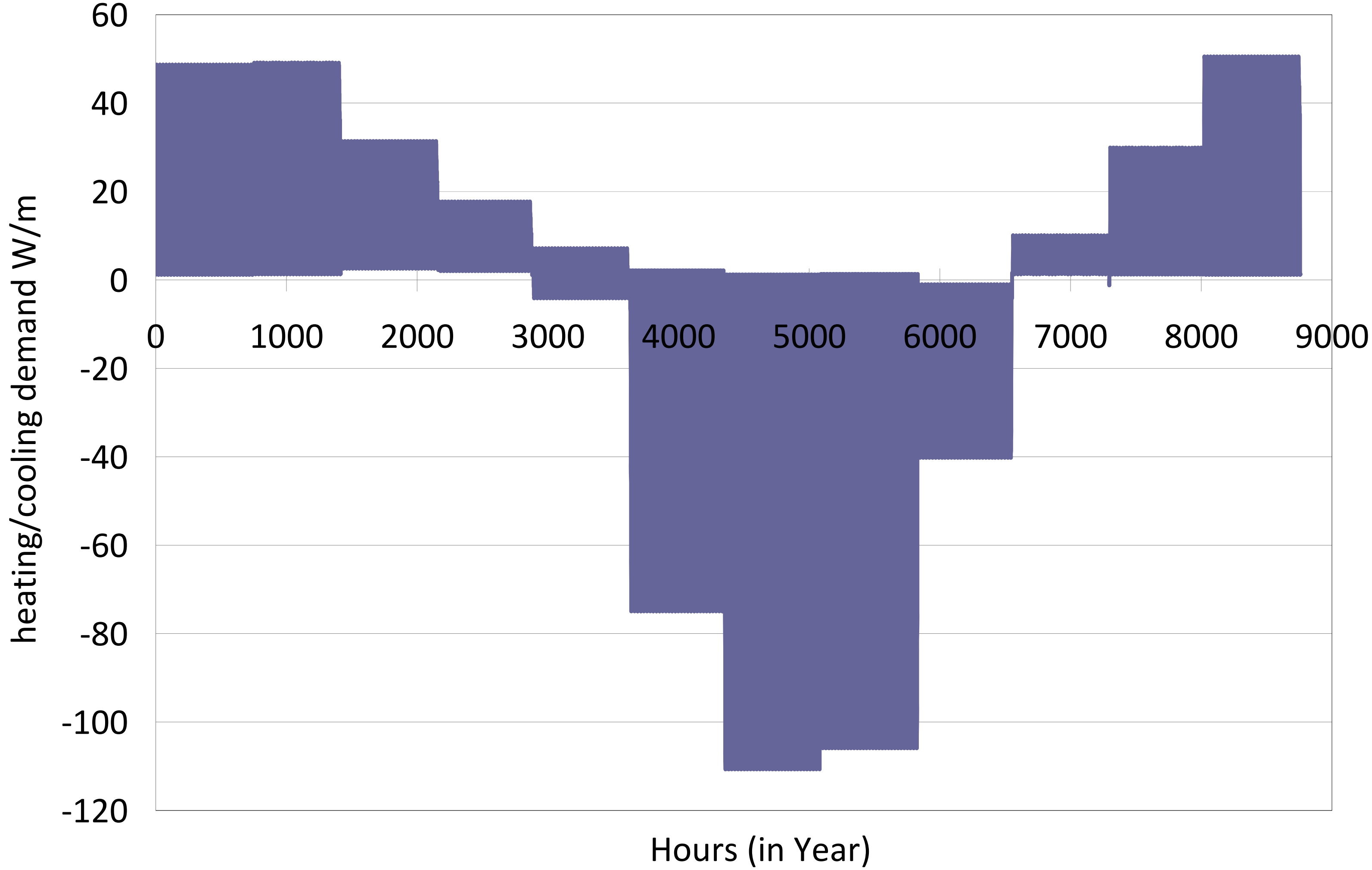
Thermal Pile G-function



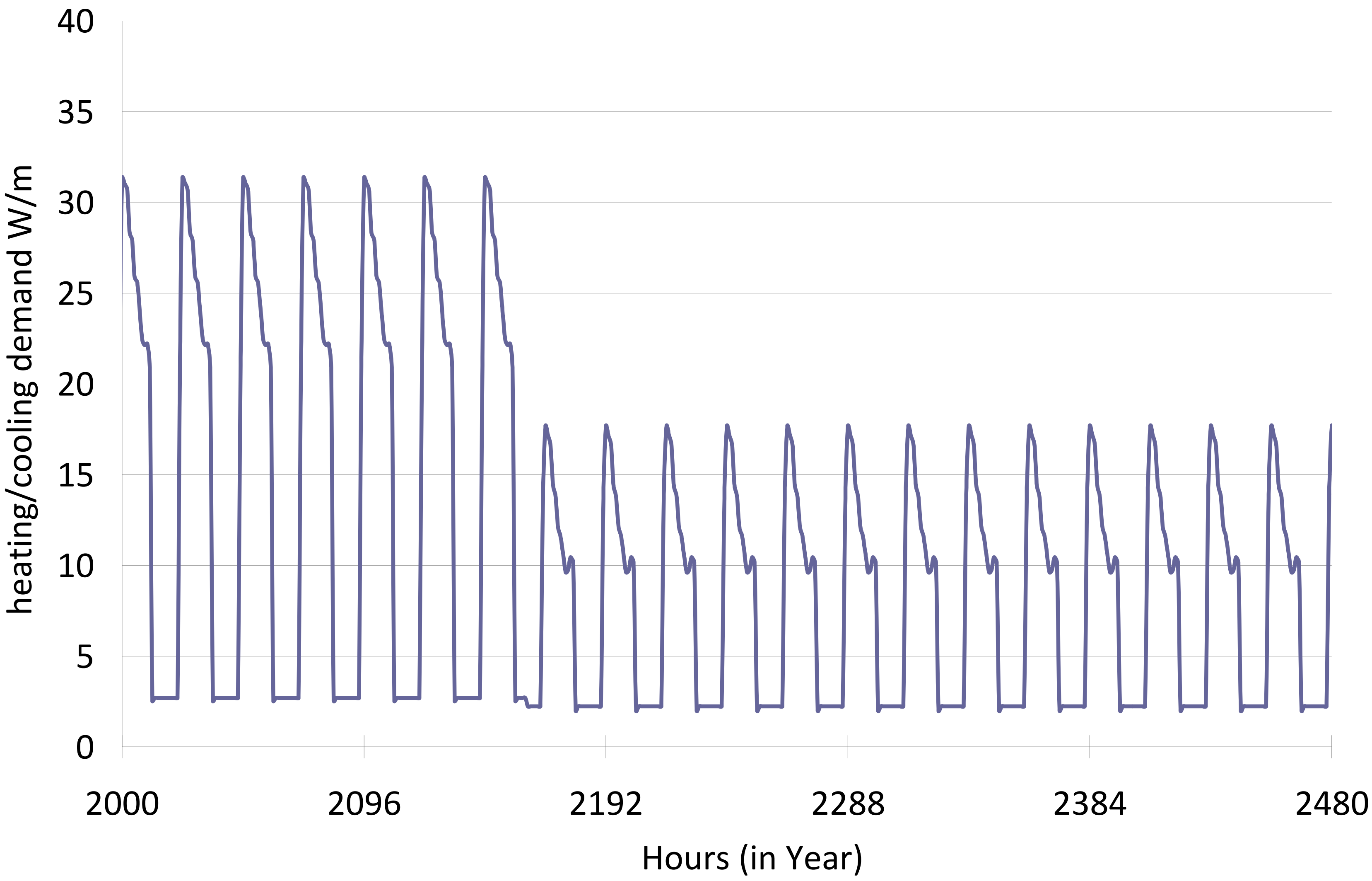
Pile Concrete G-function



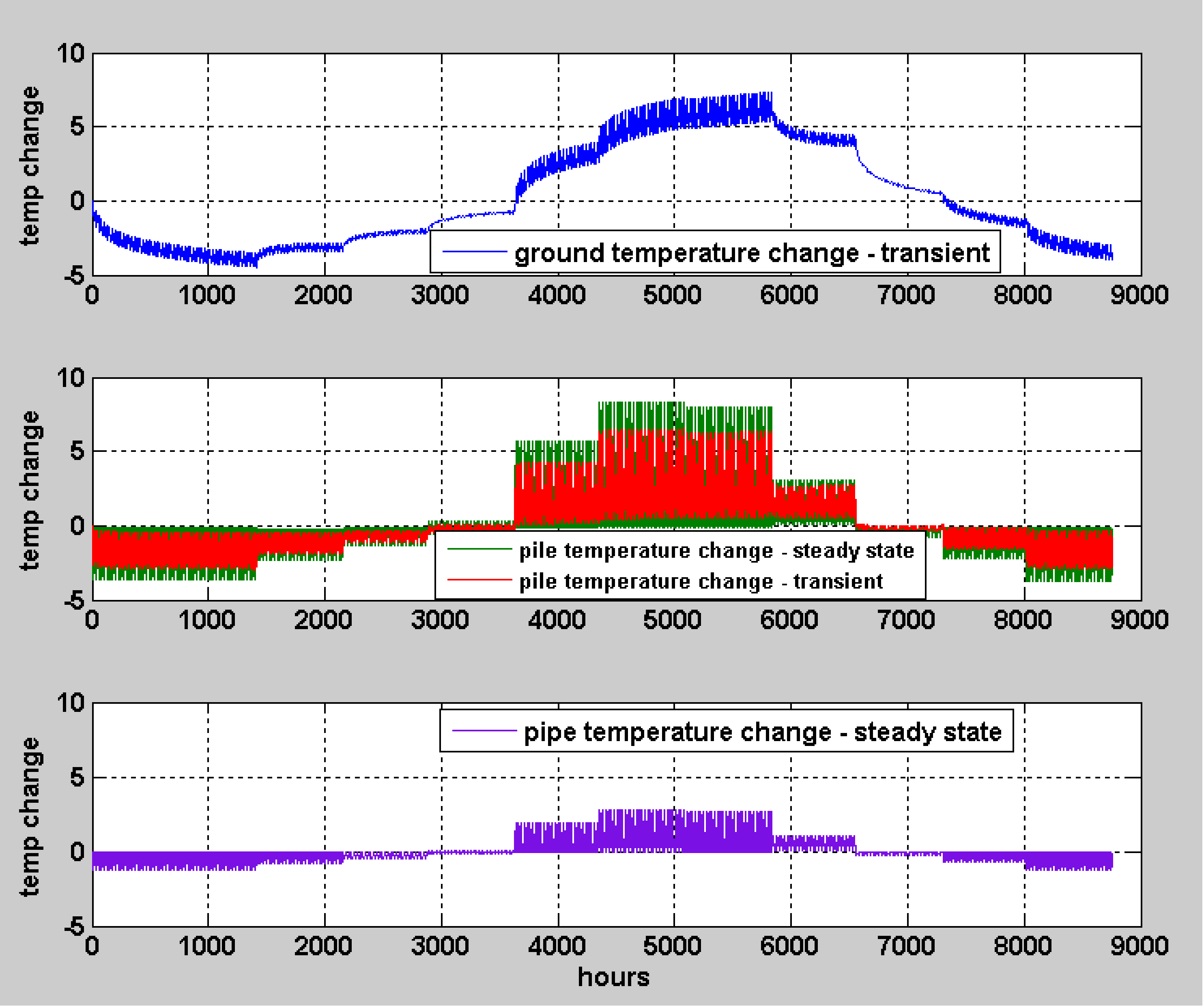
Thermal Loads



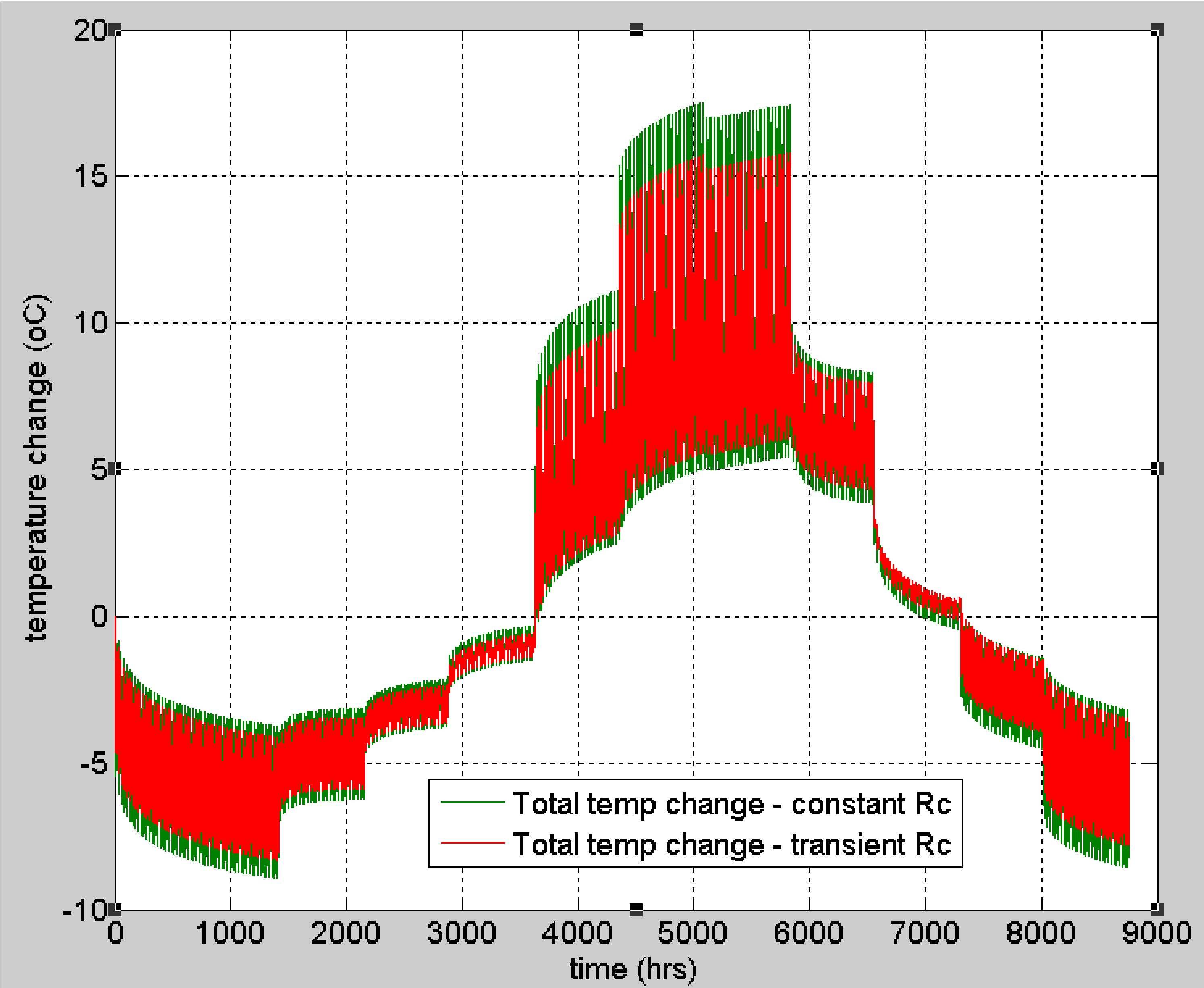
Thermal Loads: Daily Variation



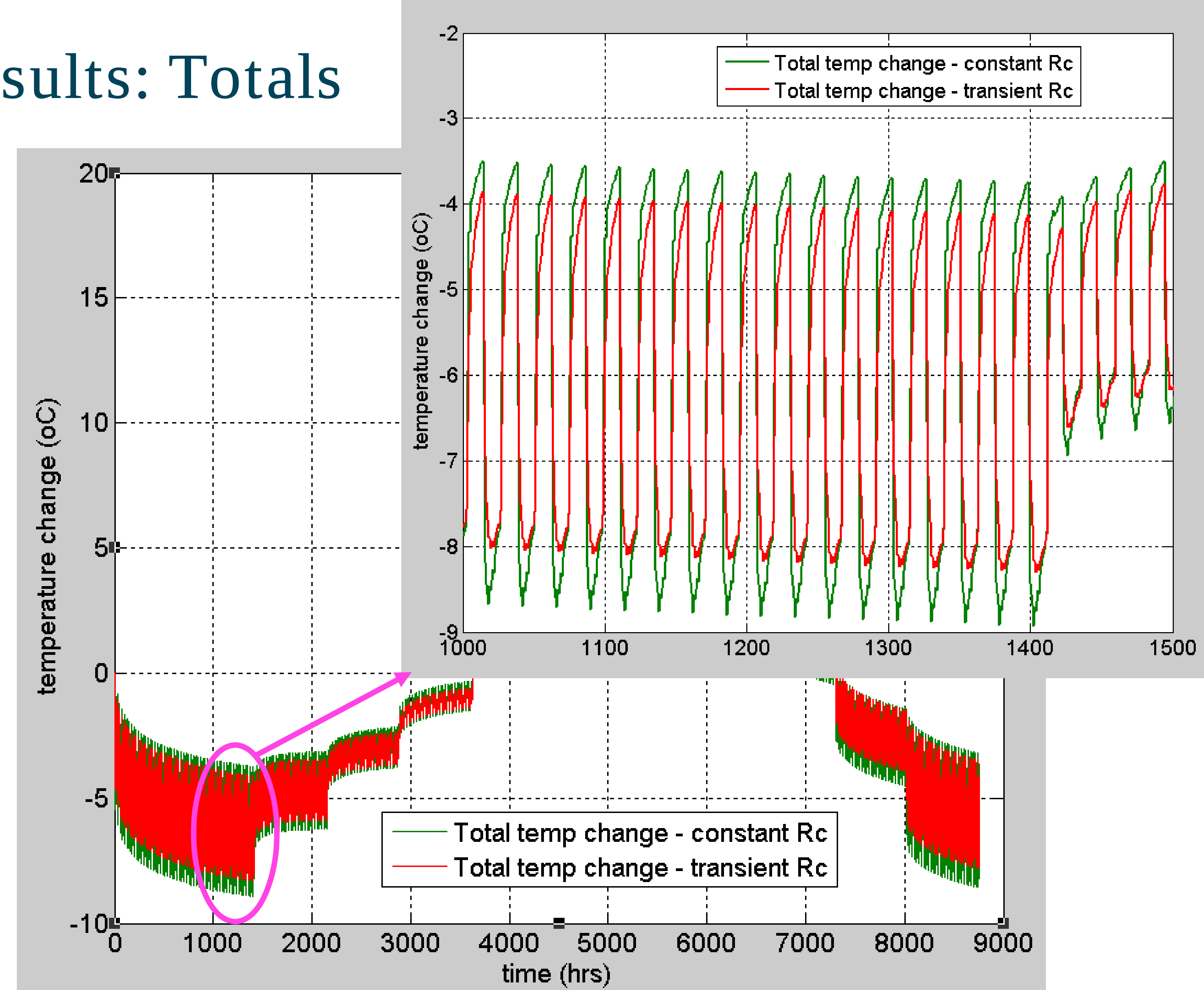
Results: Components



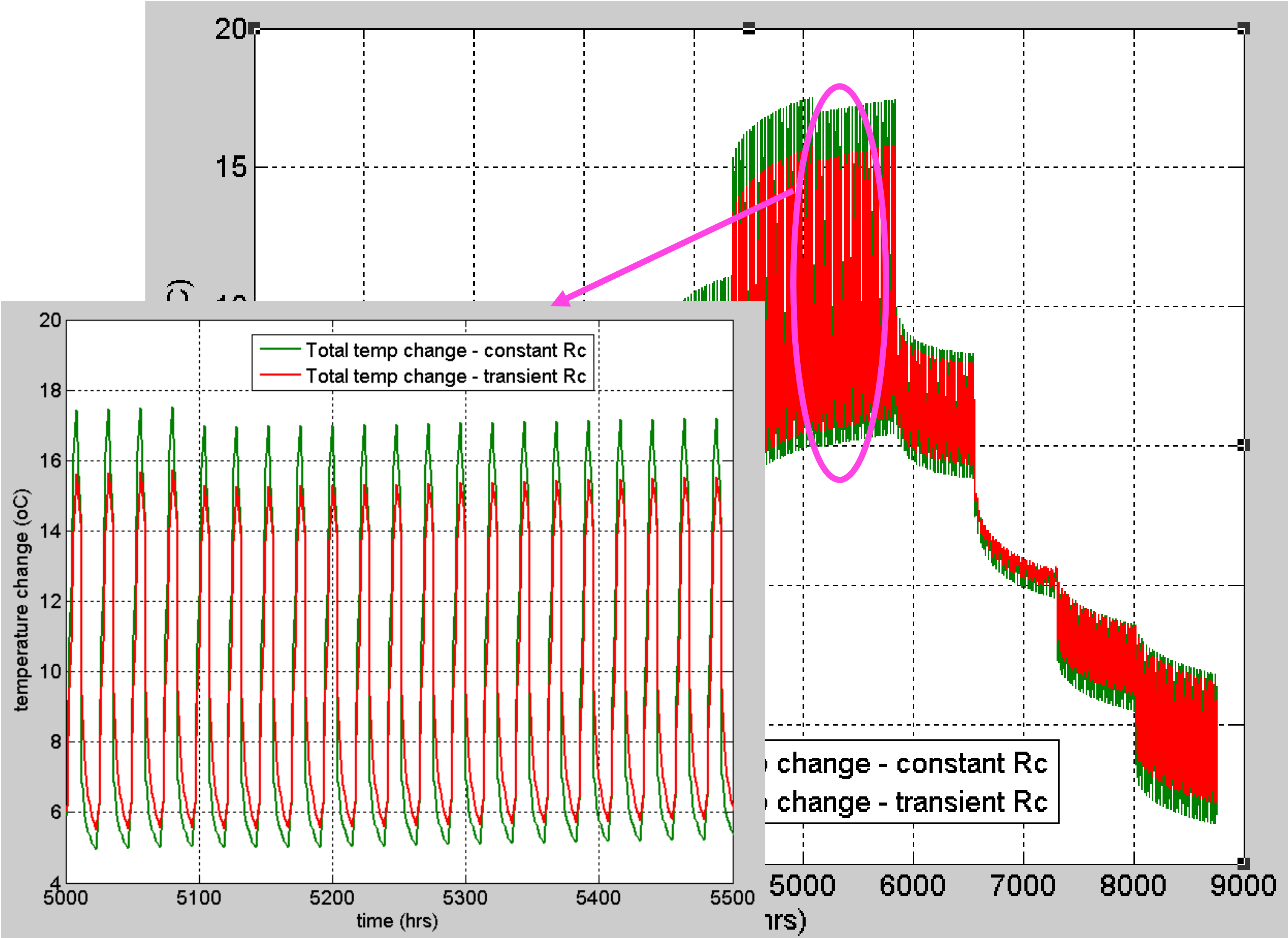
Results: Totals

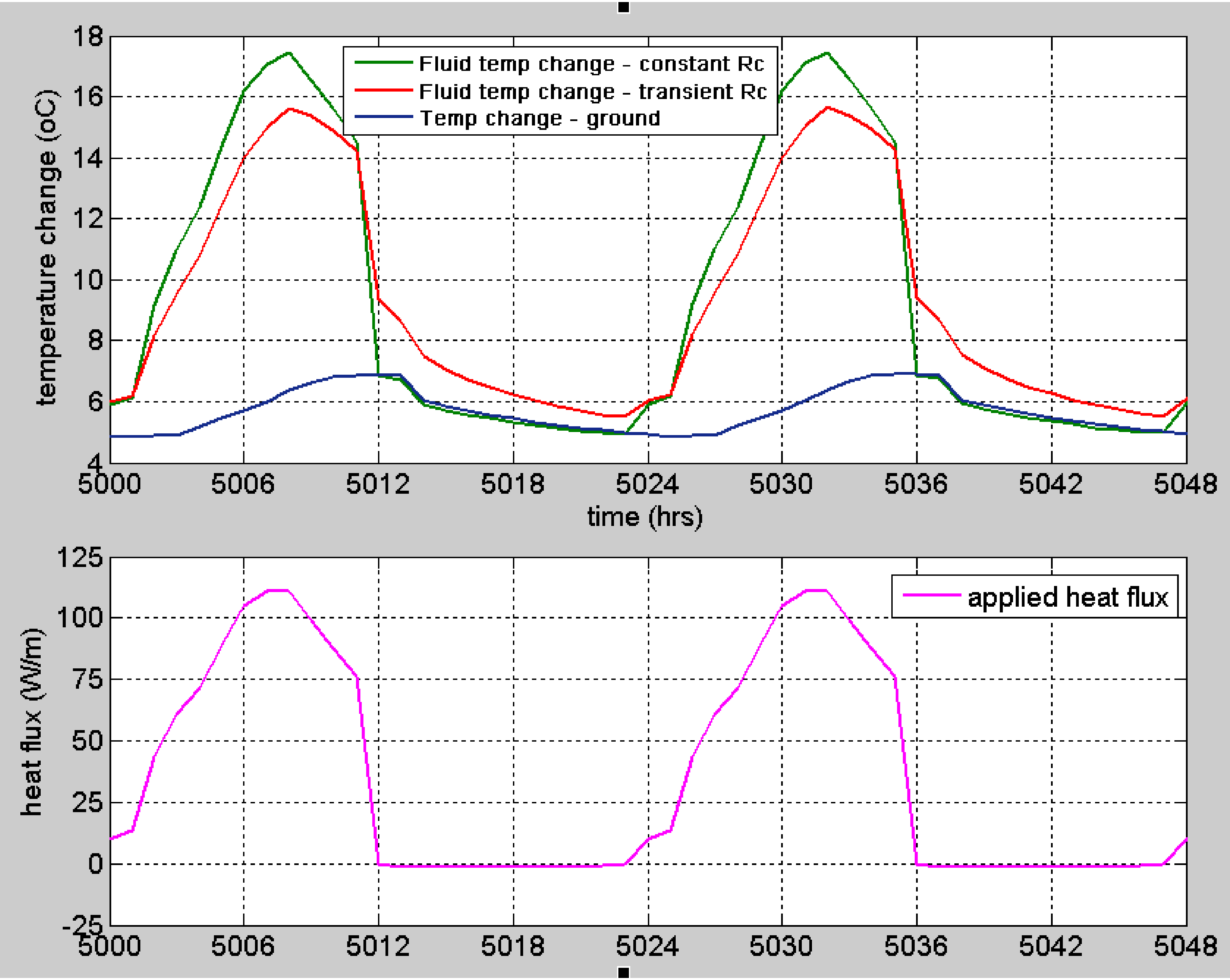


Results: Totals



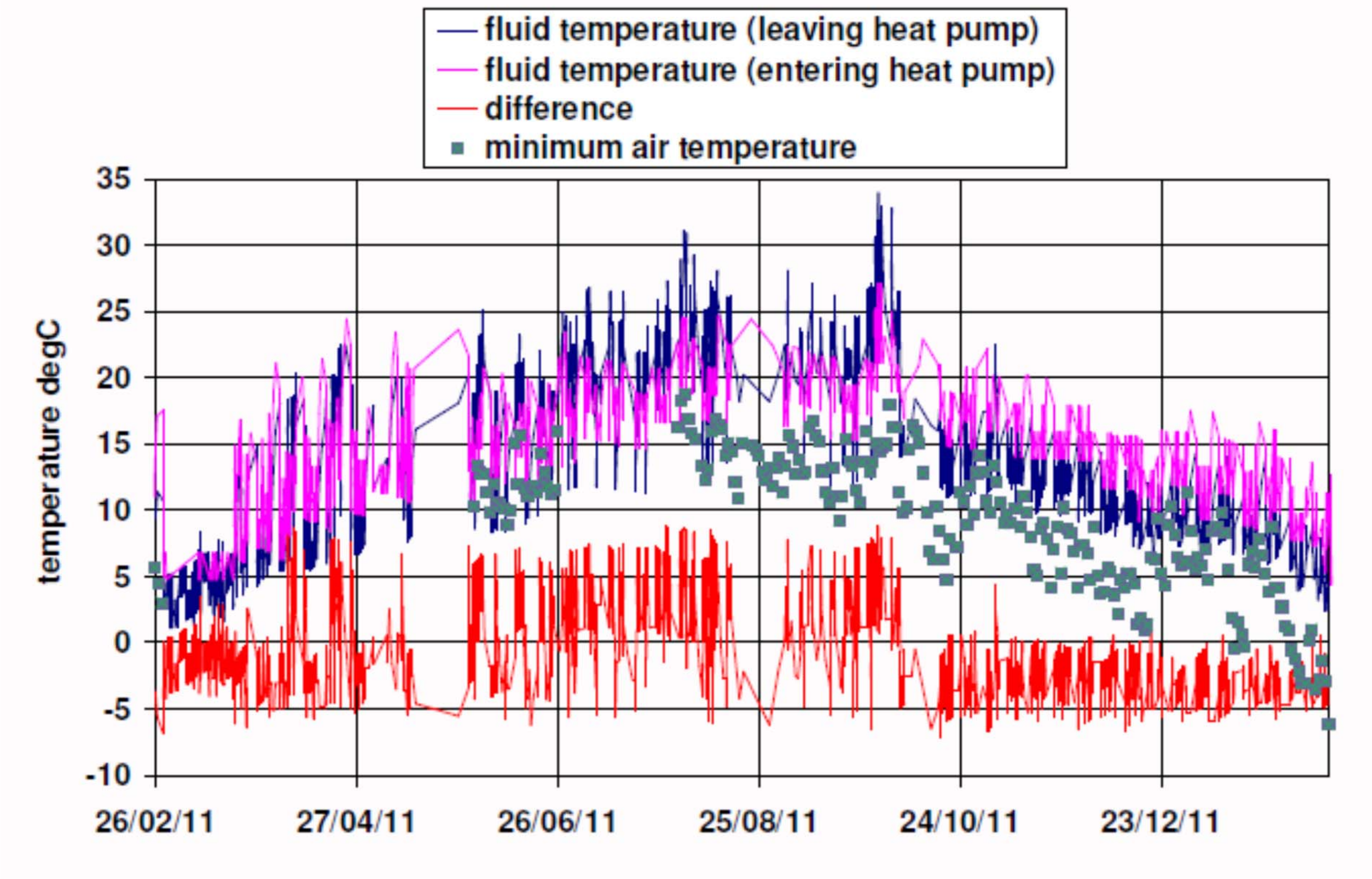
Results: Totals





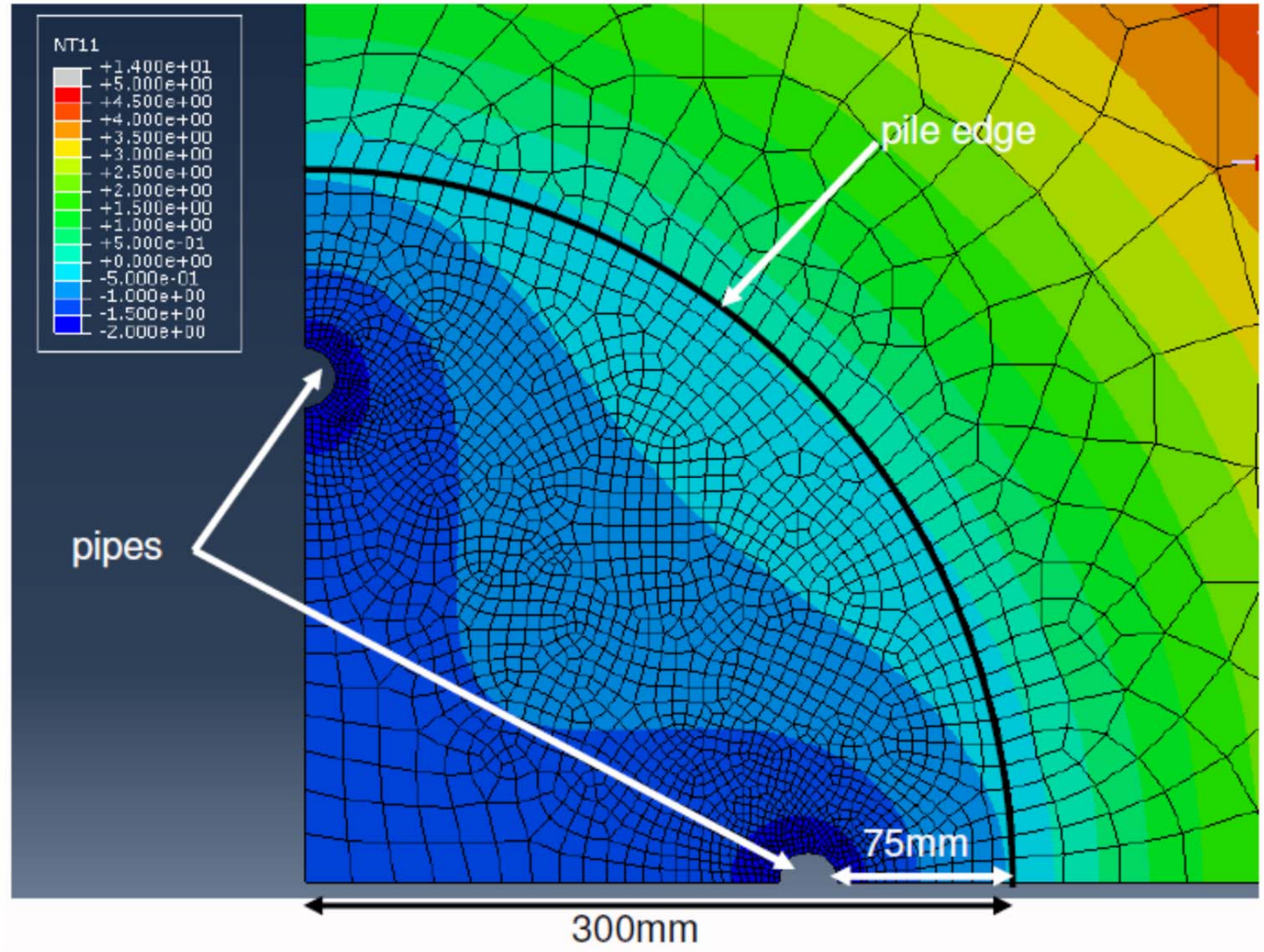
Fluid temp change - constant Rc
Fluid temp change - transient Rc
Temp change - ground
temperature change (oC)
time (hrs)
18
16
14
12
10
8
6
4
5000
5006
5012
5018
5024
5030
5036
5042
5048
applied heat flux
heat flux (W/m)
125
100
75
50
25
0
-25

Real Thermal Loads



Numerical Model

(2D ABAQUS)



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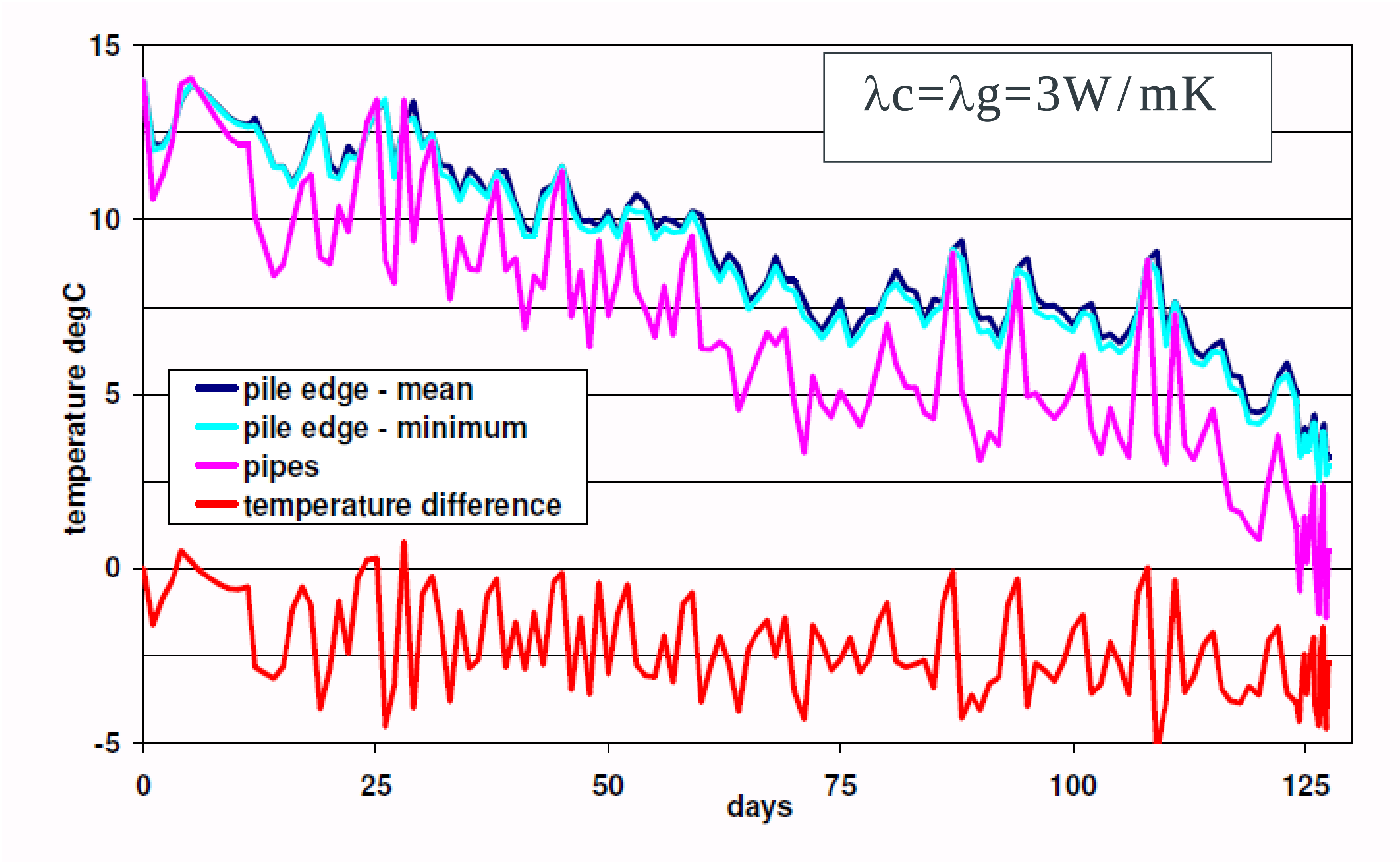
Results: Temperatures



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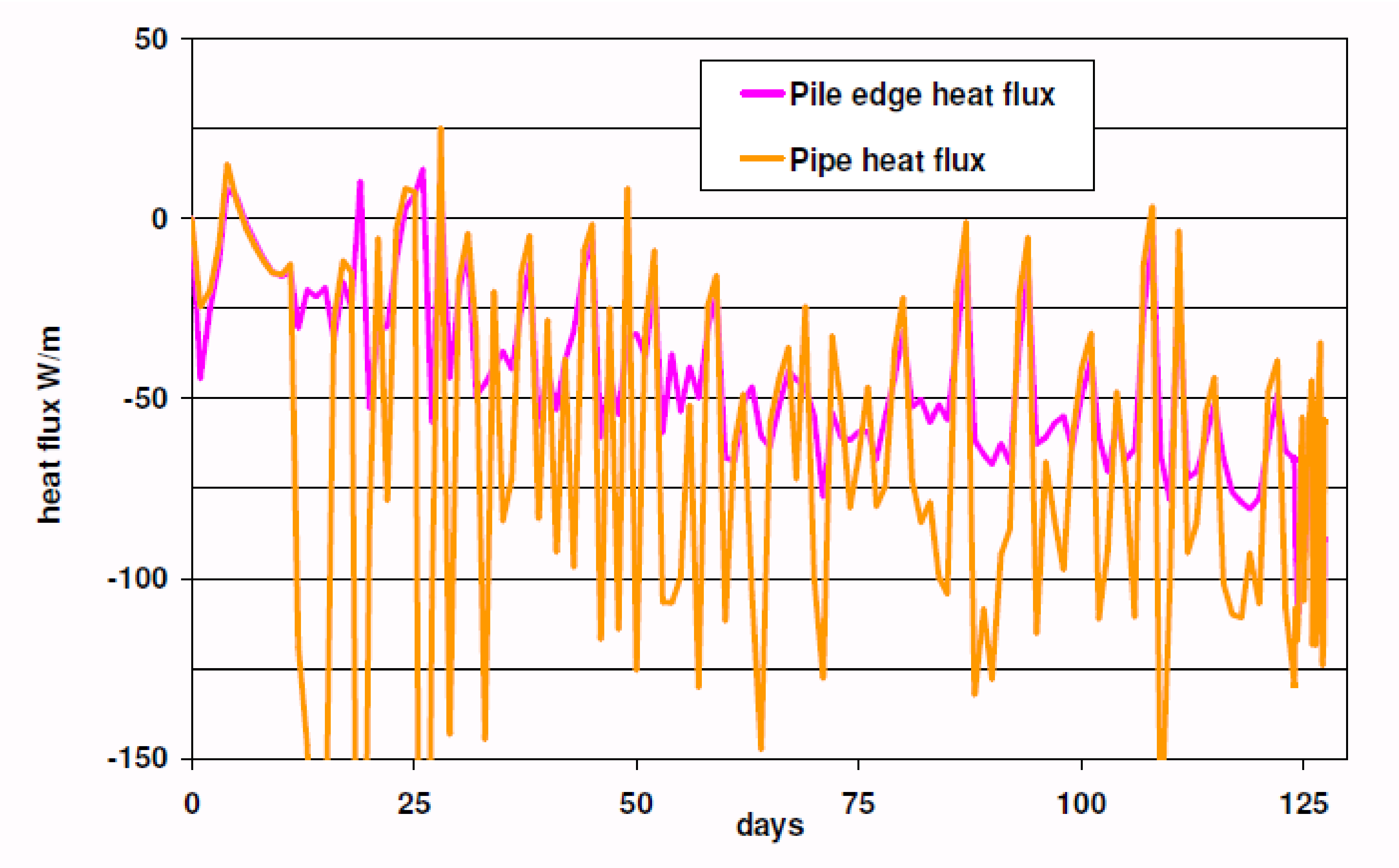
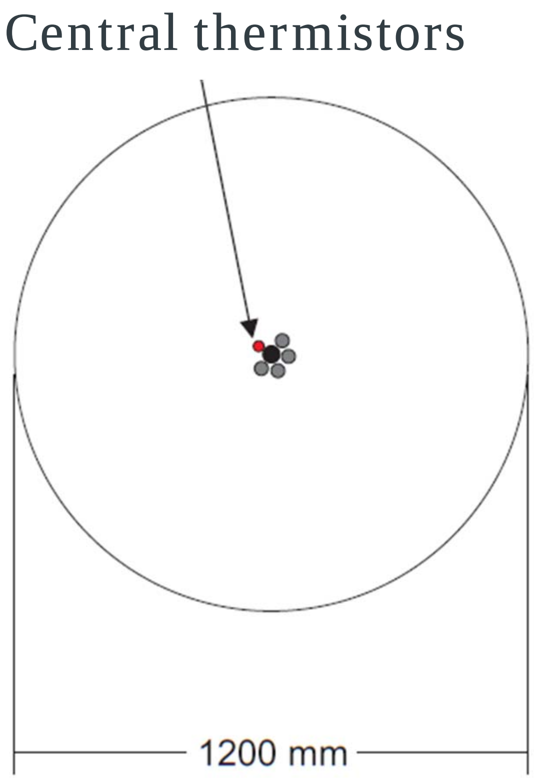
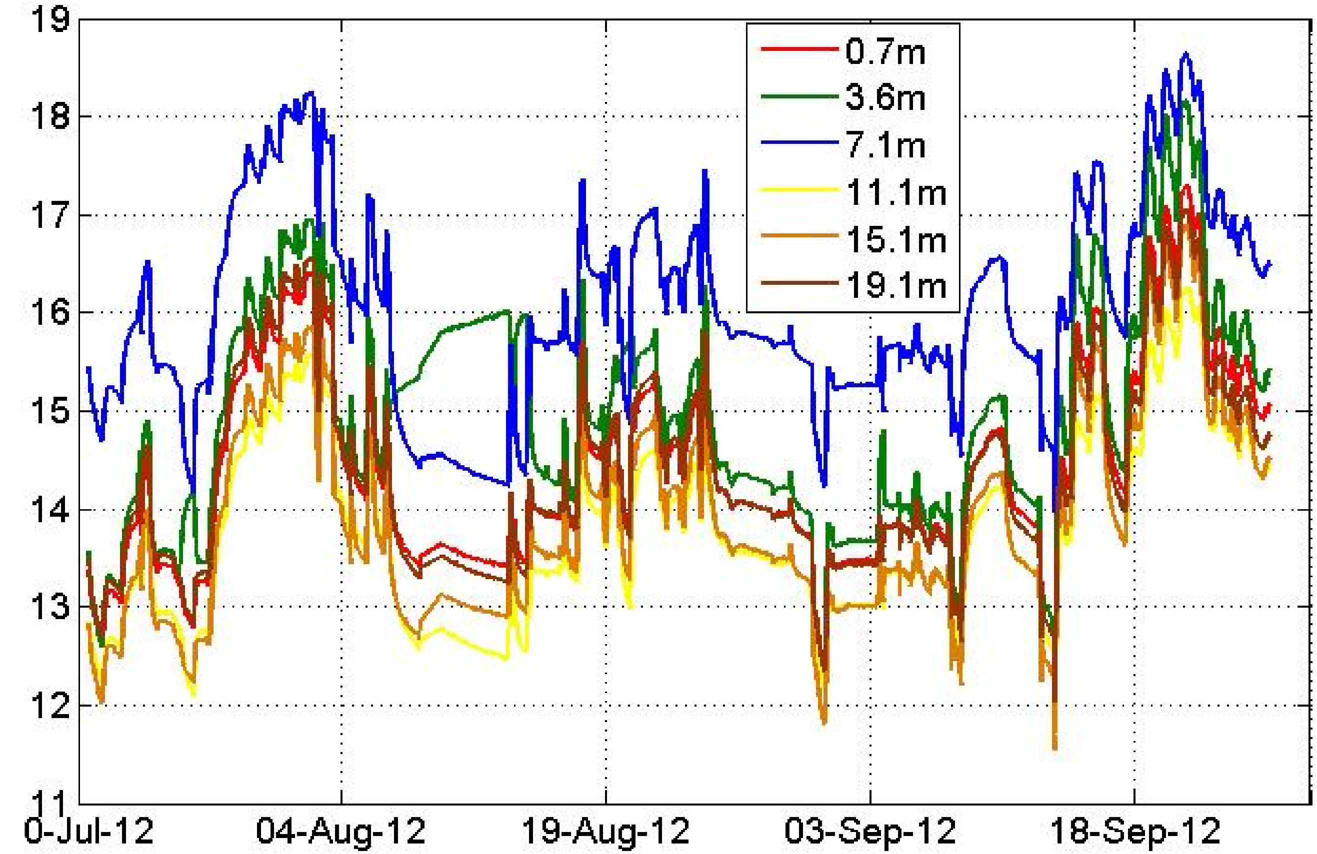
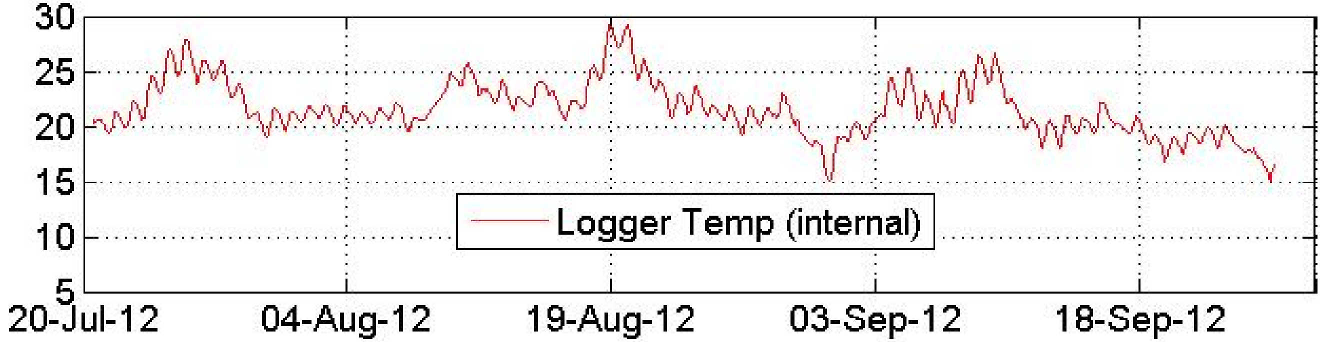
Results: Heat Flux



Siemens USC Site Data







Siemens USC Site Data

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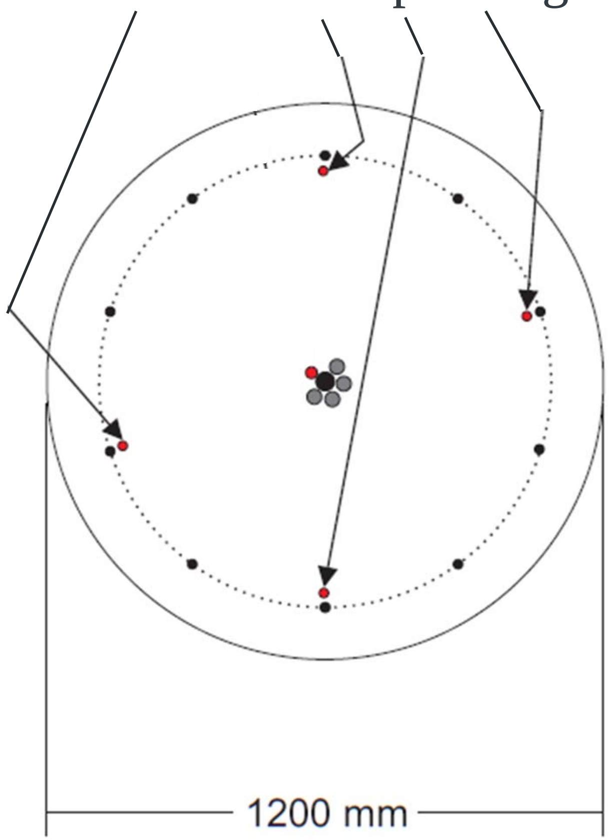
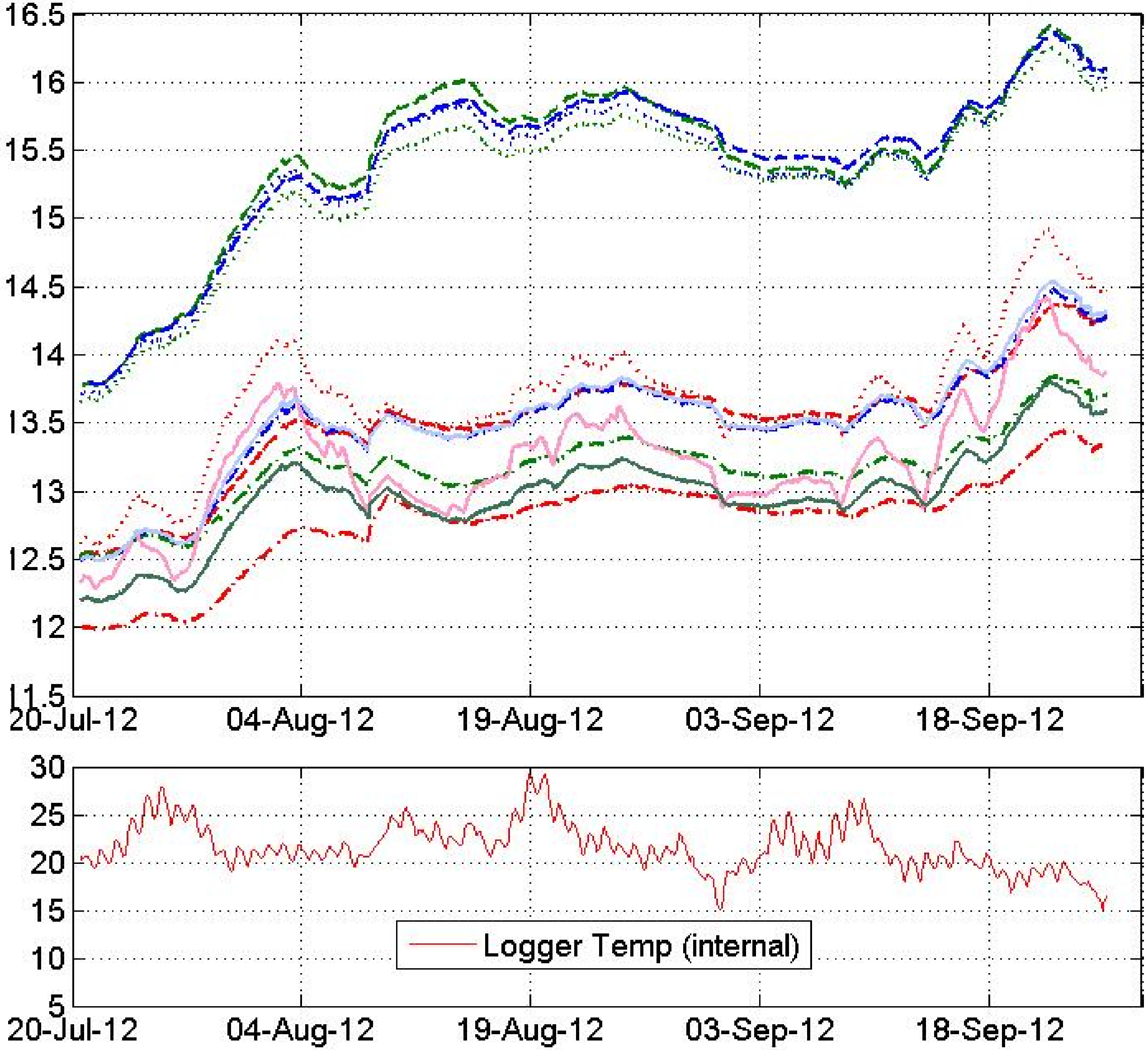
Thermistors on pile cage



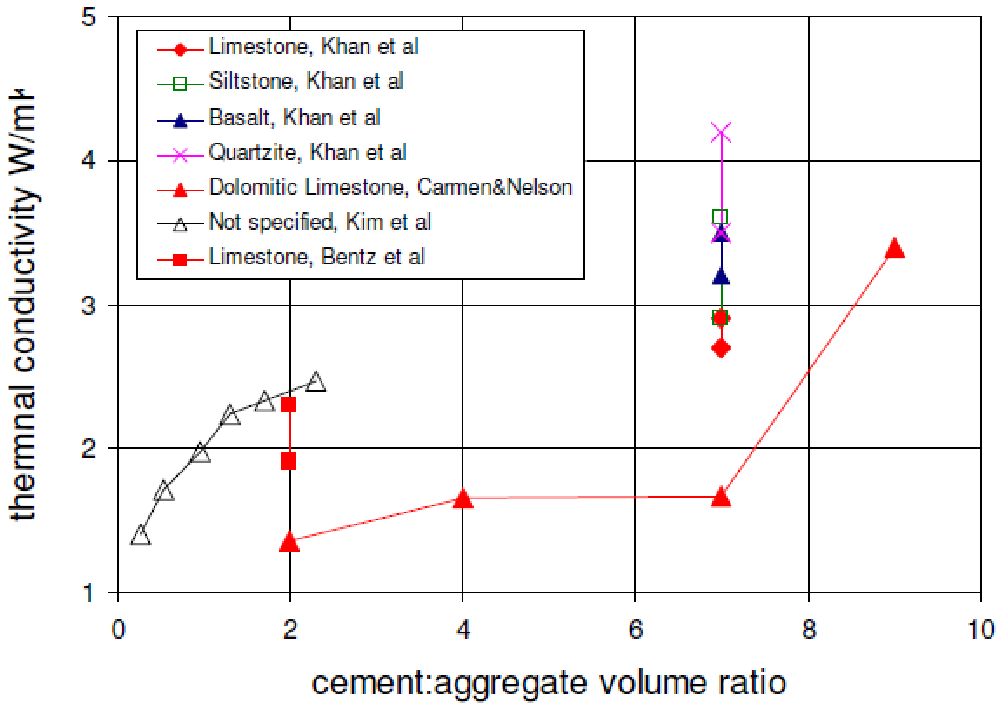


Consequences

- Importance of concrete for storage not just transfer of heat
- Thermal buffering, preventing extreme temperatures reaching the ground
  - Effect greatest when λ_c lower than λ_g
  - Impact on geotechnical design
- More important to determine concrete thermal properties (not just Rb)
- Concrete properties has greatest impact in largest diameter piles as furthest from steady state

Concrete Thermal Properties

- Thermal conductivity: 1.2 to 4W/mK
- Volumetric heat capacity:2 to 3 MJ/m3K
- Depends on:
  - Moisture content
  - Aggregate type and ratio
  - Additives, cement replacement products
- Is rapid heat transfer desirable?



Conclusions

- Under constant q piles may take days to approach steady state.
  - Caution with thermal response tests
- Pile concrete is rarely at a thermal steady state during thermal pile operation
- Pile is being used as an energy store
- Pile is protected the ground against extreme temperatures
- Need more emphasis on determining pile properties
- Treating the pile as transient during design will improve thermal efficiency

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