Geothermal Tunnel Linings

Principles of Geothermal Tunnel Linings

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11.00 – 11.30hrs 18 October 2012

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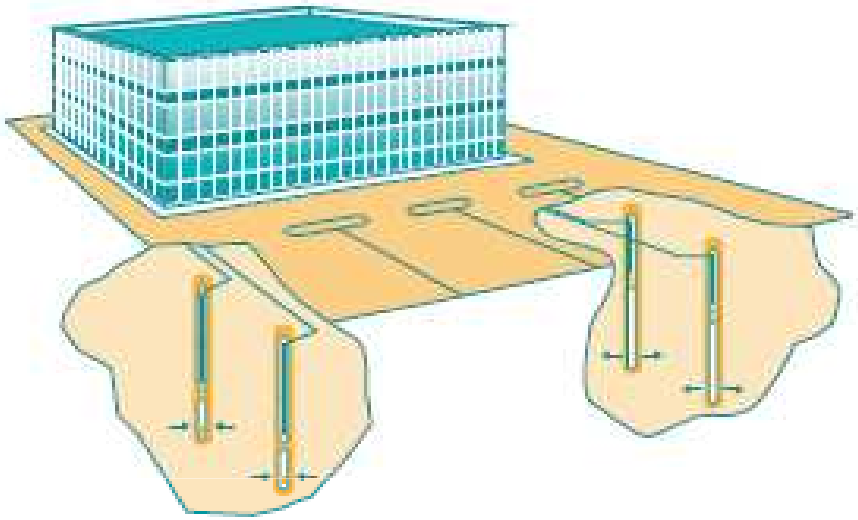
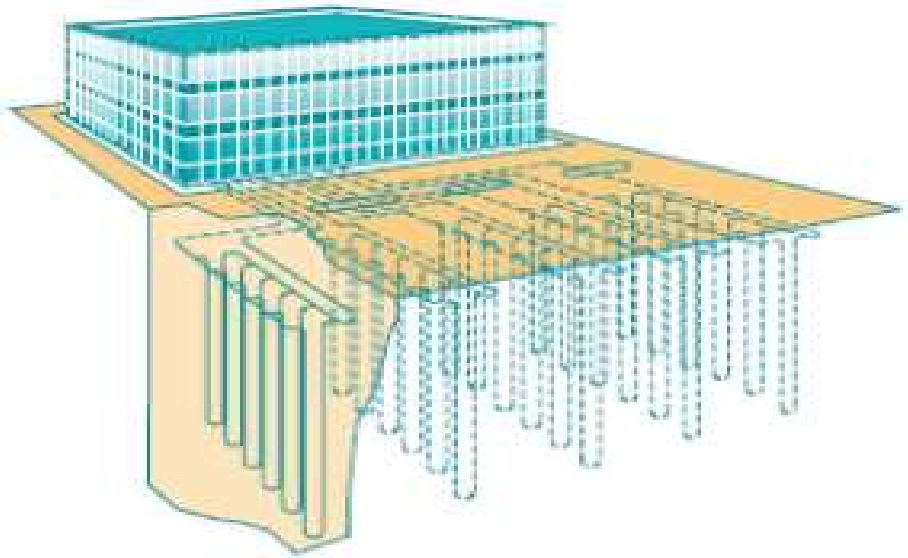
- **Background – Ground source heat energy**
- **Concept - Thermal tunnels**
  - Pipes in segments and connenctions
  - Cold tunnels and hot tunnels
- **Design development process**
  - Linking to surface
  - Thermal / ventilation design
  - Fire
- **Building market for tunnel heat**

Background – Ground Sourced Heat Energy





Source: Commercial Earth Energy Systems (Canada Natural Resources)

Open Systems

- Water wells
- Extract water
- 500kW / hole

Closed Systems

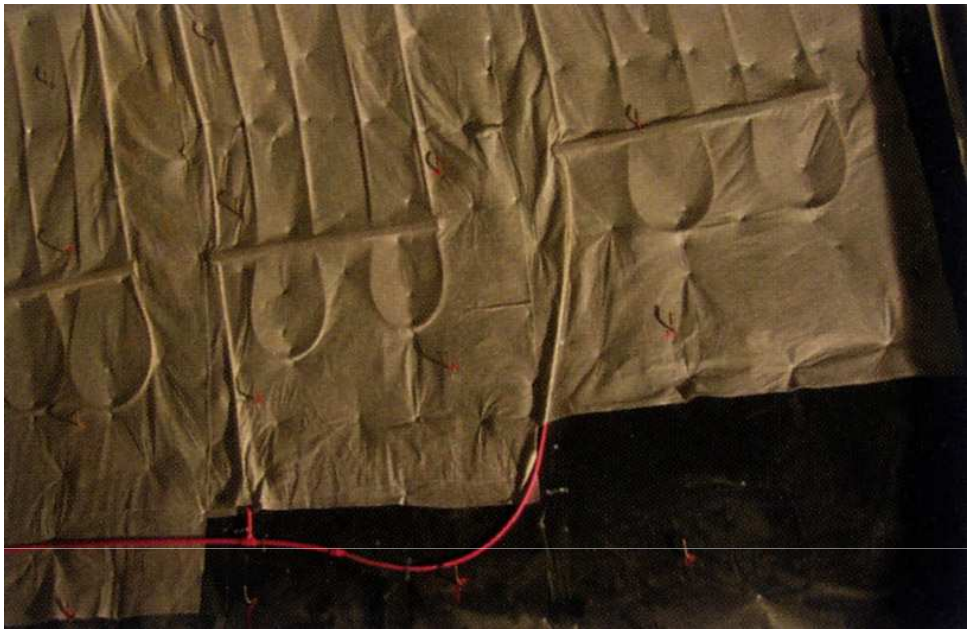
- Vertical or horizontal loops
- Extract heat
- 3.5kW / hole

Thermal Piles and Sprayed Lining

Geothermal Piles at

One New Change,

Arup (2009)

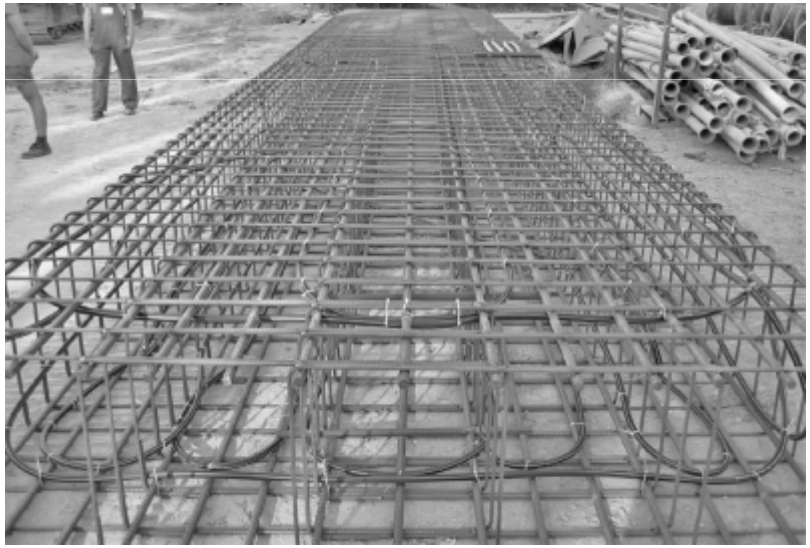


Austrian Sprayed concrete lining at Lainzer Tunnel,

After Brandl (2006)

Other Infrastructure Projects

- **Loops are used in;-**
  - Diaphragm walls
  - Base slabs
  - Linings of the station tunnels, eg metro NATM tunnel lining,
  - Channel Tunnel heat-exchange pipes

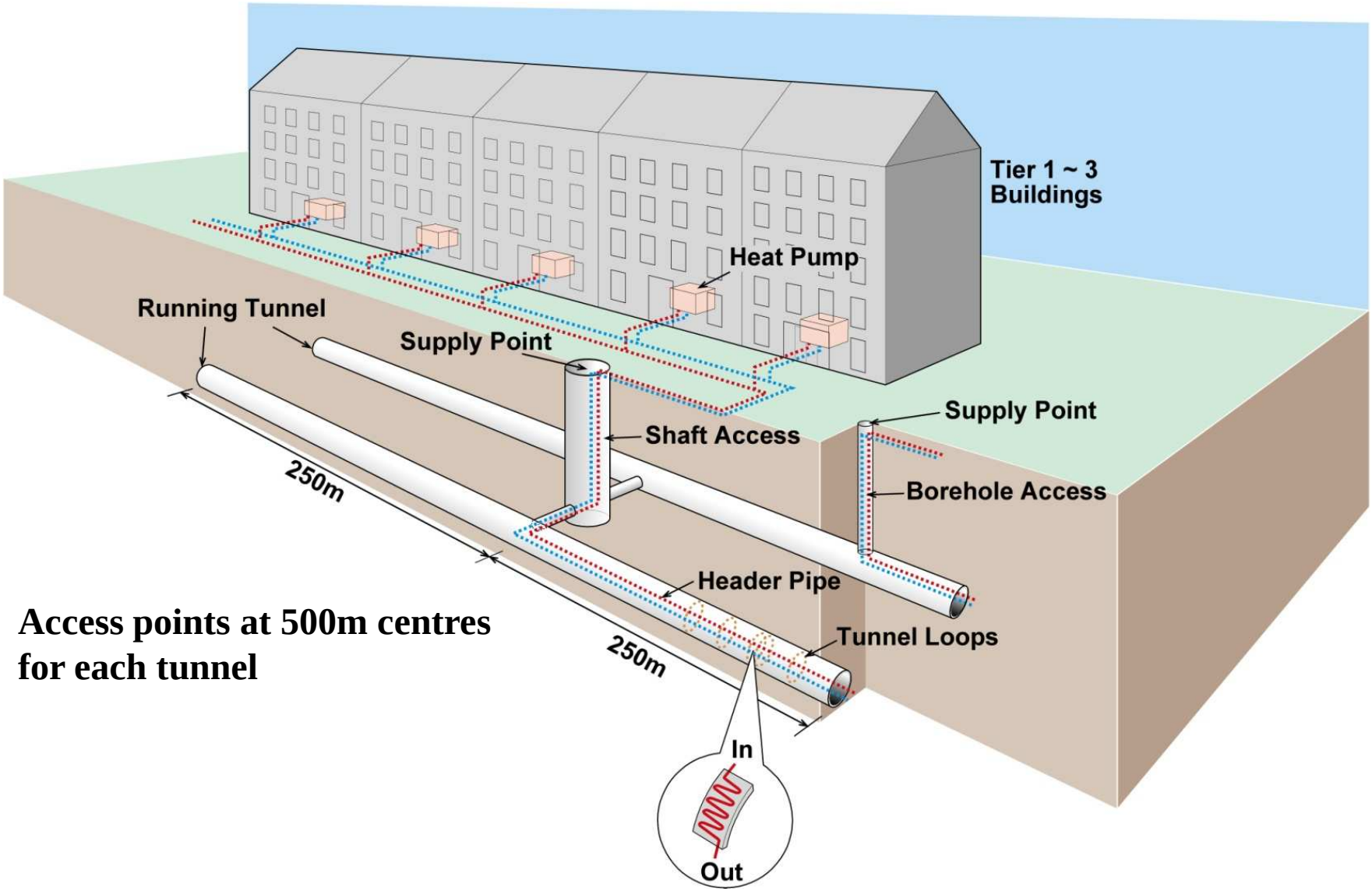


Diaphragm wall, Brandl (2006)

Crossrail – Stations boxes

- Thermal diaphragm walls
- Thermal piles

Concept - Thermal Tunnel



Access points at 500m centres for each tunnel

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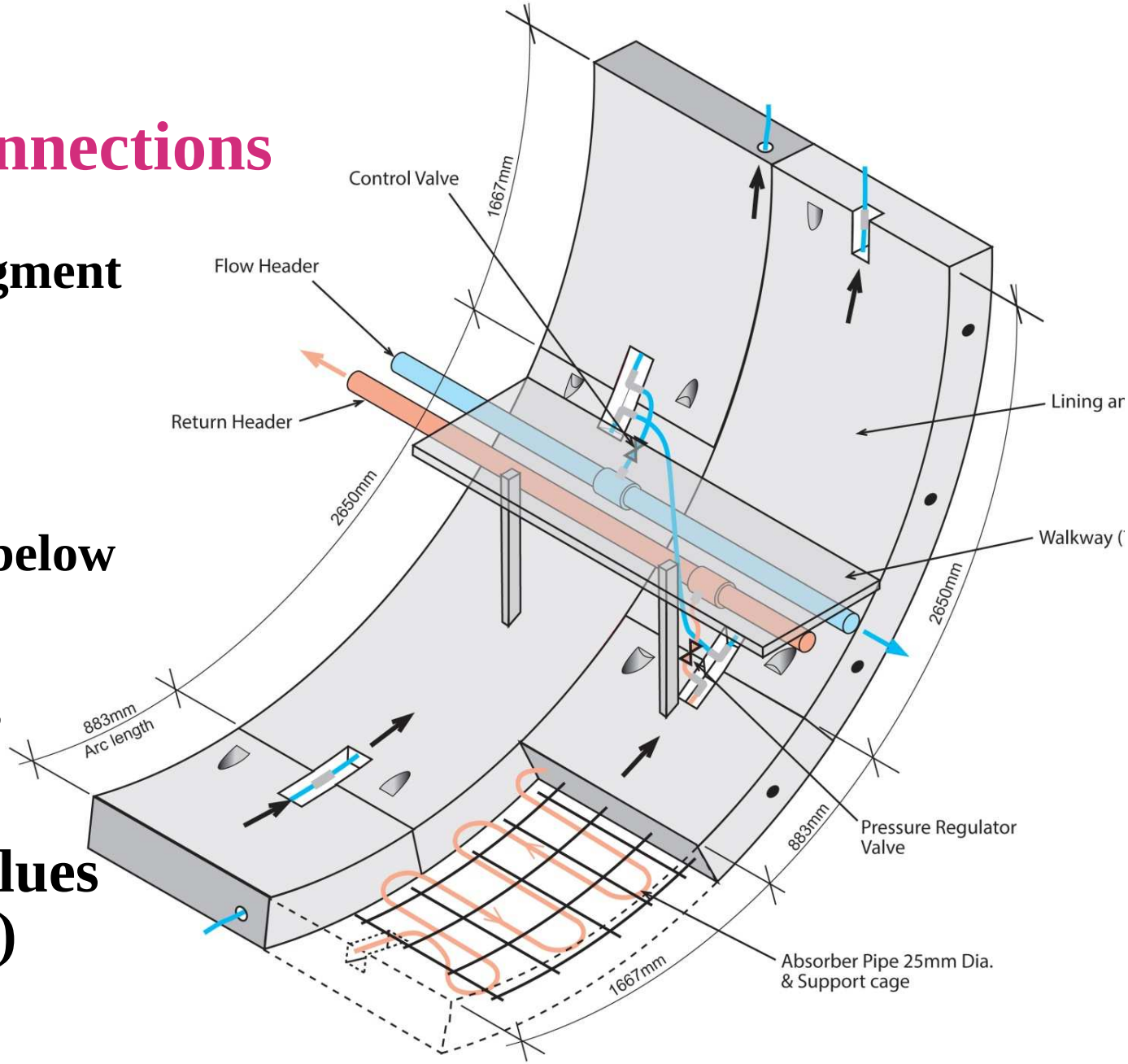
Concept - Segment Connections

- **Segment to segment**
- **Box-outs**
- **Ring to ring**
- **Header pipes below walk way**
- **Control valves**
- **Pressure regulator values (if two pipes)**



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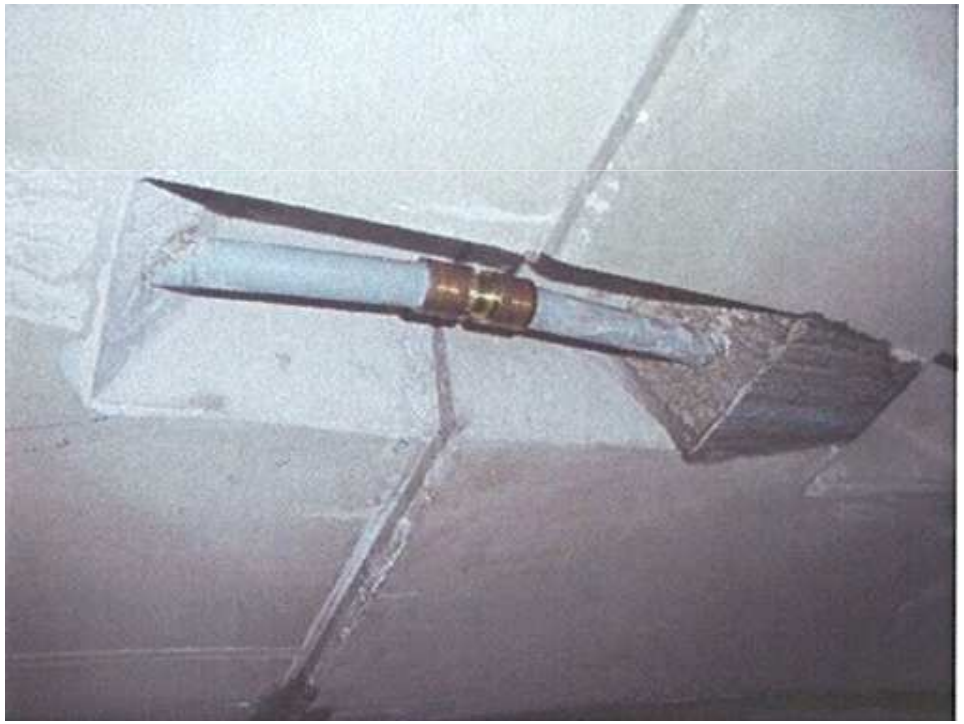
Concept - Pipes and Box-Outs

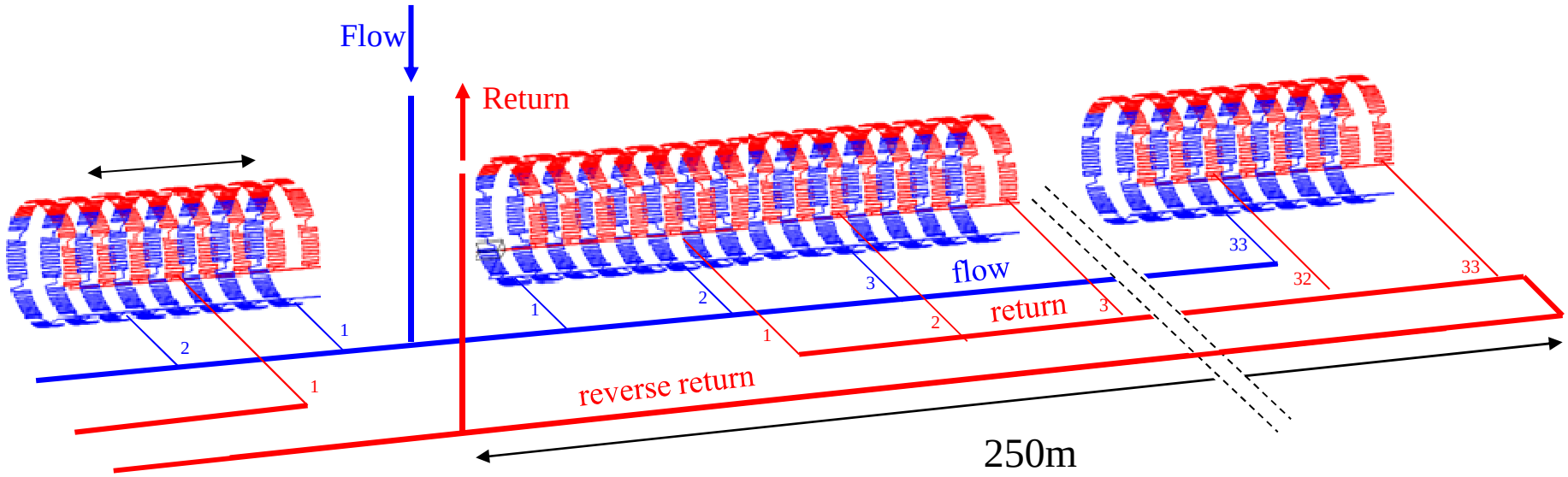
- **PE-Xa grade plastic pipe provides:-**
  - **Durability – 120 yrs at operating temperatures pressure.**
  - **Permanent mechanical joint for segment to segment - fast.**
  - **Good bend radius.**



- **Box-out provides:-**
  - **Connection space.**
  - **Joint rotation / extension.**
  - **Mortar filler option.**

Concept - Circuit Diagram

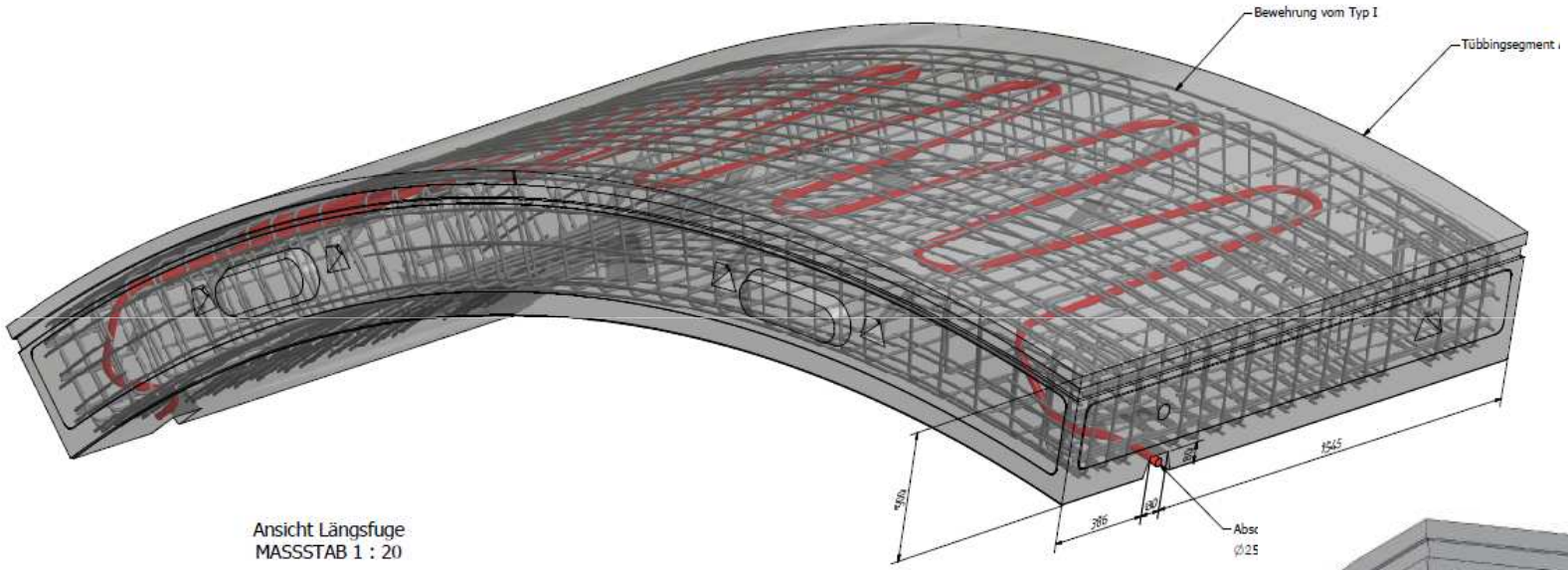
- **11 metres of pipe per segment**
- **6 segments to one ring**
- **5 rings to one circuit**
- **33 circuits to branch**
- **4 branches to one shaft**
- **Shafts at 500m centres**



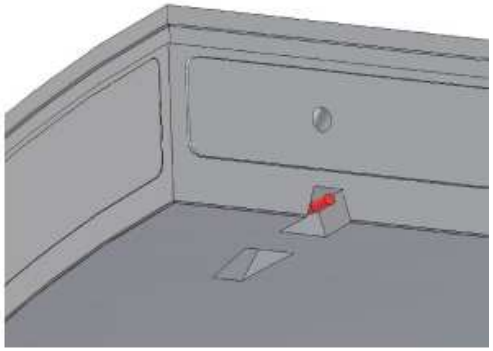
Reverse return header pipe:-
Three pipes - no pressure regulator valve - Control values

Concept - Thermal Loops Inside Segment

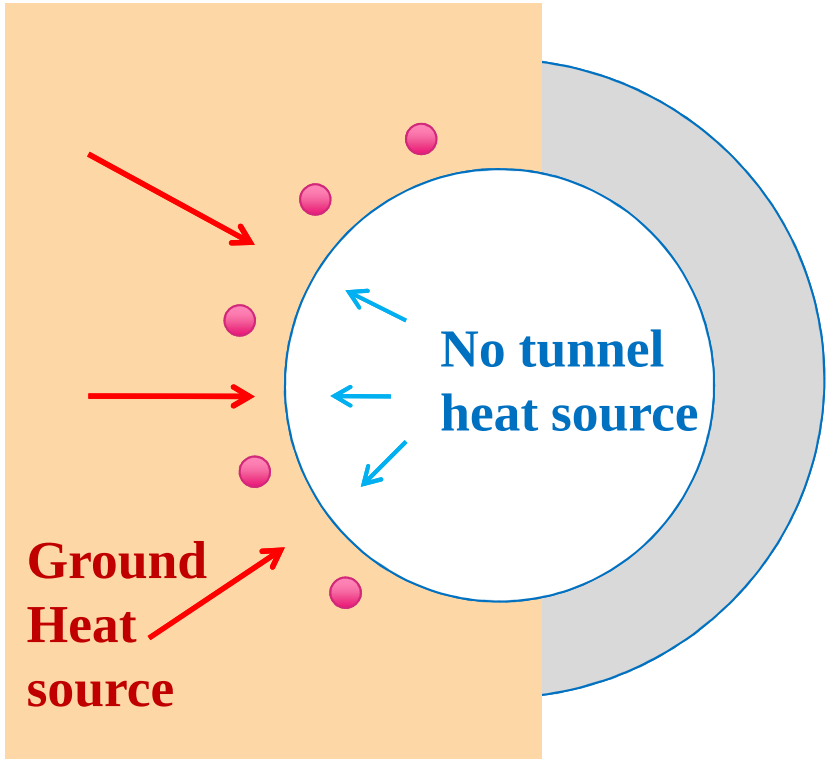
Position of pipes inside tunnel segment



Box out section for the pipe connections.



Concept - Cold Tunnels



Cold Tunnels:

- No tunnel heat source
- Tunnel air temperature low
- Provides building heating and cooling
- Heat energy mostly from soil mass not tunnel

Cold Tunnel locations

- Short road and rail tunnels
- Cold climates
- Good natural air ventilation

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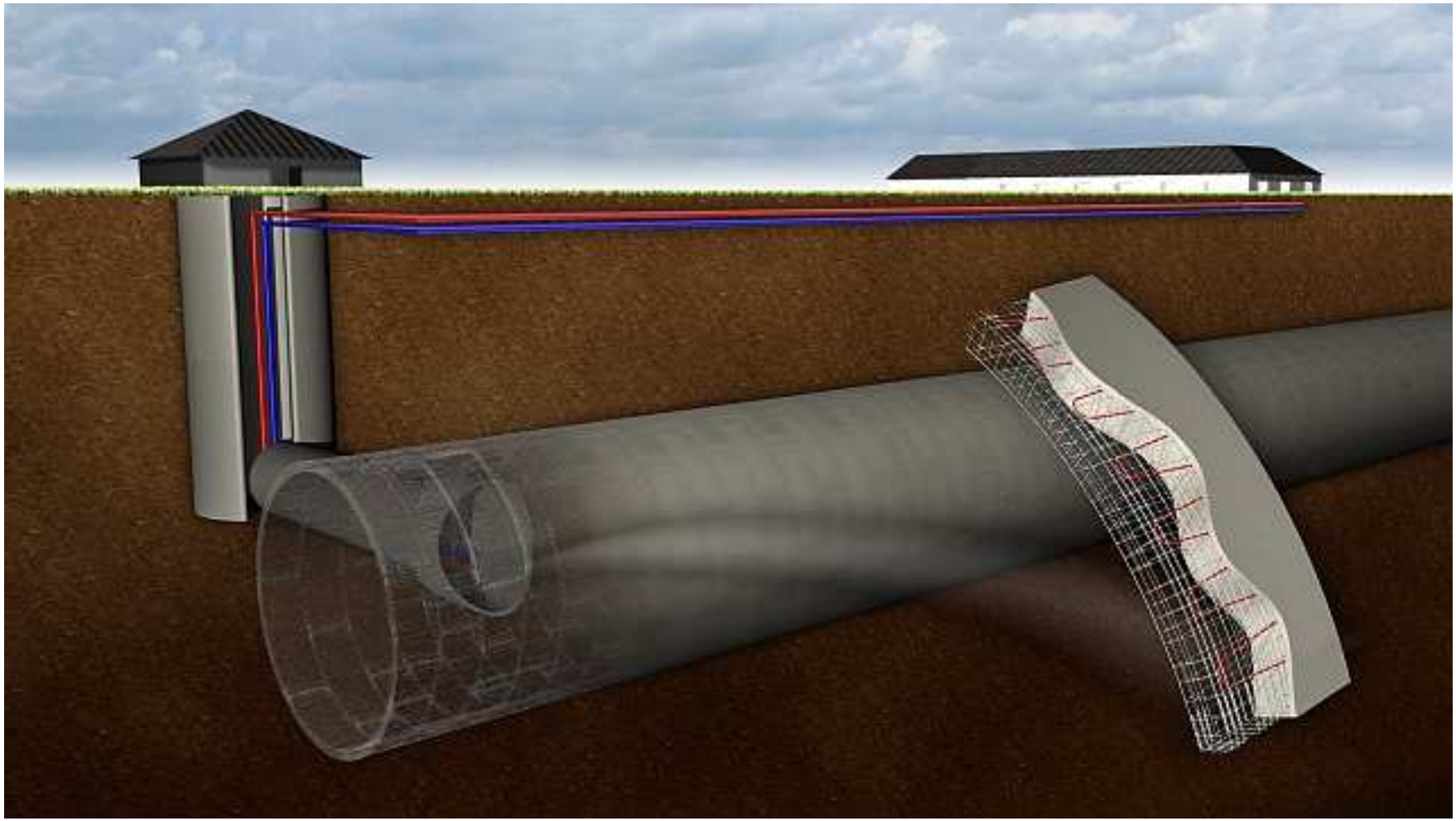
Cold Tunnel Example – Janbech Tunnel

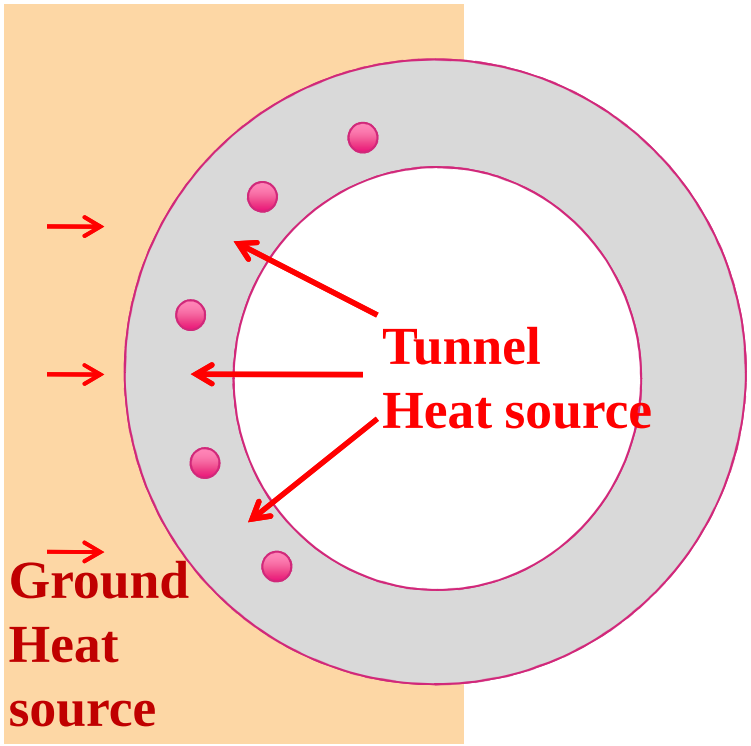


Details to be given by Dr Franzius from Züblin

Segment – Reinforcement

- **Fibre Reinforcement – just pipe support cage**
  - Crossrail
- **Steel Cage**
  - Janbech Tunnel
- **Segment mould effects**
- **Production and testing**

Concept - Hot Tunnels



Crossrail train motors – 1MW heat
Trains at 2.5min intervals

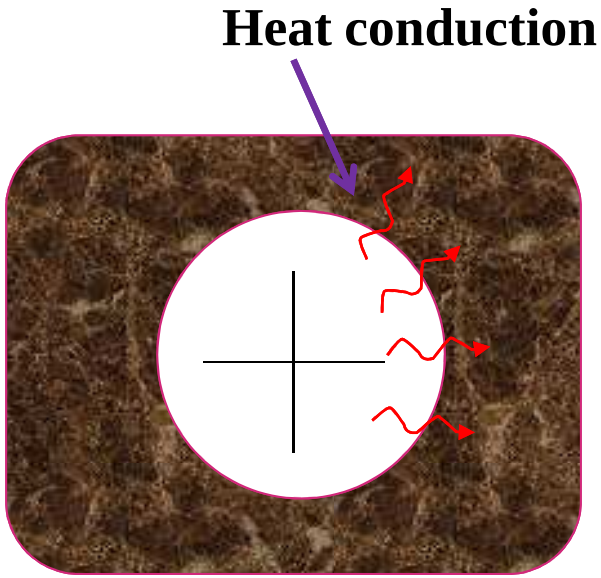
Hot Tunnels:

- Tunnel air temperature higher than ground
- Heat Energy mostly from tunnel
- Mainly for building heating
- helps to cool the tunnel
- Not efficient for cooling building

Hot tunnel locations :-

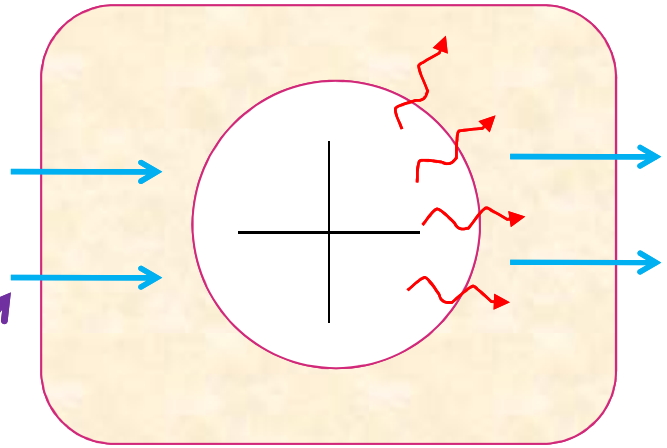
- cable tunnels,
- foul sewers,
- Deep/long rail and road tunnels

Concept – Effect of Ground



- **Tunnels in Clay:**
  - Heat stays, - local conduction
  - Access boreholes - easy to construct

- **Tunnels in Sand:**
  - Heat dissipates with ground water flow (Advection)
  - Access borehole are difficult to construct – water bearing sand



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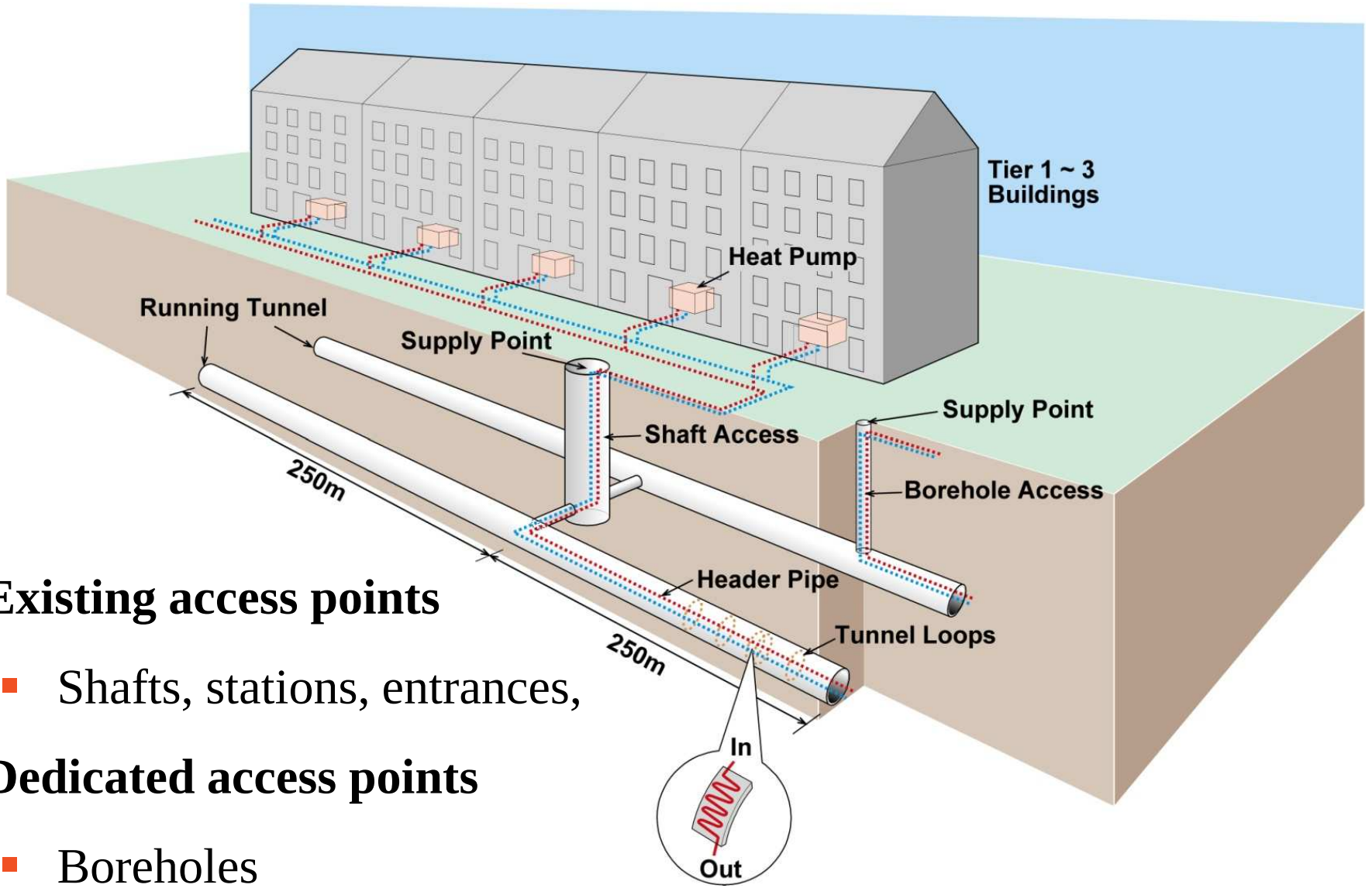
Design Development Process

- **Develop concept – overall economics / carbon savings**
- **Identify design issues – many disciplines**
- **Tunnel design issues :-**
  - Linking header pipes to surface
  - Lining construction
  - Design Process
    - Segment heat transfer model
    - Tunnel ventilation model
    - Tunnel thermal stress model
  - Fire
- **Surface heat market**
- **Costings / carbon savings**

Linking Header pipes to surface



- **Existing access points**
  - Shafts, stations, entrances,
- **Dedicated access points**
  - Boreholes

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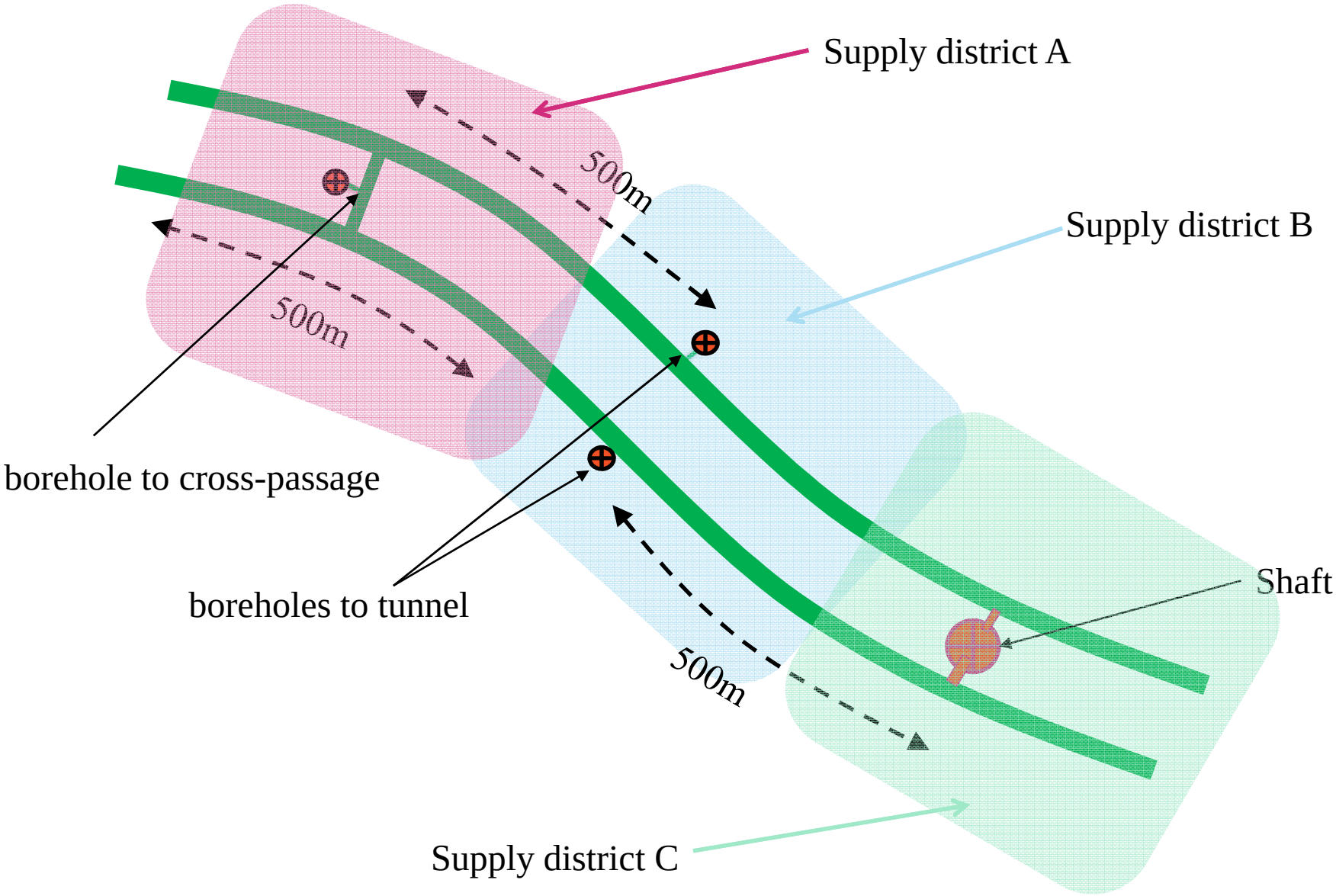
Heat Supply to surface buildings



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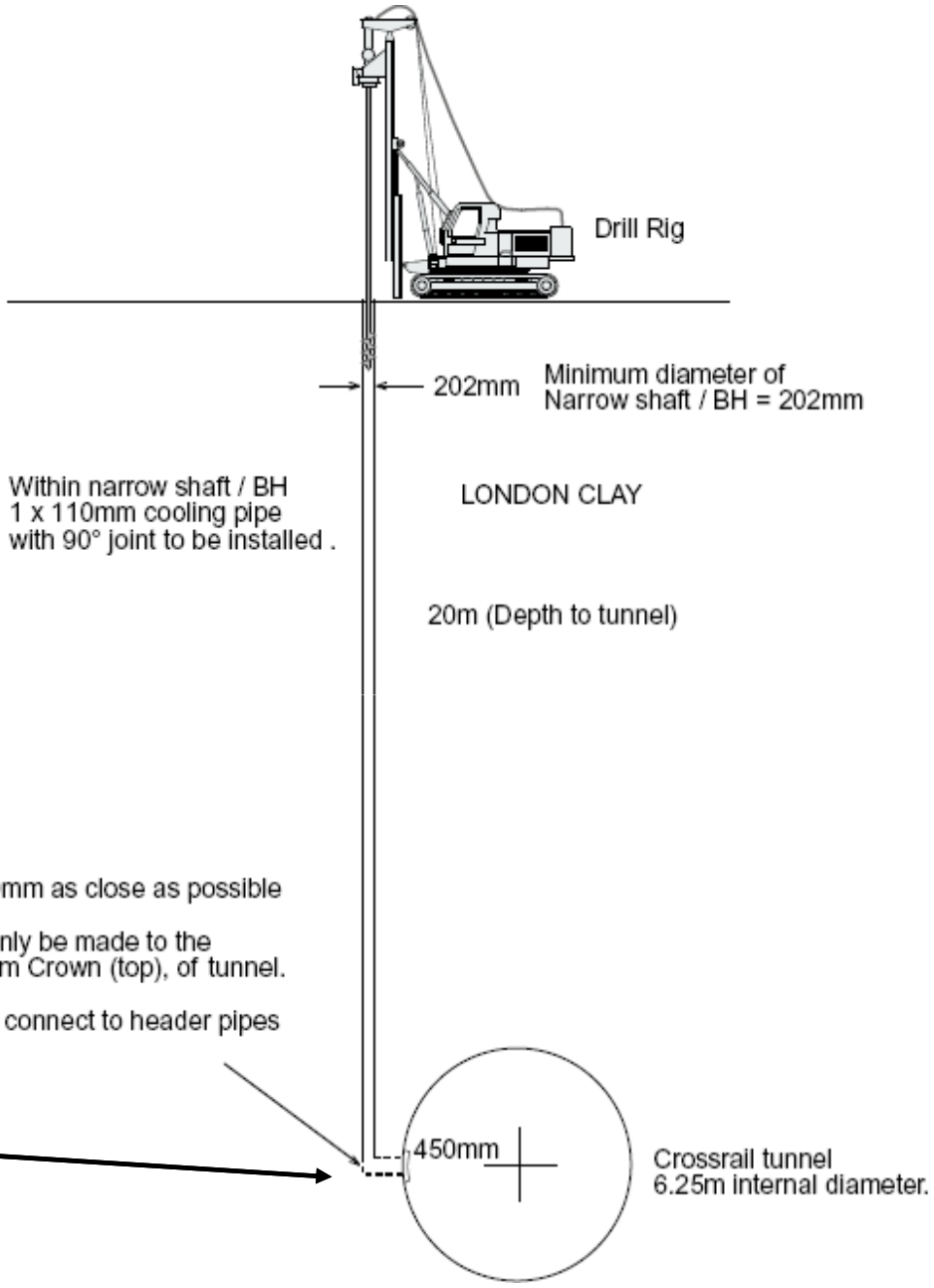
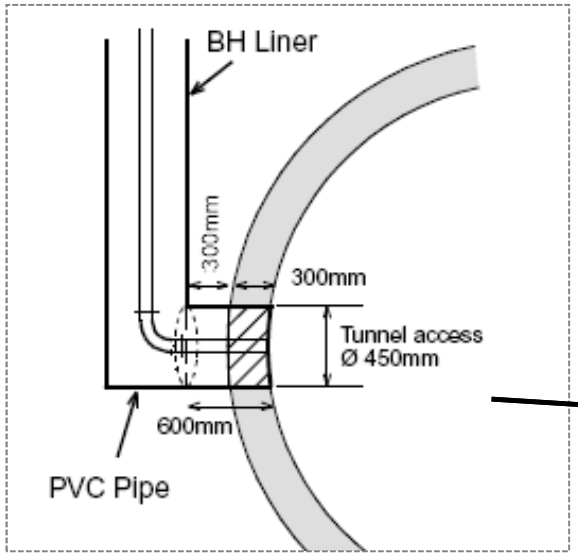
Vertical Drilling

- **Connect cross passage or tunnel**
  - 202 borehole casing with 110mm pipe
- **Verticality tolerance**
  - 1 in 200 (+/-100mm at 20m depth)

- 2 boreholes per access point for header and return
- ~ £40K for a pair

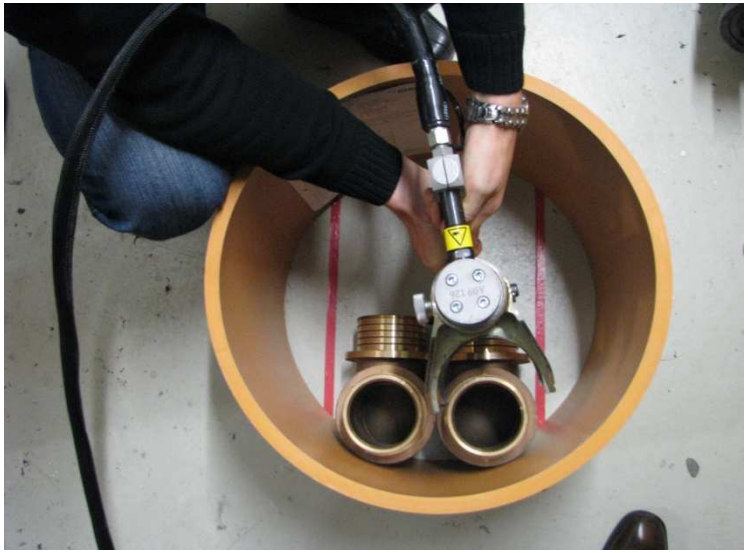


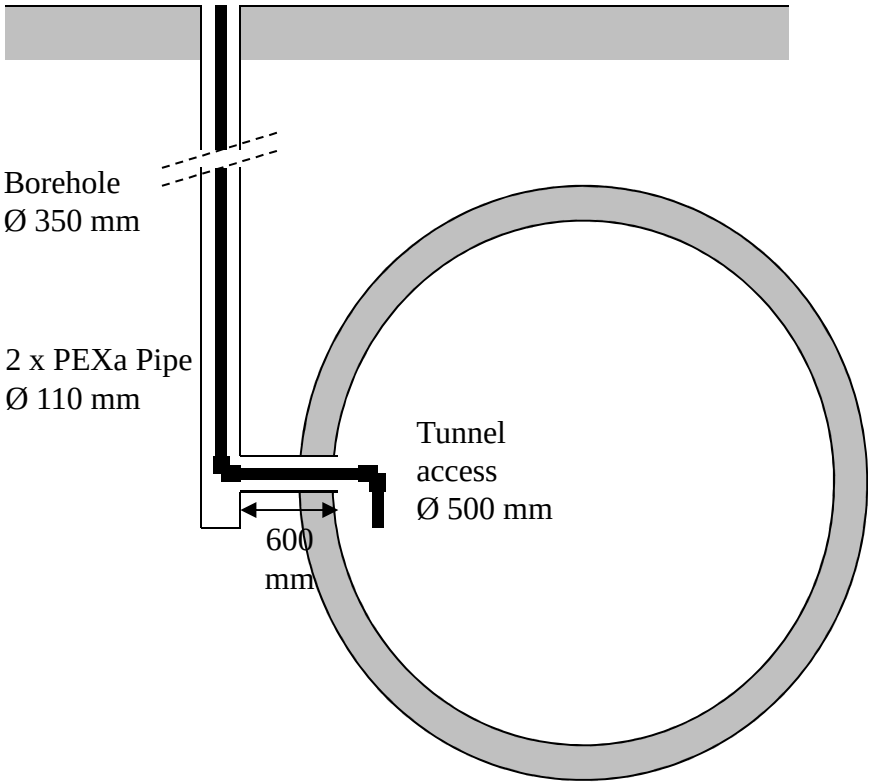


Borehole to tunnel connection

- 110 mm flow & return pipe

-500mm opening





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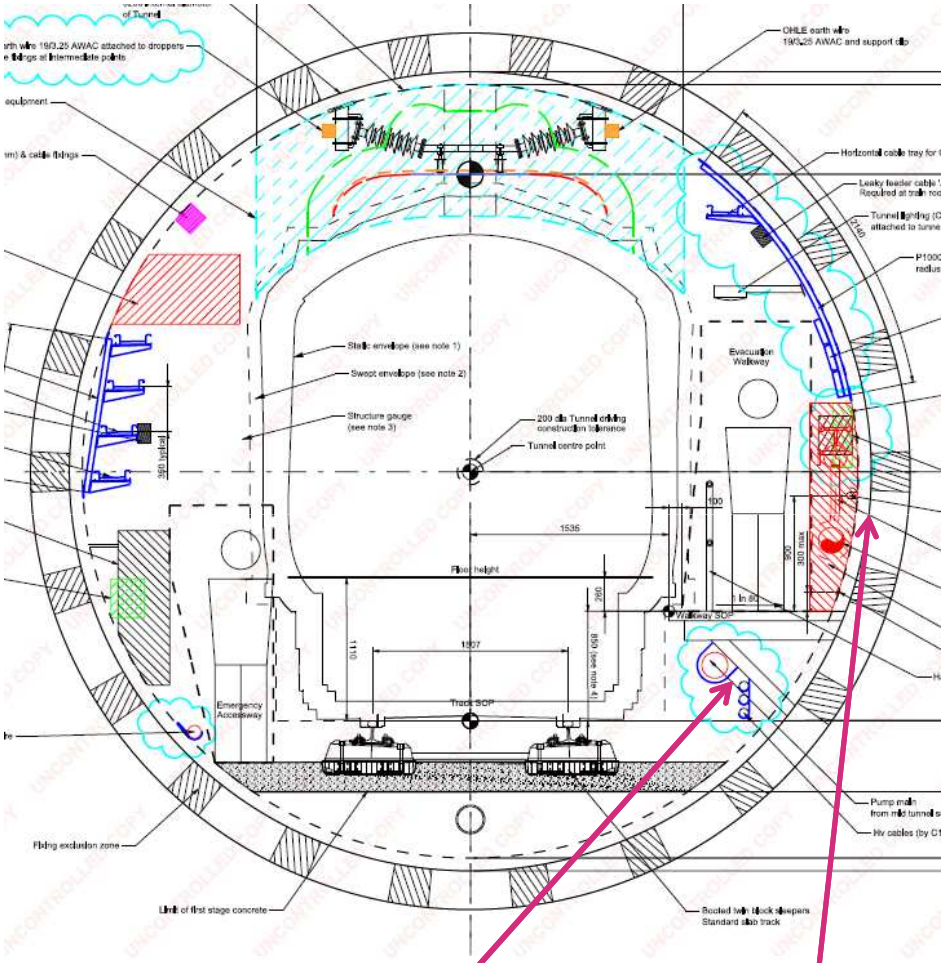
Impacts on Tunnel Construction

Impact on:-

- Segment construction
- Segment erection
- Space use inside tunnel
- Construction cost
- Tunnel maintenance



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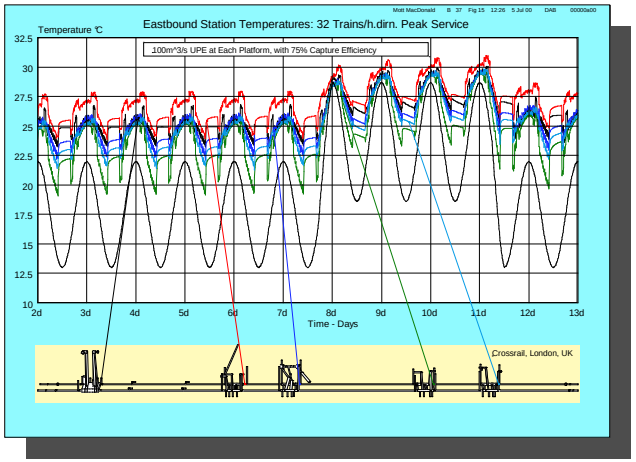
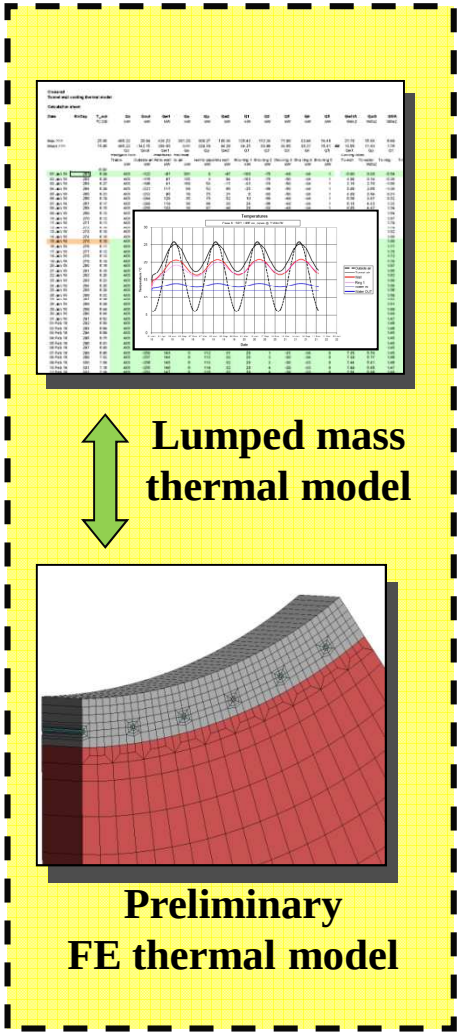
Tunnel Design Process – Hot Tunnels



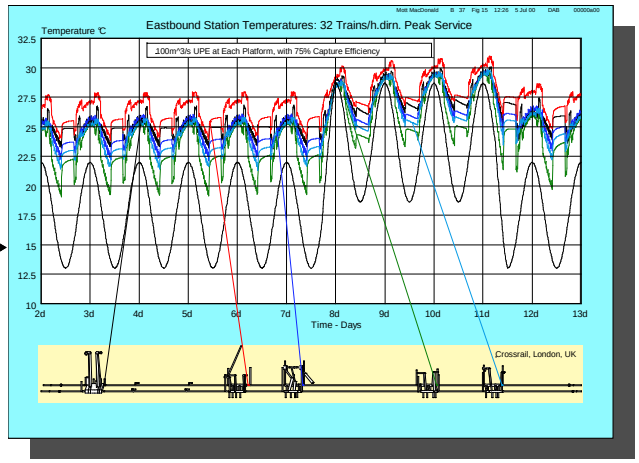
Existing 1-D
Tunnel ventilation model

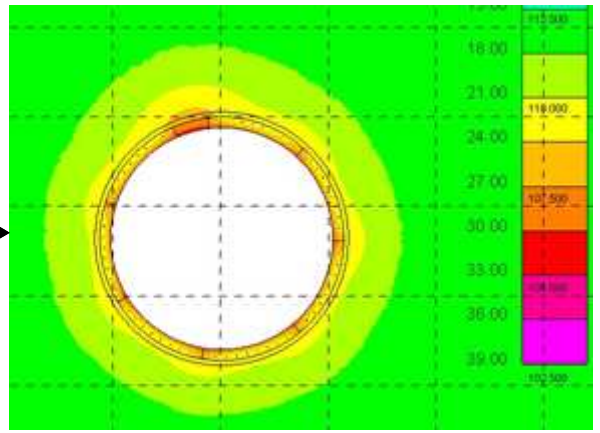


Lumped mass thermal model

Preliminary FE thermal model

Revised 1-D model with tunnel wall cooling





FE stress analysis thermal model

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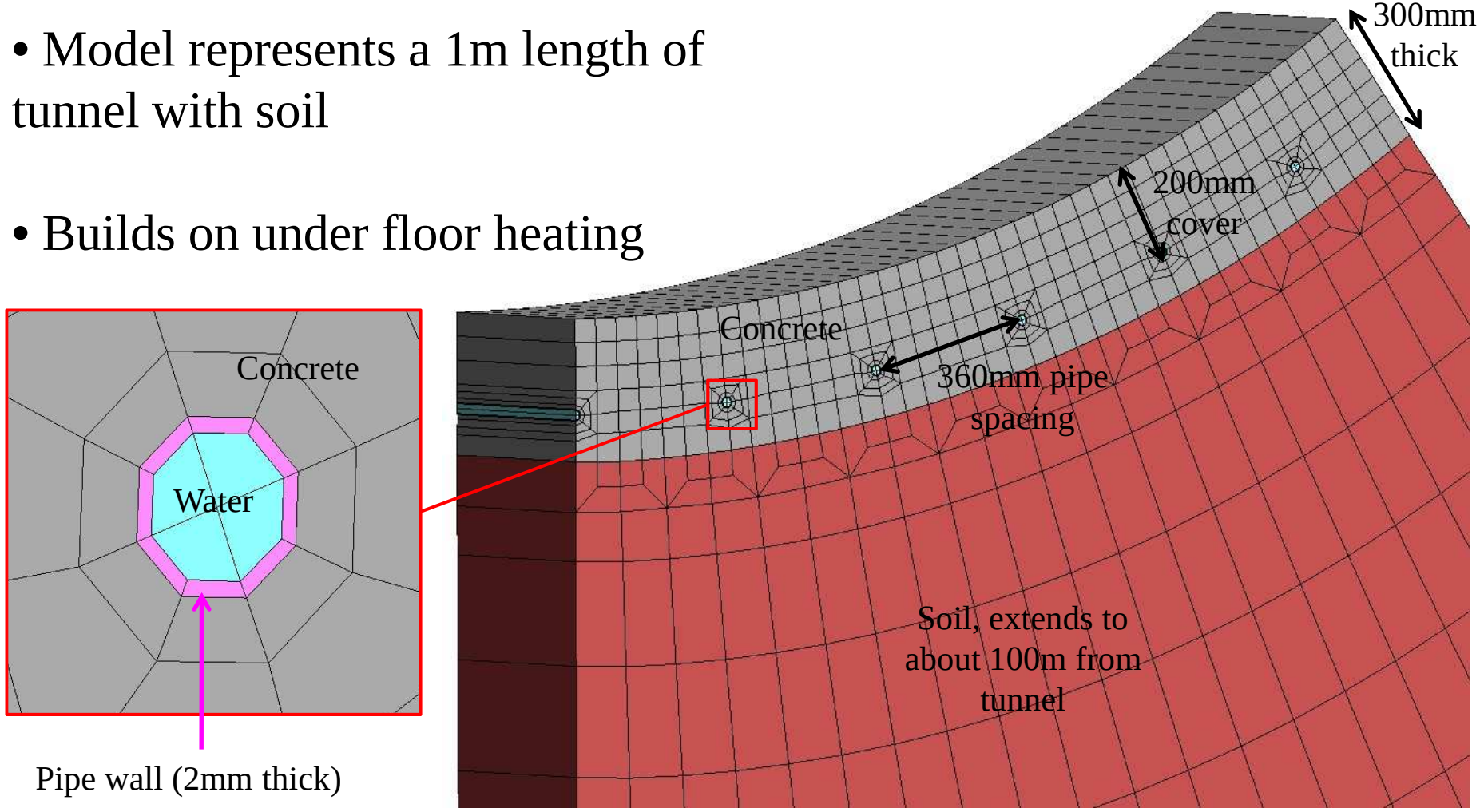
Segement Thermal Model (DYNA)

- Model represents a 1m length of tunnel with soil

- Builds on under floor heating



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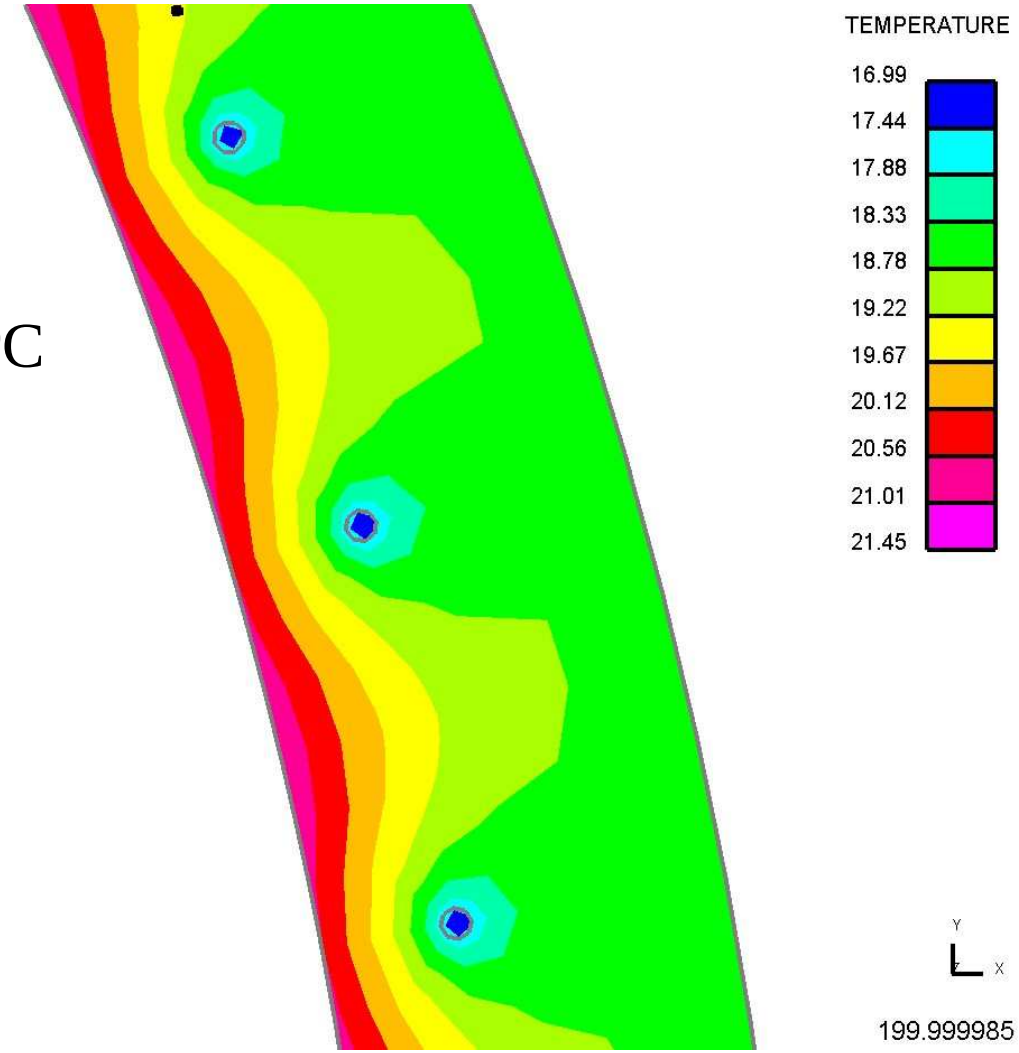
Temperature contours in tunnel lining

Model considers:

- Air temperature in tunnel
- Boundary condition in soil 15^{o}C at 150m
- Assign extraction rates from pipes



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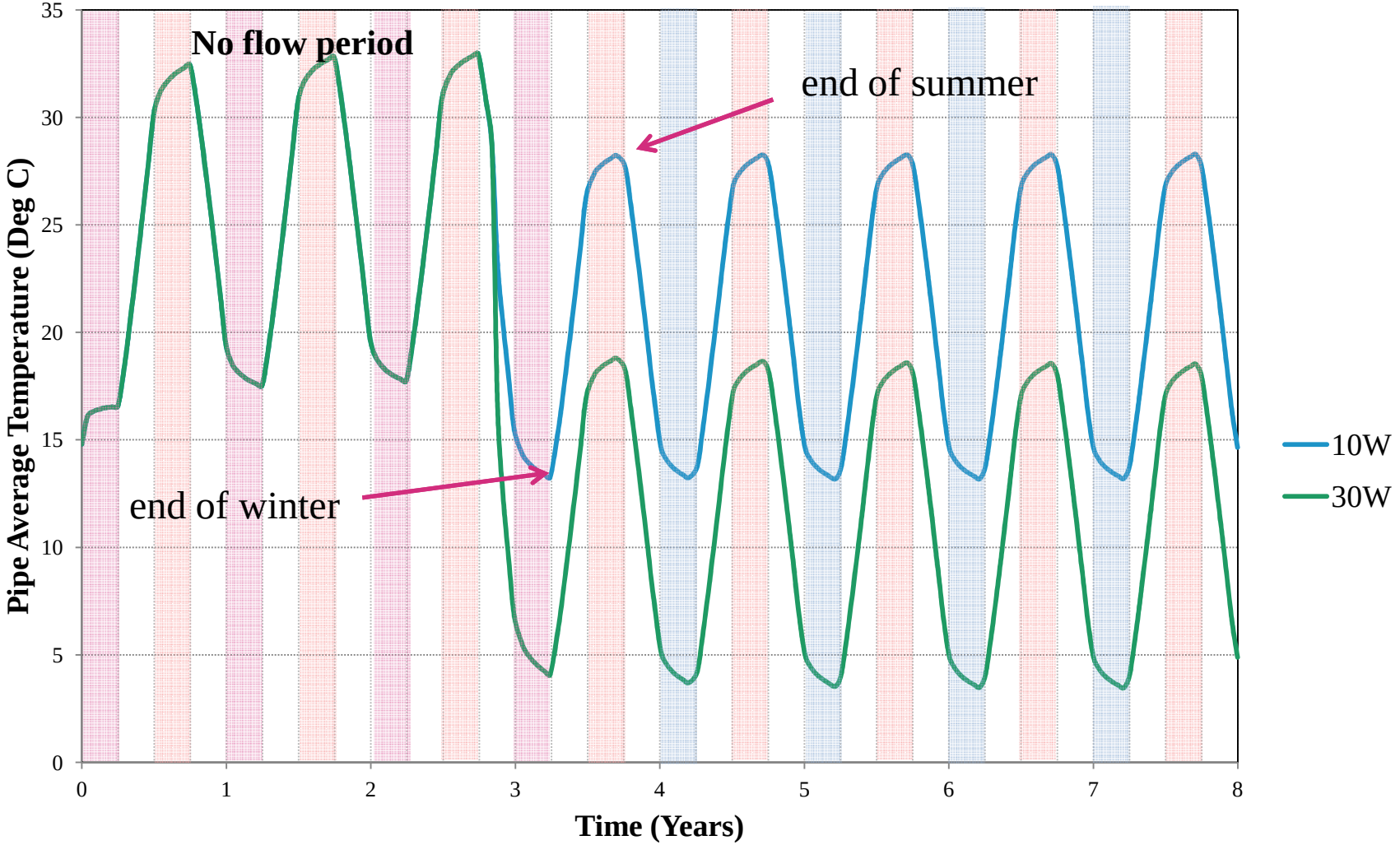
Temperature variation in the pipe – continuous extraction



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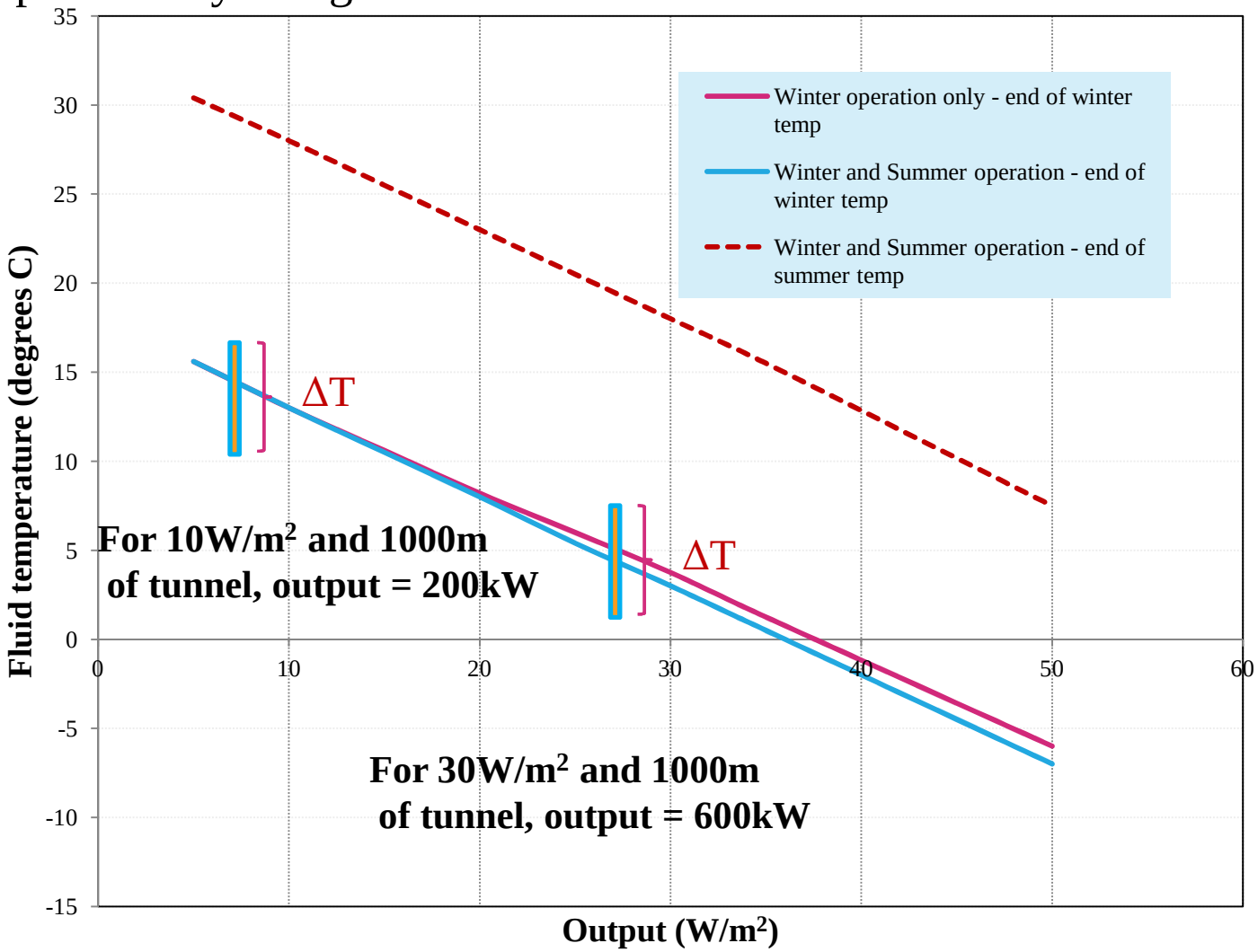
Heat extraction rate vs. fluid temp

Fluid temp half-way along tunnel



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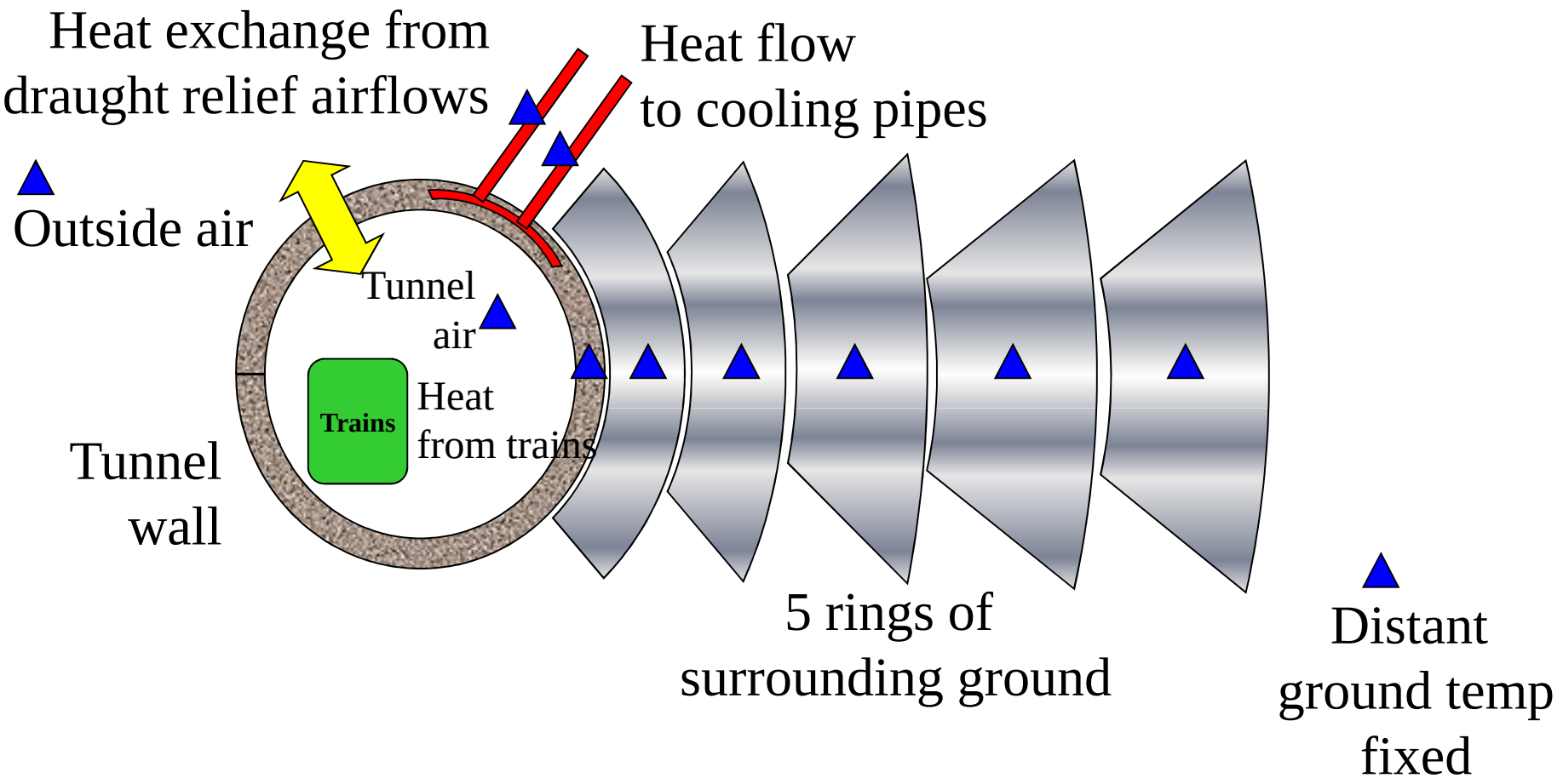
Tunnel Ventilation Model (Motts input)



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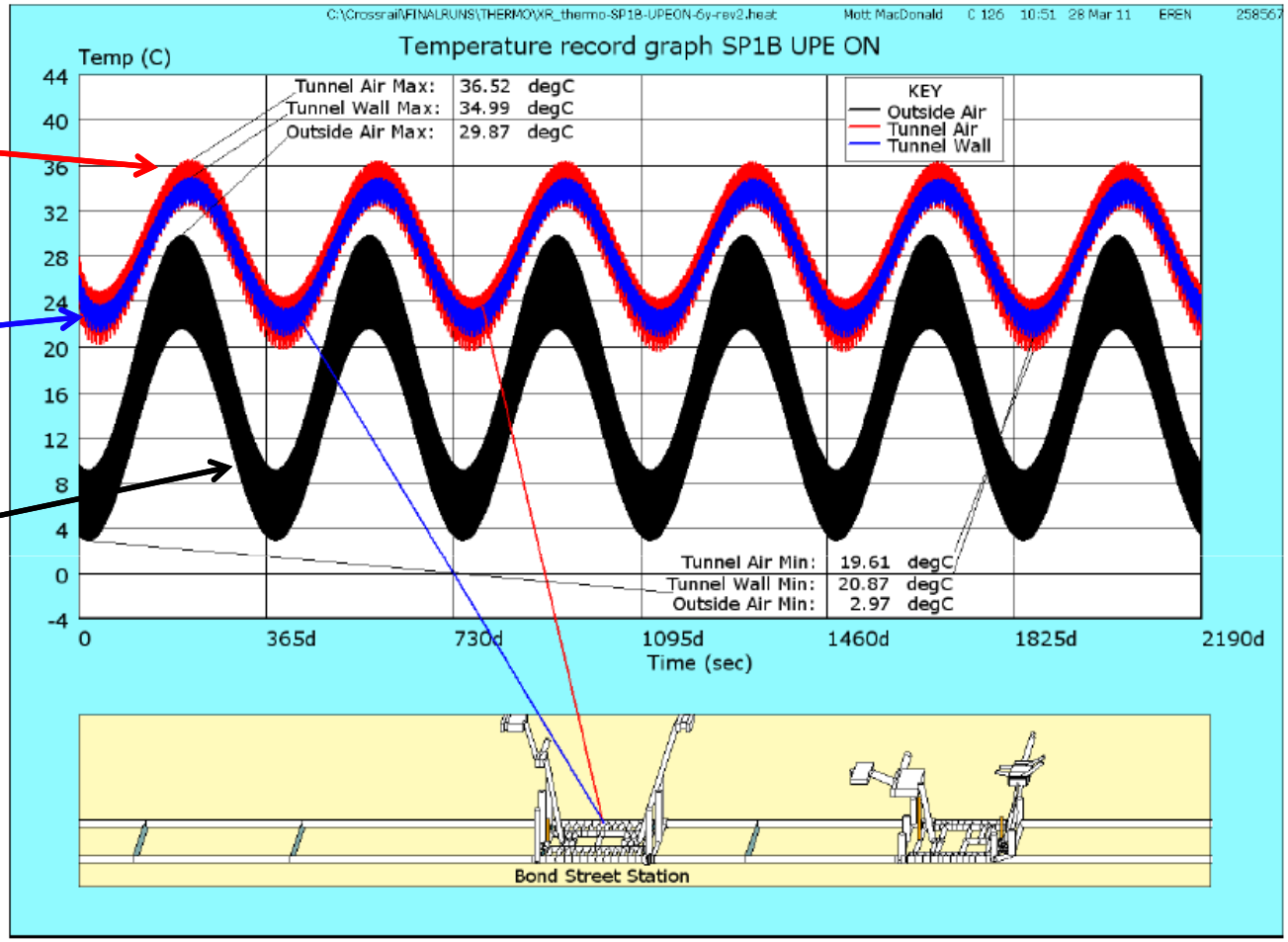
Ventilation Modelling (1)

Tunnel Air Max temp

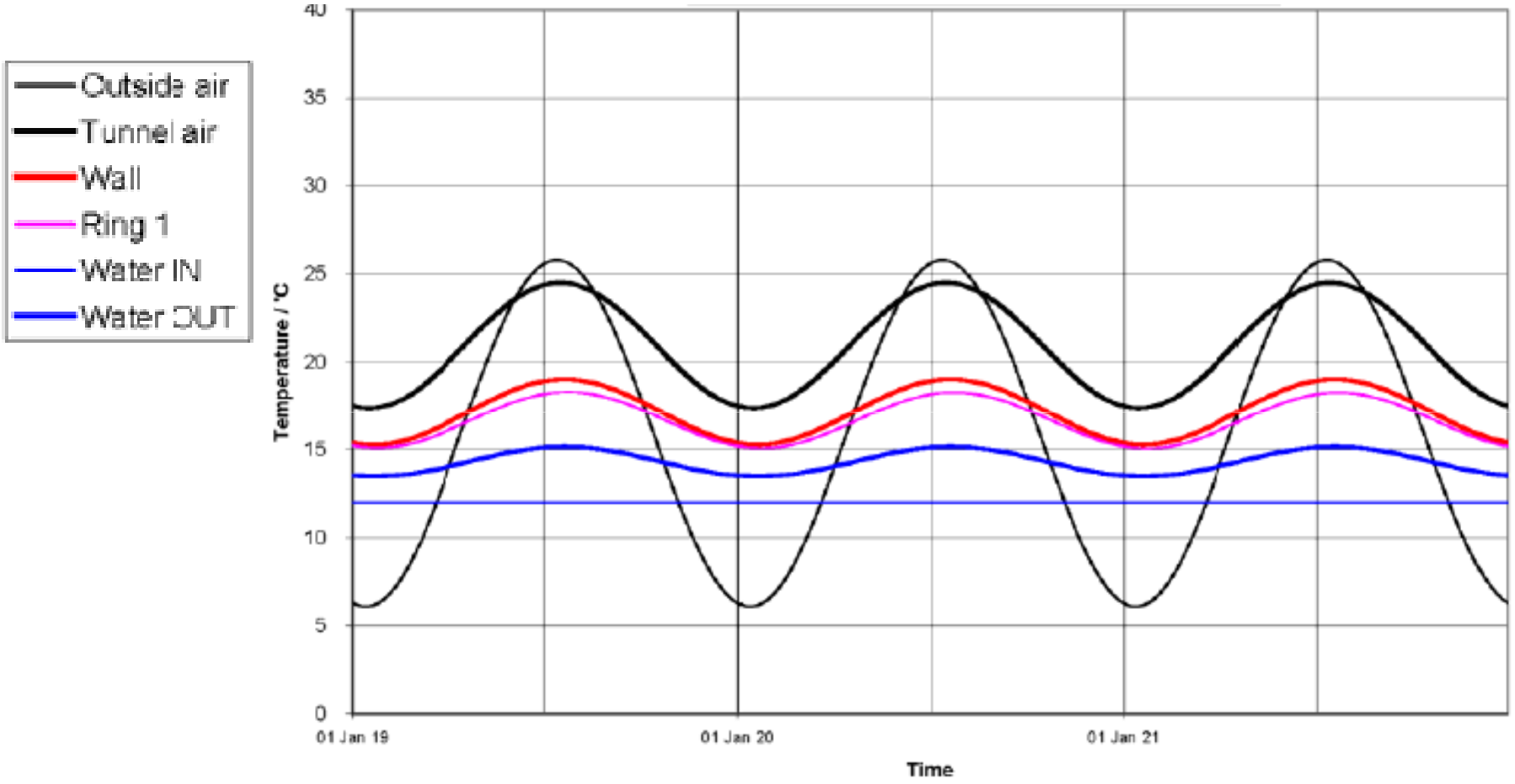
Tunnel Wall Max temp

Outside Air Max temp



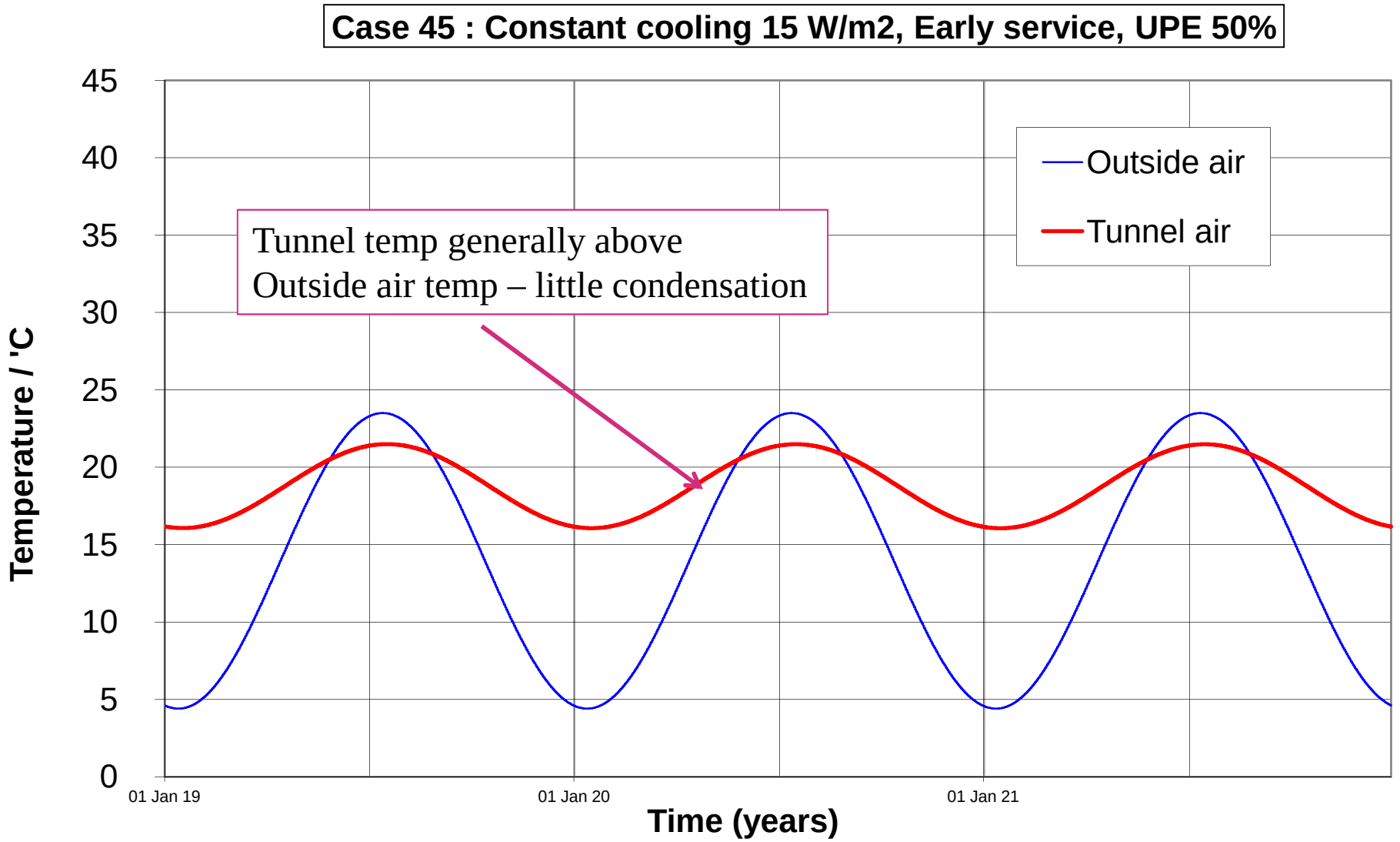
Typical tunnel temperature for service pattern SP1B
(240m trains, 30TPH peak hour service frequency- 2076)

Ventilation Modelling (2)



Predicted tunnel temperature with heat extraction system operating

Tunnel Cooling @ 15W/m² UPE 50%

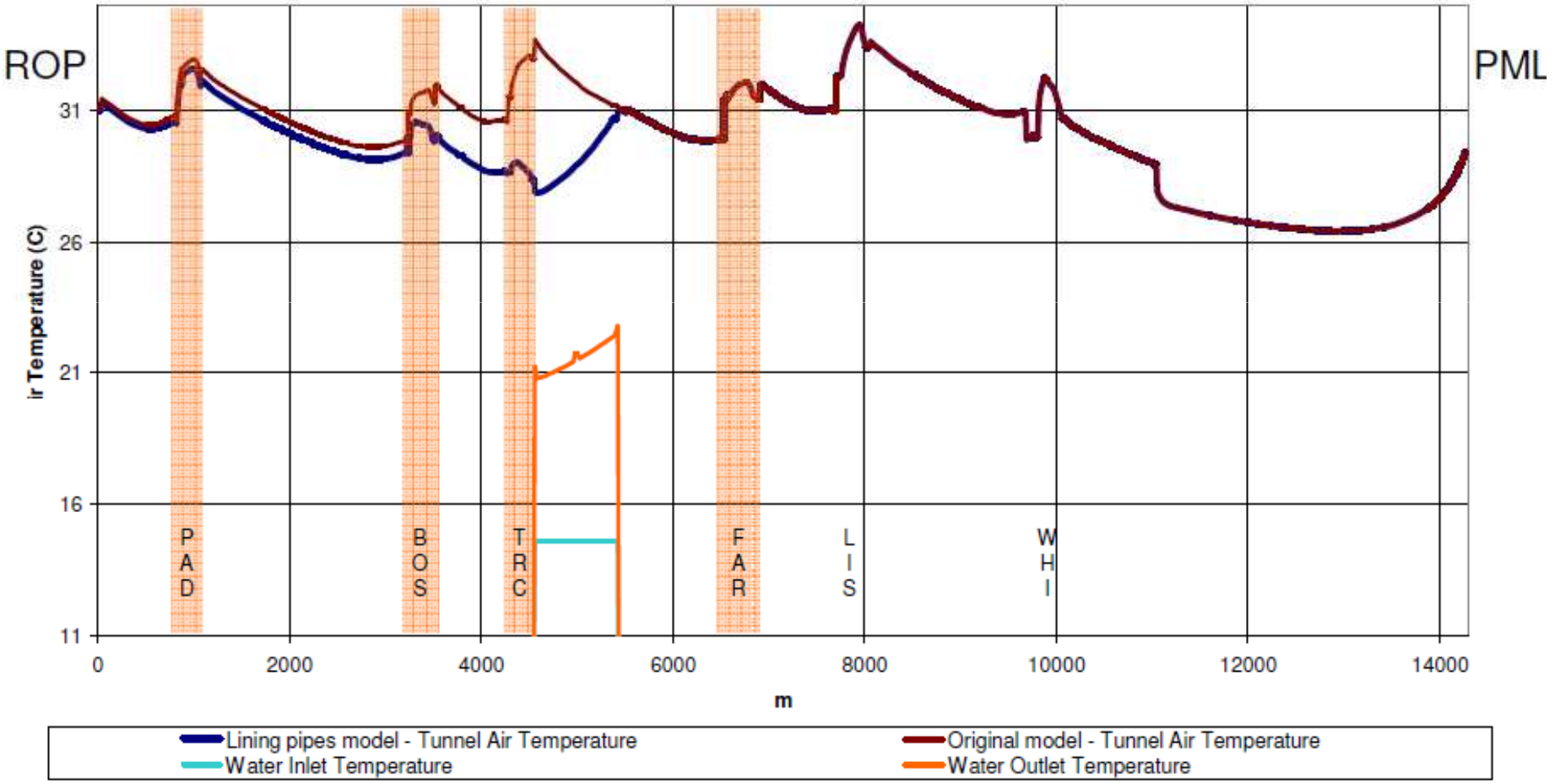


Tunnel Cooling Effect – Local Installation

800m demonstration tunnel -East of Tottenham Court Road Stn

West bound tunnel – Summer peak

Best to focus tunnel cooling either side of stations



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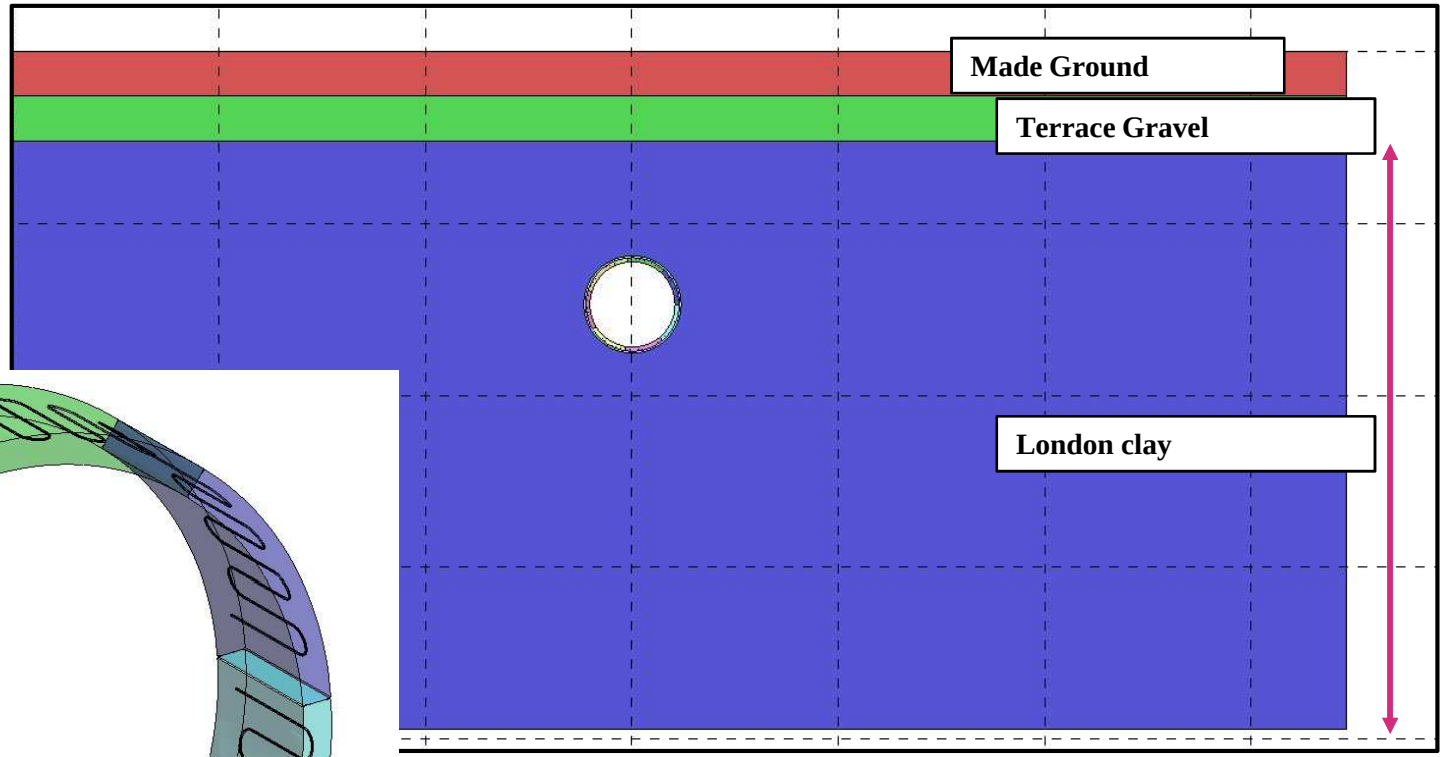
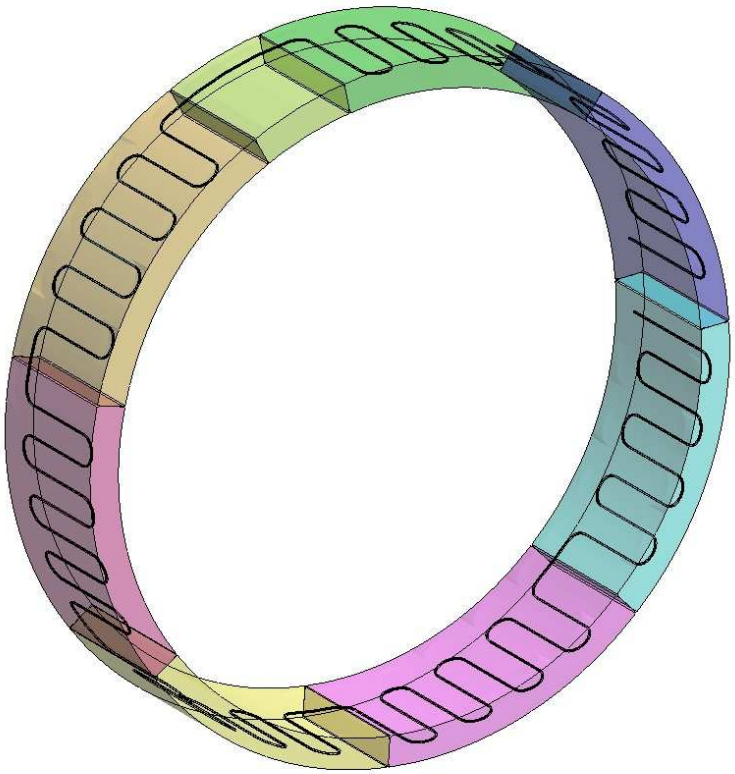
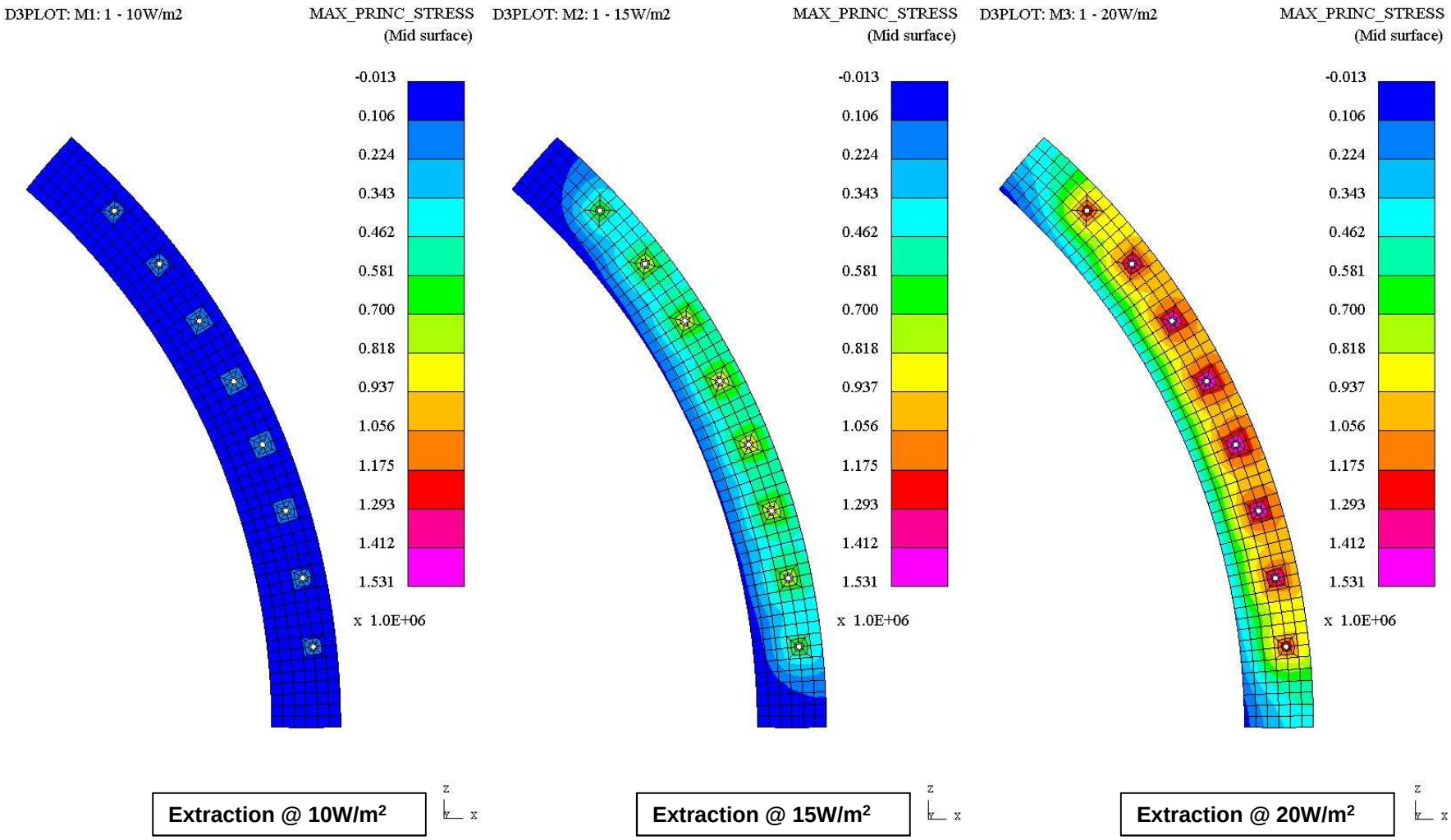
FE model – tunnel segments with pipe





- Model of one segment ring + Soil
- Plastic pipes
- Curved segment bearing surfaces

Stress reduction - Due to cooling round pipes



Extraction @ 10W/m²

Tensile Stress = 253kPa

Extraction @ 15W/m²

886kPa

Extraction @ 20W/m²

1.53MPa

Stresses reductions combined with earth pressures – (contraction round the outer face)

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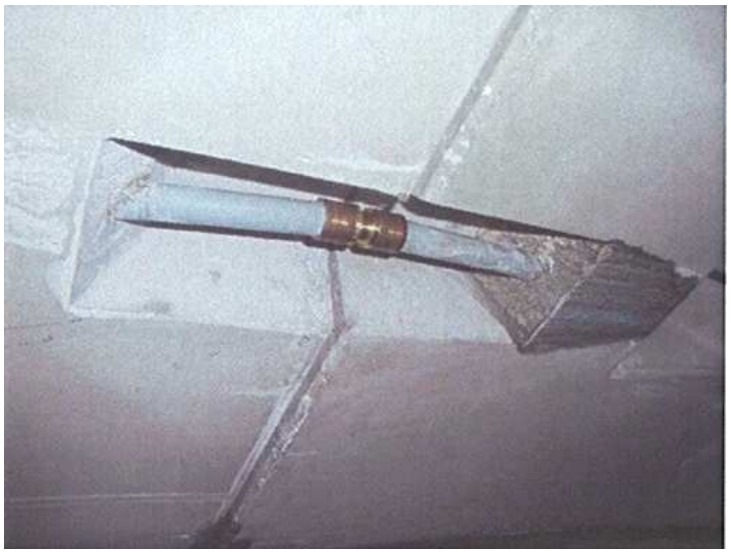
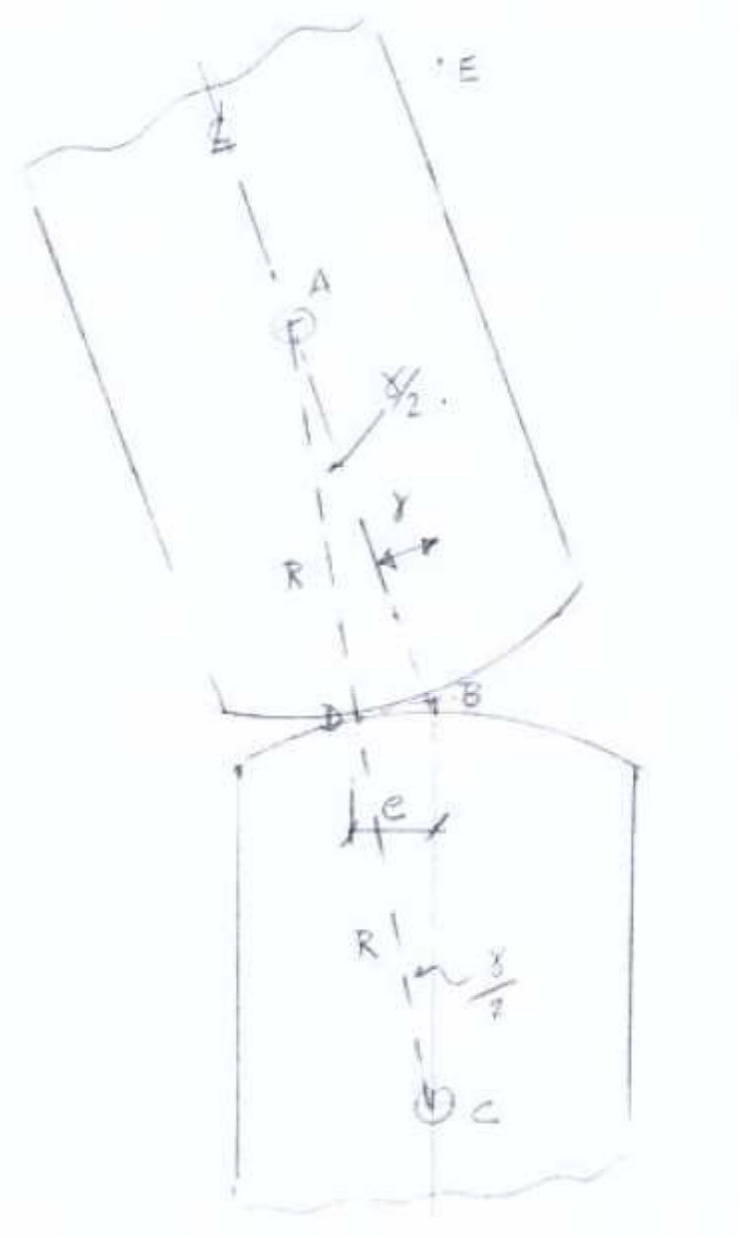
Joint Rotation Effects and Box Out length

- Max ring deformation = 1% of dia.
- Joint rotation is 1.45 degree
- Joint opening = 150mm tan 1.45^{o}
- = +/- 3.8mm
- Combined box out lengths = 300mm





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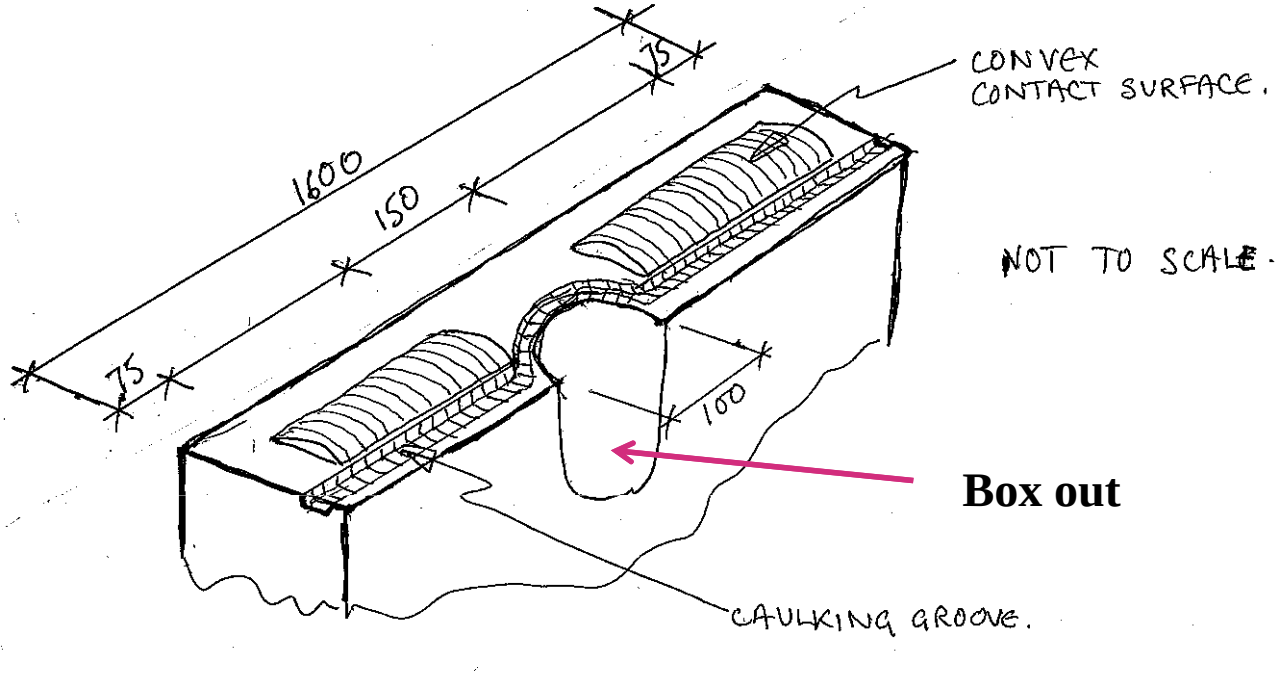
Segment joints and box-outs – Caulking groove and bearing



Based on hand calculations – anti bursting reinforcement needed for tunnel depths >31m with box-out, or 35m without box-out.

Concrete Section loss - Pipe diameter is 20mm and lining is 300mm - 6.7% loss

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Fire

- Fire load - EUREKA fire curve
- Spalling margin of the segment
- Stakeholders: To consider PE pipes
  - LU 1-085 Fire Safety of Materials
- PEX-a Pipes: Durability 100 years at 20^{o}C and 15 bar (according to DIN 16892/16893, EN ISO 15875) incl. FoS 1.25
- Check ventilation capacity to remove smoke

Fire – Segment Pipes and Header pipes

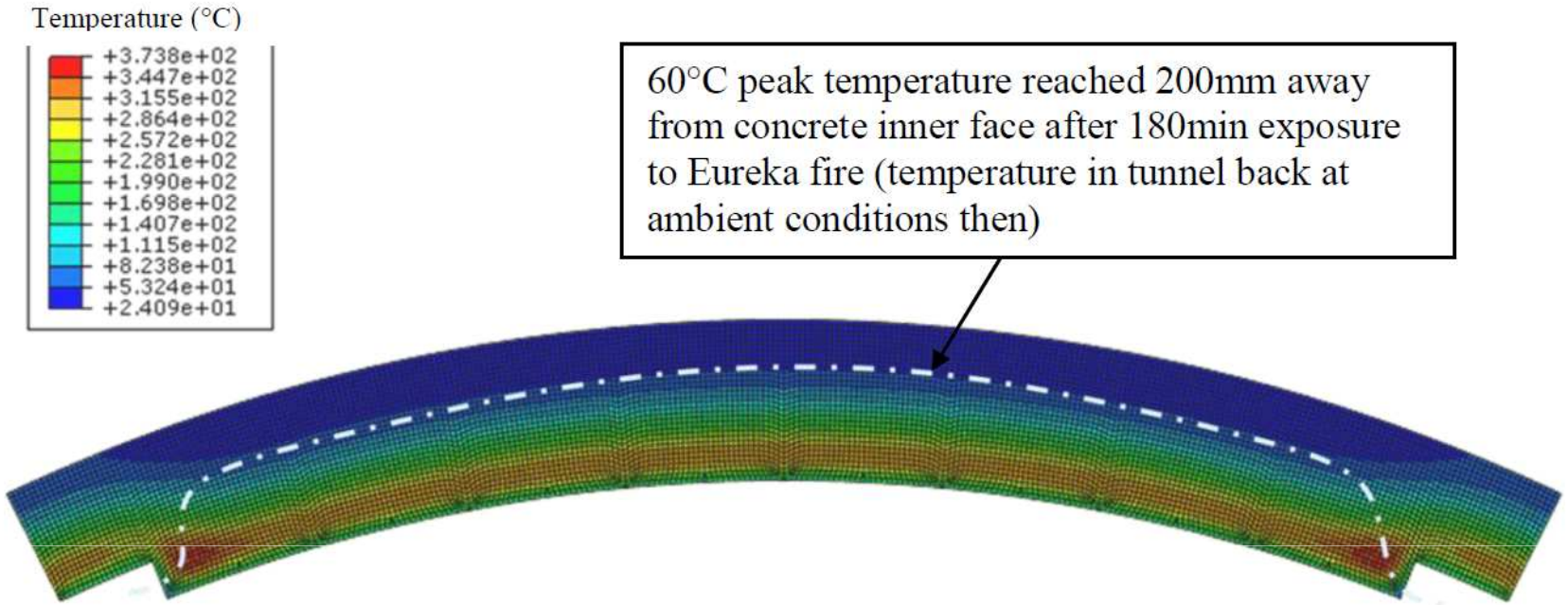

Figure 5 – Temperature pattern in concrete segment after 180min exposure to Eureka fire curve (Approximate pipe location indicated by dashed line)

- **Pipes melt at header pipes and box outs**
- **Gas given off – low load for segment pipes – Header pile in concrete?**
- **After fire - Repair header and omit damaged rings**

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Market for Tunnel Geothermal

- **Low grade energy source – use locally**

- **Residential buildings – heating demand +Hot water**
- **Office blocks – cooling and heating demands**

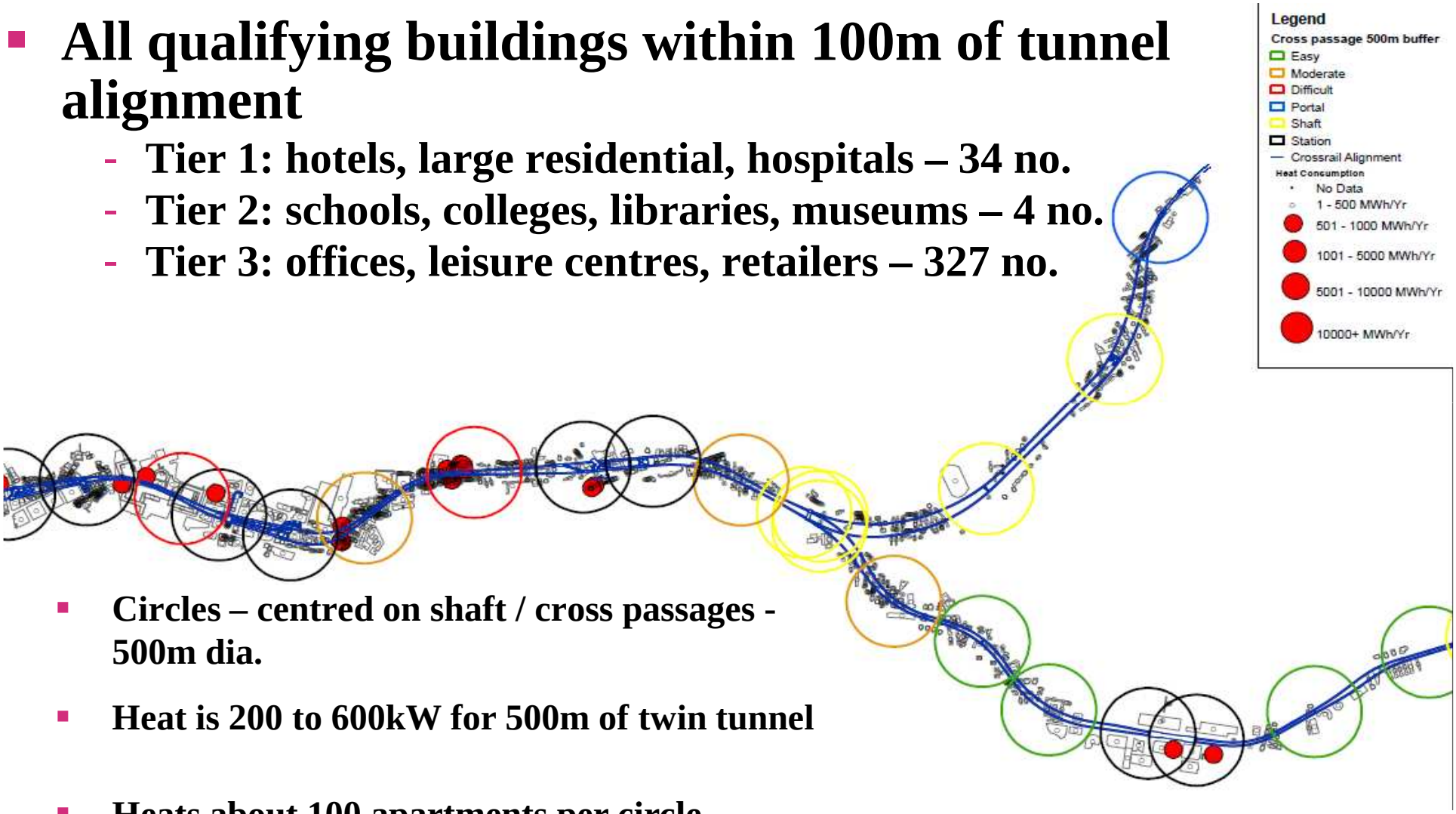
- **Old buildings - refurbishment – heat + Hot water**
- **New buildings - renewable source requirement**
  - Helps at Planning Stage with Part L
- **Cools tubes / ground – reduces ventilation costs**

Typical London Residential Building

- **Typical 5 Storey – refurbished buildings**
  - heating needs – 40-50W/m2 of floor.
- **Say 16 flats /building unit**
  - Space heating – 40kW. – seasonal
  - Hot water – 25kW. – continuous
- **Similar to 50 to 100m long tunnel section.**

Tunnel Heat Market and Assess Points

- **All qualifying buildings within 100m of tunnel alignment**
  - **Tier 1: hotels, large residential, hospitals – 34 no.**
  - **Tier 2: schools, colleges, libraries, museums – 4 no.**
  - **Tier 3: offices, leisure centres, retailers – 327 no.**



- **Circles – centred on shaft / cross passages - 500m dia.**
- **Heat is 200 to 600kW for 500m of twin tunnel**
- **Heats about 100 apartments per circle. – Link with ESCOS**

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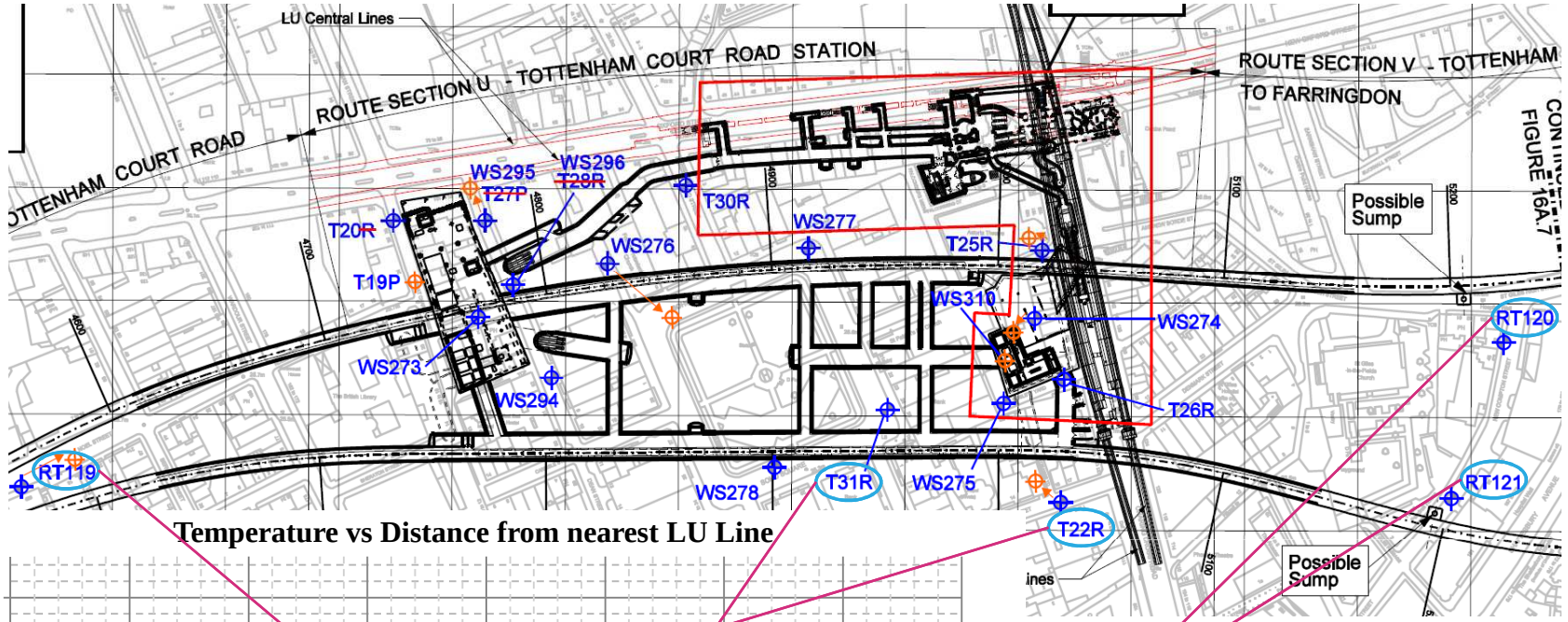
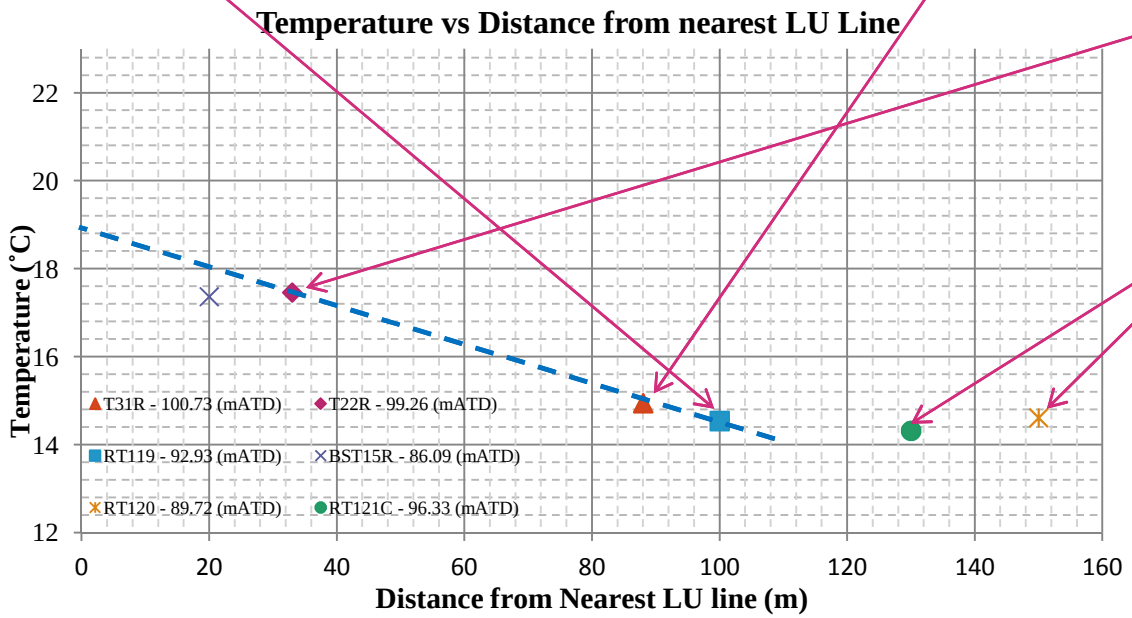
Market for Tunnel Geothermal

- **Building options:**
  - **Existing buildings**: residential housing dominated by space heating over the cold season, with DHW through out year
  - **Existing building**: office/retail complex, heating and cooling
  - **New buildings -** heating and cooling
- **Base Load and Peak Load**
  - Combined heat pump and gas boiler
- **GIS mapping of potential users along tunnel alignment**
- **Cheaper the GSHP borehole loops and higher COP**
- **Link with ESCO – District heating – sell heat**

Crossrail increase ground temp at Oxford Street





- Ground temperature at tunnel level
- Next to tunnel temperature 19ºC
- Temperature drops to ~15ºC at about 90m from tunnel

ARUP

Conclusions

1. **Thermal tunnels – similar to GSHP systems**
2. **Concept - Well developed - Janbech tunnel**
3. **Hot tunnels – Greater heat outputs - cools tube.**
4. **Shaft access preferred – Boreholes provide flexibility.**
5. **Detailed design issues:-**
   - **Thermal and ventilation models**
   - **Concrete stresses**
   - **Joint rotation**
   - **Fire impacts**
6. **Buildings assessment process – GIS**
7. **Commercial case:-**
   - **Cheaper than GSHP borehole loops to install**
   - **Save tunnel / station cooling costs**
   - **High COP when used at low flow rates – carbon efficient**
   - **Work with ESCO district heating provider**

Thank you for your attention

Any Questions?