Ascertaining thermal and energy benefits of intensive tropical green roof

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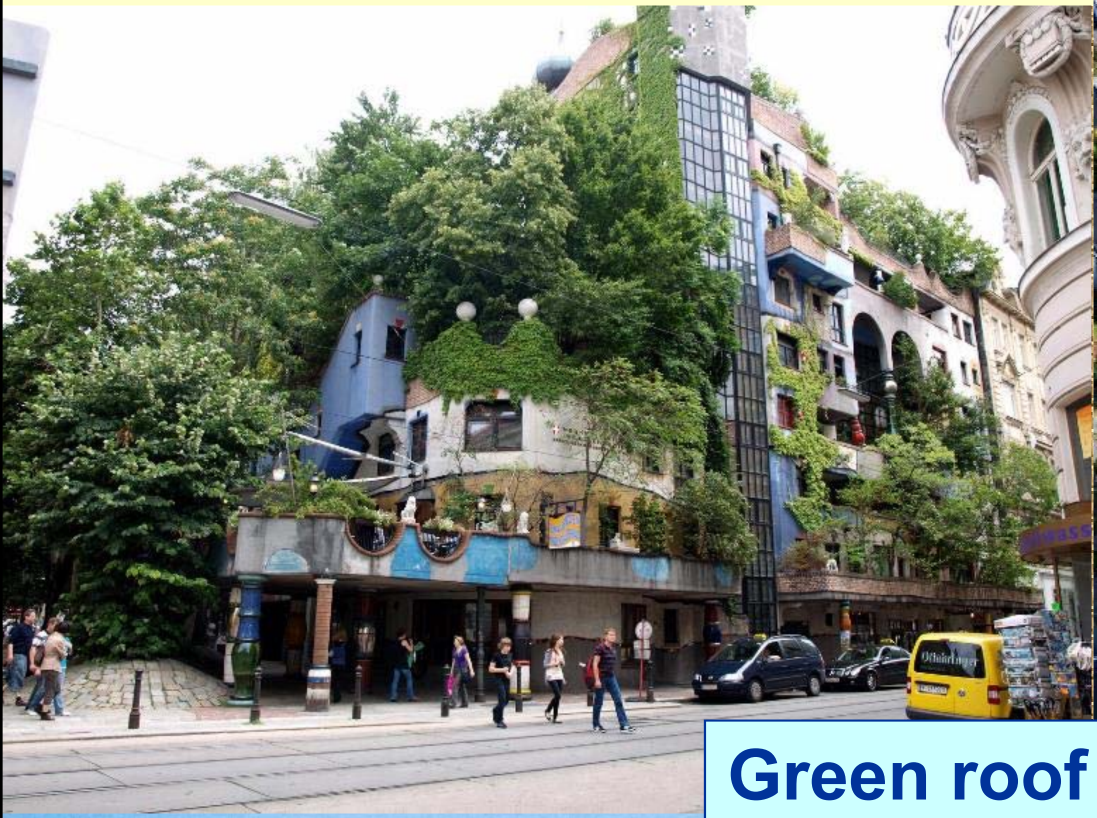
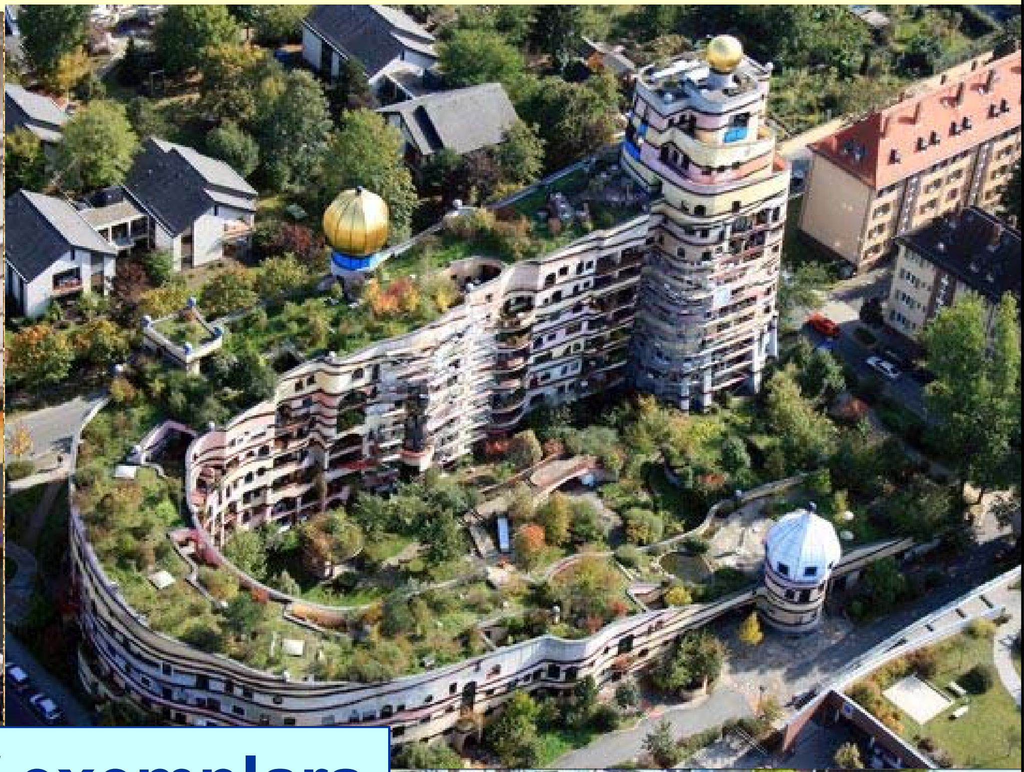
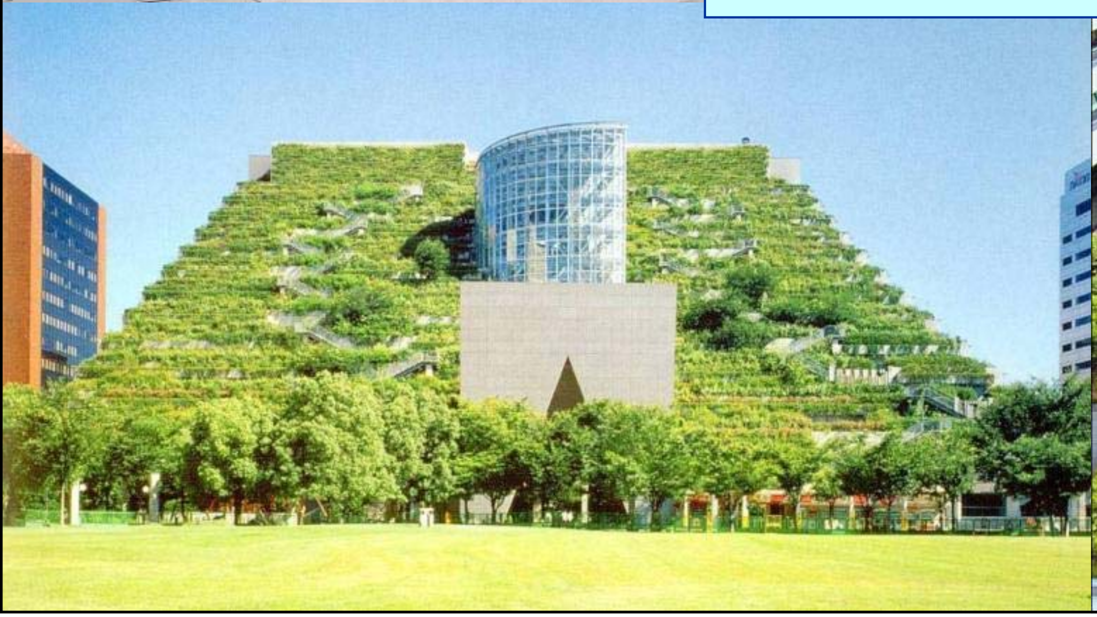
Sky woodland: Worldwide exemplars





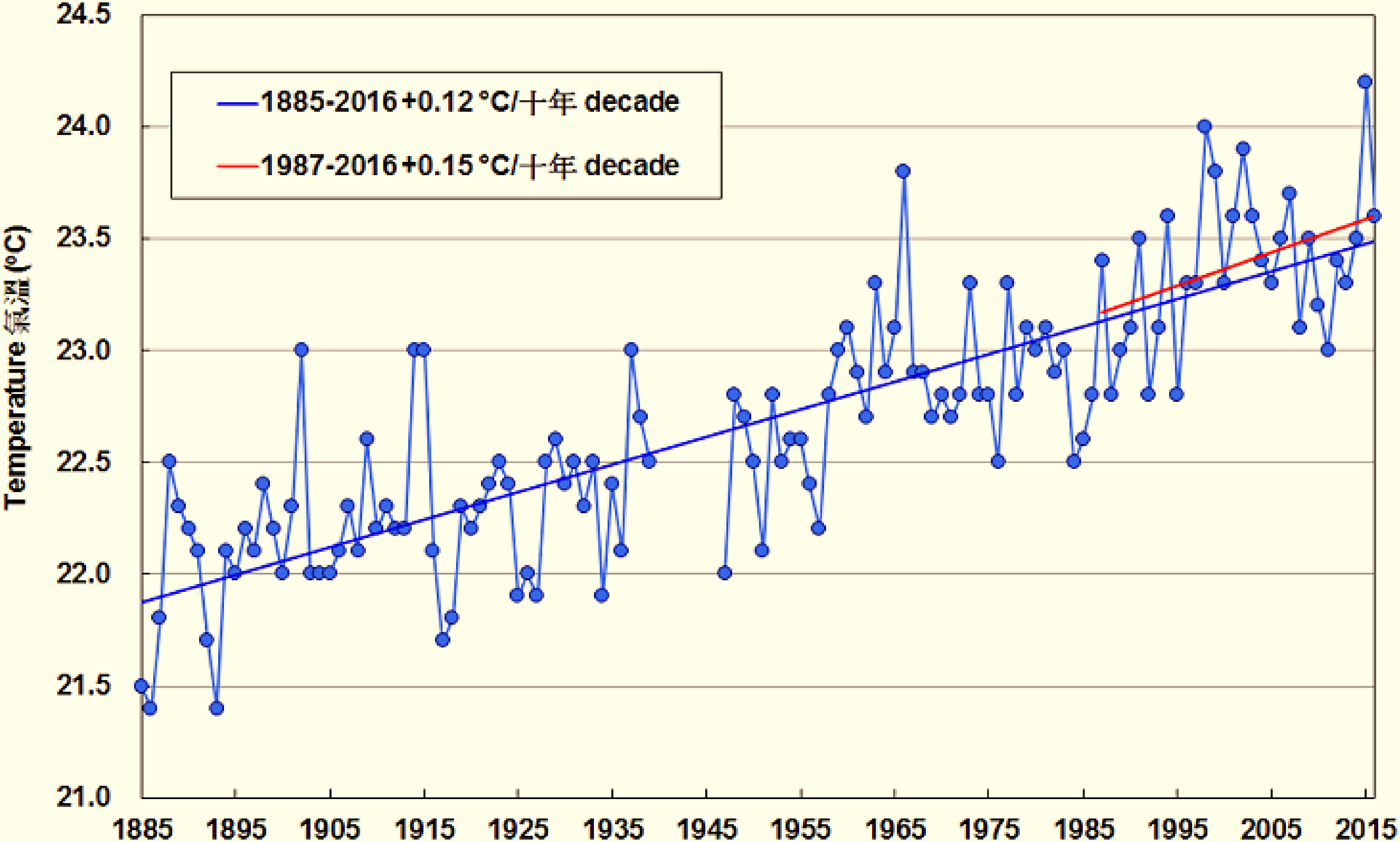
Green roof exemplars



Hong Kong: Compact city

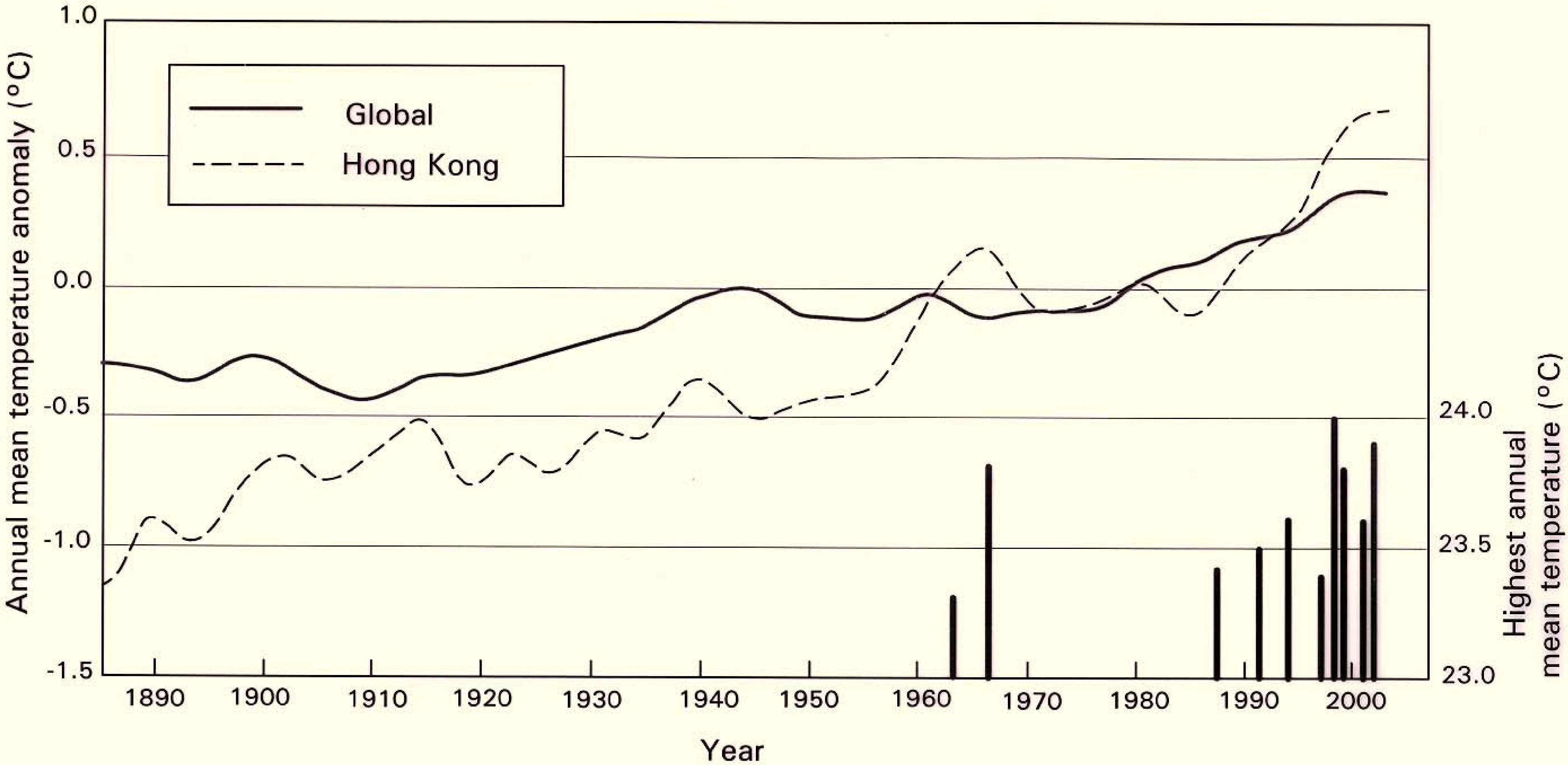
Hong Kong: Barren roofs

Hong Kong: Warming trend



Data source: Hong Kong Observatory

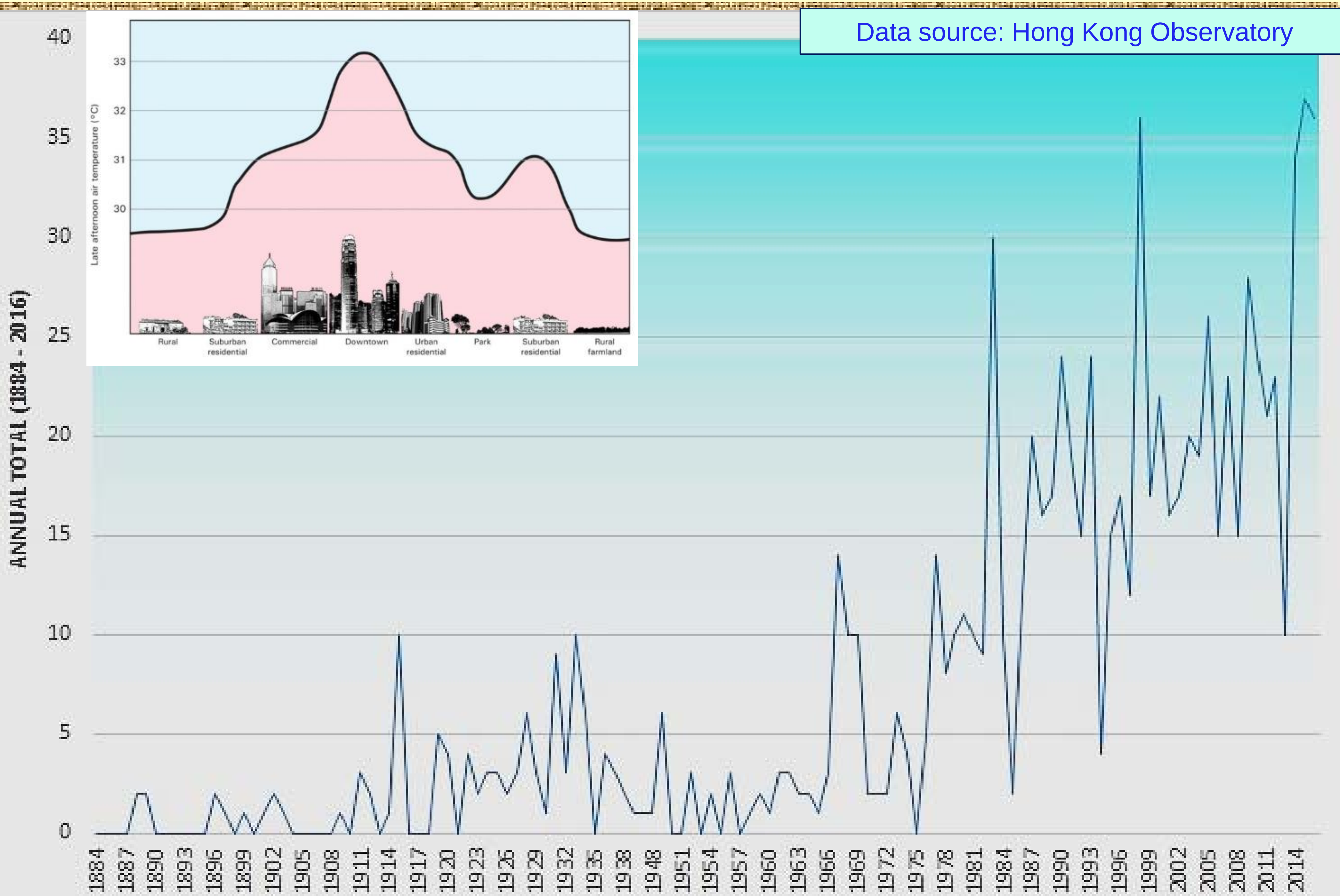
Hong Kong versus global warming



Data source: Hong Kong Observatory

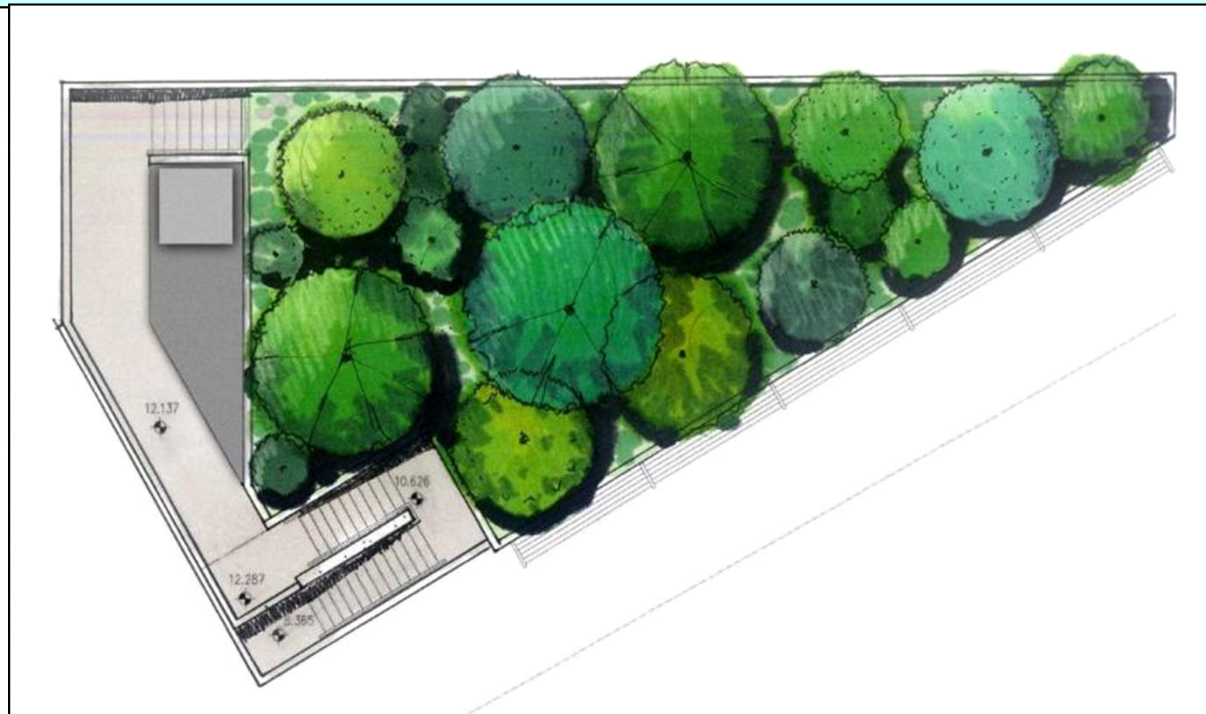
Hot nights (≥28˚C) and heat island effect in HK

Data source: Hong Kong Observatory



Sky woodland design principles

- New building designed for the **rooftop woodland**
  - Green roof design before building construction
  - Roof slab loading to support 1 m thick soil layer
  - Multiple layer green roof design
  - Modern proprietary manufactured materials
  - Local plant and soil materials
  - Low-input maintenance



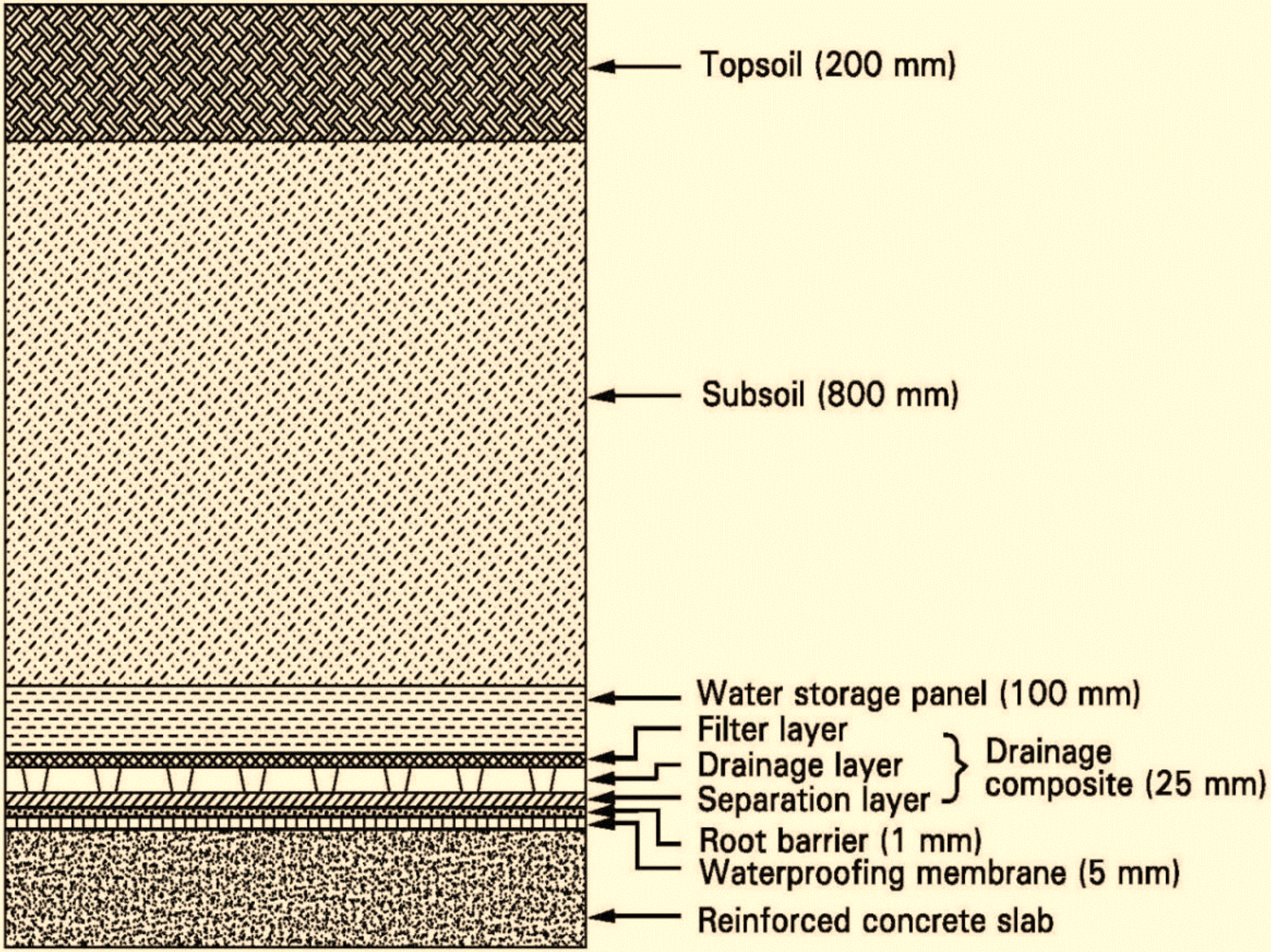
Local woodland with high biodiversity

Sky woodland design principles

- Emulate pertinent ecological traits of **humid-subtropical native woodland** in south China
- Diverse assemblage of indigenous tree species
- Ecological functions with ornamental bonus
- High ecological diversities
- Mixture of large, medium and small final tree dimensions
- Small trees mixed with medium and large trees
- Random planting pattern
- High tree density and vegetation coverage
- Complex biomass structure with vertical stratification
- Interlocking tree crowns, wind resistance
- High leaf area index (LAI)
- Local woodland soil composition and profile
- Self-sustaining woodland ecosystem

Modern multiple layer design

Saturated weight 2158 kg/m²



Multiple ecosystem services

- Habitat island and stepping stone for wildlife
- Emulation of habitat corridor or greenway
- Significant environmental benefits
- Passive recreational use
- Educational use
- Scientific experiment
- Visual delight for the site and the neighbourhood
- Exemplary green roof design for compact city environment of Hong Kong

Multiple criteria for species selection

Natural woodland ecosystem

Diversity in species

Native species

Diversity in seasonality

Diversity in tree height

Multiple tree strata

Diversity in tree form

Random tree pattern

Crown interlocking

Closed canopy

Attractive flowers

Attractive fruits

Food for wildlife

Food chains

Shelter for wildlife

Nutrient cycling

Nutrient accumulation

Diverse native tree species palette

Tabe 3. The three tree species selection lists for the sky woodland.

Higher priority	Lower proirity
List A: very small trees <5 m final height	
Camellia granthamiana (Grantham's Camellia)	*Aporusa dioica* (Aporusa)
Litsea cubeba (Fragrant Litsea)	*Itea chinensis* (Itea)
Magnolia championii (Hong Kong Magnolia),	*Mallotus paniculatus* (Turn-in-the-wind)
Myrica rubra (Strawberry Tree)	*Elaeocarpus chinensis* (Chinese Elaeocarpus)
List B: small trees 5-7.5 m final height	
Garcinia oblongifolia (Lingnan Garcinia)	*Aquilaria sinensis* (Incense Tree)
Ilex rotunda var. *microcarpa* (Small-Fruited Holly)	*Castanopsis fissa* (Castanopsis)
Pyrus calleryana (Callery Pear)	*Cinnamomum burmanii* (Cinnamom Tree)
Reevesia thrysoidea (Reevesia)	*Cratoxylum cochinchinense* (Yellow Cow Wood)
Sapium sebiferum (Chinese Tallow Tree)	*Ficus variolosa* (Varied-leaf Fig)
List C: medium trees 7.5-10 m final height	
Bauhinia 'Blakeana' (Hong Kong Orchid Tree)	*Artocarpus hypargyrea* (Silverback Artocarpus)
Camellia hongkongensis (Hong Kong Camellia)	*Cyclobalanopsis glauca* (Blue Japanese Oak)
Cleistocalyx operculatus (Water Banyan),	*Ligustrum lucidum* (Glossy Privet)
Rhodoleia championii (Rhodoleia)	*Machilus velutina* (Wooly Machilus)
Sterculia lanceolata (Scarlet Sterculia)	
Tutcheria spectabilis (Common Tutcheria)	

Native tree species examples

Rhodoleia championii Rhodoleia

Sterculia lanceolata Scarlet Sterculia

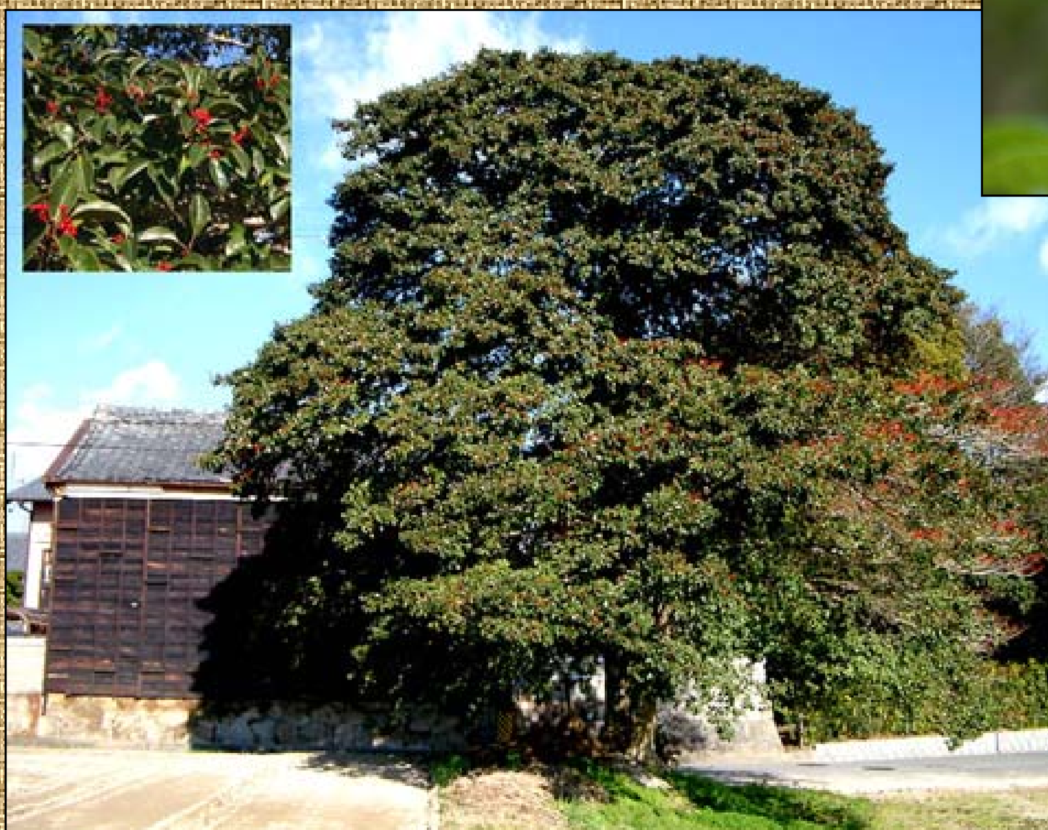
Native tree species examples

Pyrus calleryana Callery Pear

Native tree species examples

Pyrenaria spectabilis Tutcheria

Native tree species examples



Ilex rotunda var. *microcarpa* Small Fruited Holly

Native tree species examples

Sapium sebiferum Chinese Tallow Tree

Native tree species examples

Aquilaria sinensis Incense Tree

Root barrier and drainage layer

Water storage and soil layers

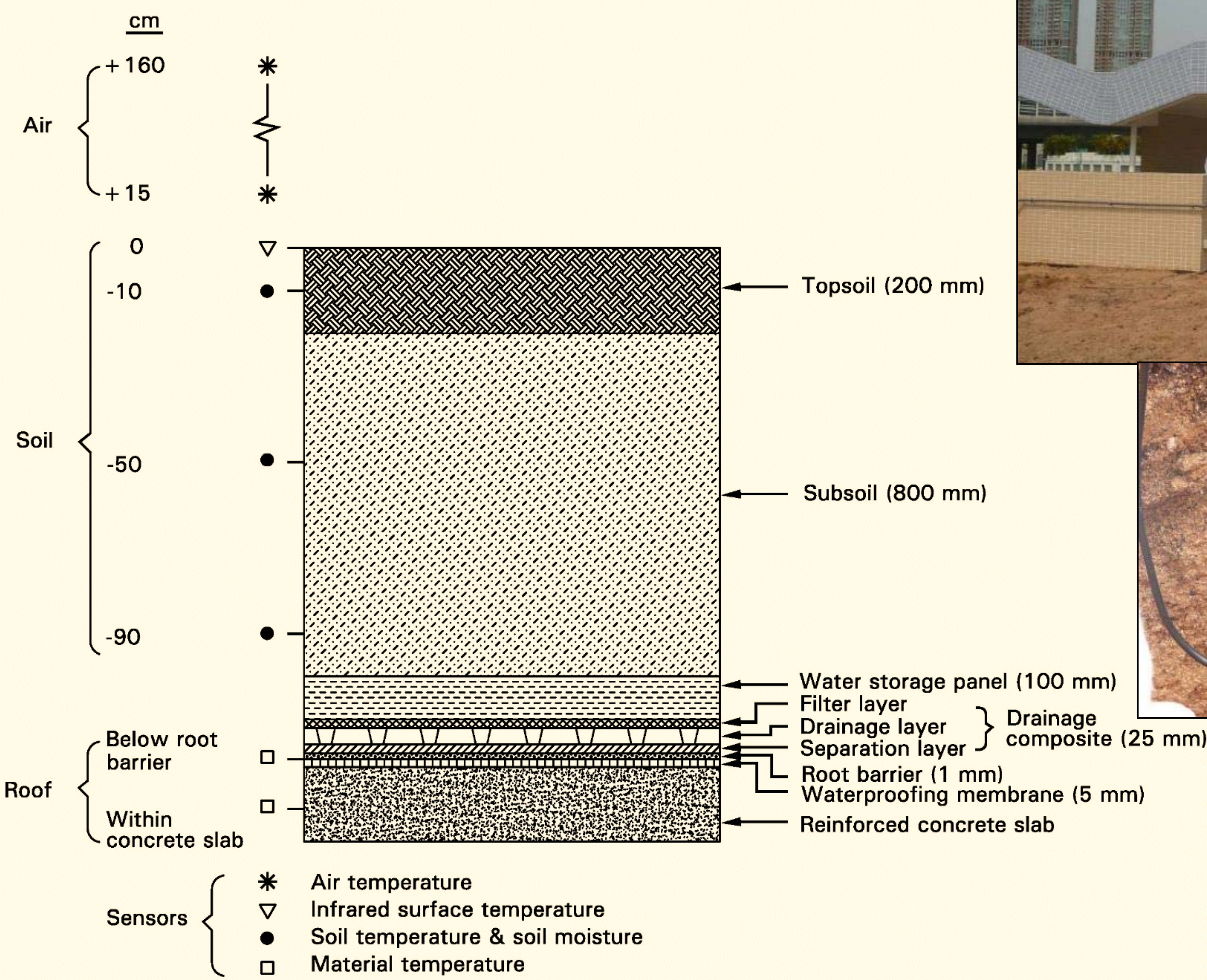
Quality of planting materials

Lifting tree saplings to the rooftop

Tree planting

Maturing sky woodland

Environmental monitoring sensors



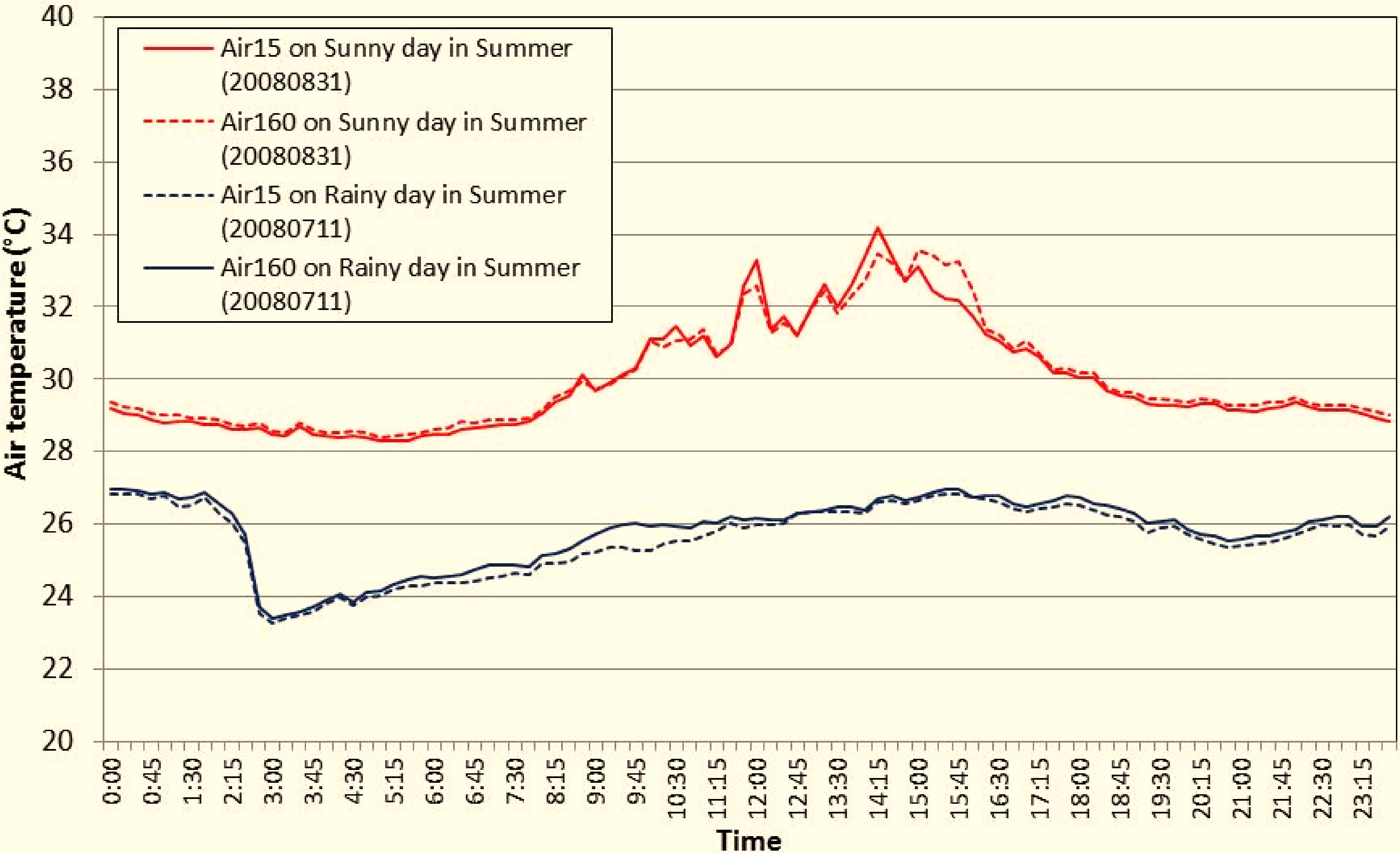
Sensors for the experiments

Table 1

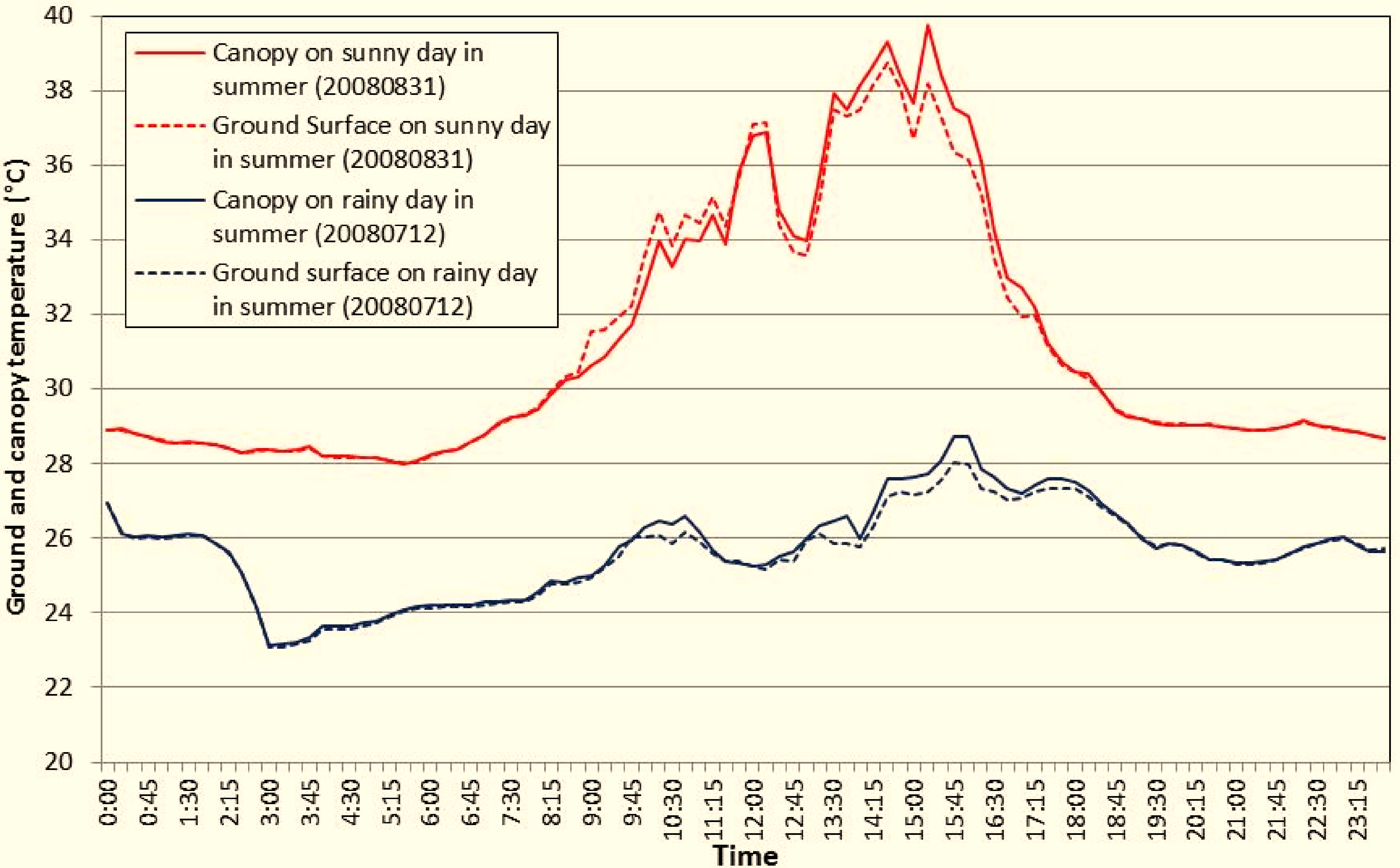
The environmental sensors and installation positions in the green roof monitoring experiment.

Site	Sensor	Measured enrvironmental parameter
A:	Soil moisture sensor	Rockwool moisture, soil moisture at 10 cm, 50 cm and 90 cm depth
Core	Air temperature sensor	Air temperature at 15 cm and 160 cm above the ground
	Soil temperature sensor	Soil temperature at 10 cm, 50 cm and 90 cm depth; tile temperature and concrete slab temperature
	Infrared temperature sensor	Surface temperature of soil with ground cover vegetation; surface temperature of tree canopy
	Relative humidity sensor	Relative humidity at 15 cm and 160 cm above the ground
	Dew point sensor	Dew point temperature at 15 cm and 160 cm above the ground
B:	Air temperature sensor	Air temperature at 15 cm and 160 cm above the ground; concrete slab temperature
Periphery	Infrared temperature sensor	Surface temperature of soil with ground cover vegetation; surface temperature of tree canopy
	Relative humidity sensor	Relative humidity at 15 cm and 160 cm above the ground
	Dew point sensor	Dew point temperature at 15 cm and 160 cm above the ground
C:	Temperature sensor	Air temperature above bare concrete roof
Control	Infrared temperature sensor	Surface temperature of bare concrete roof
	Relative humidity sensor	Relative humidity above bare concrete roof
	Dew point sensor	Dew point temperature above bare concrete roof
	Infrared temperature sensor	Surface temperature of bare concrete roof
	Pyranometer	Intensity and duration of solar radiation
	Anemometer	Wind speed and wind direction

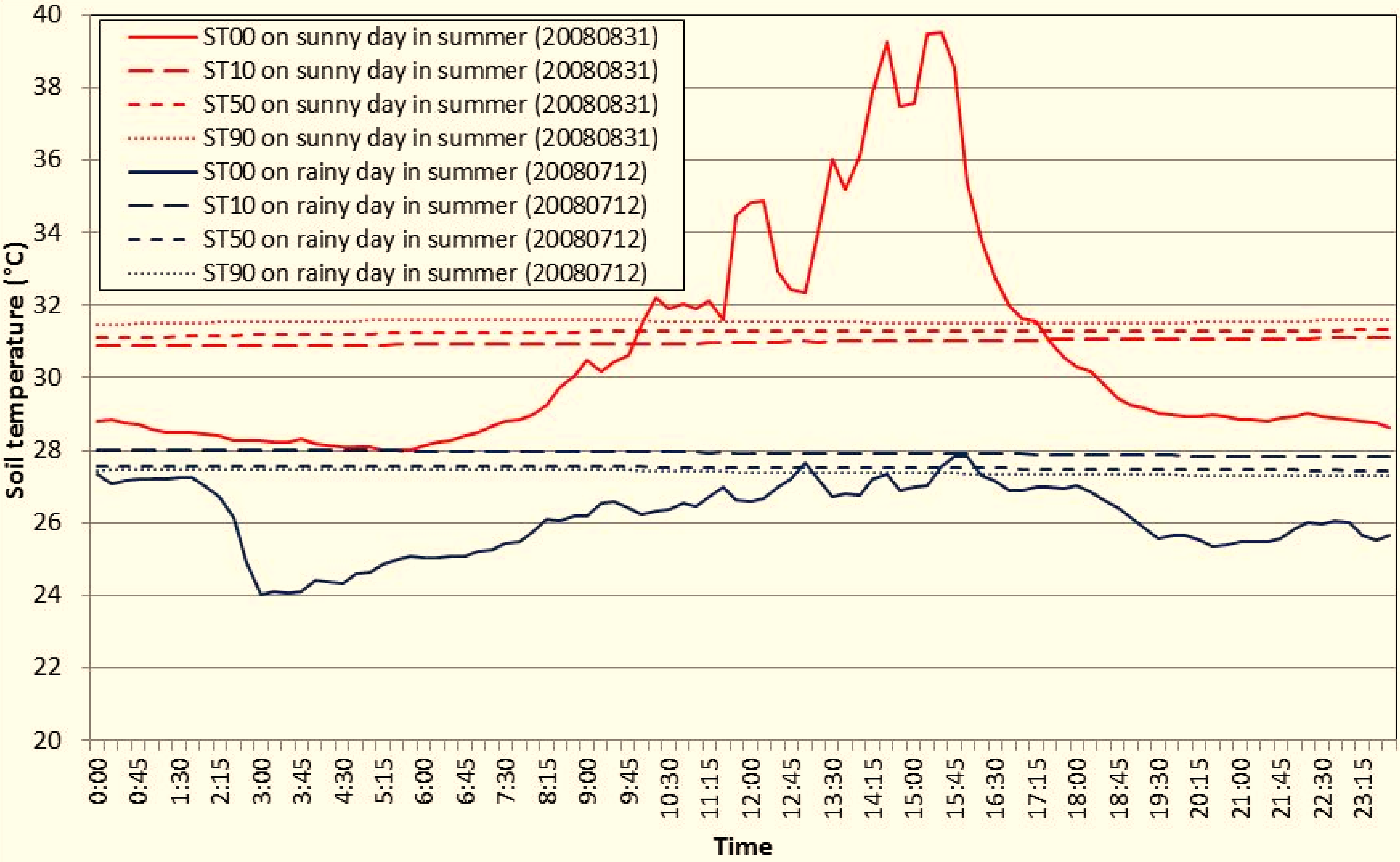
Diurnal air temperature in woodland in summer



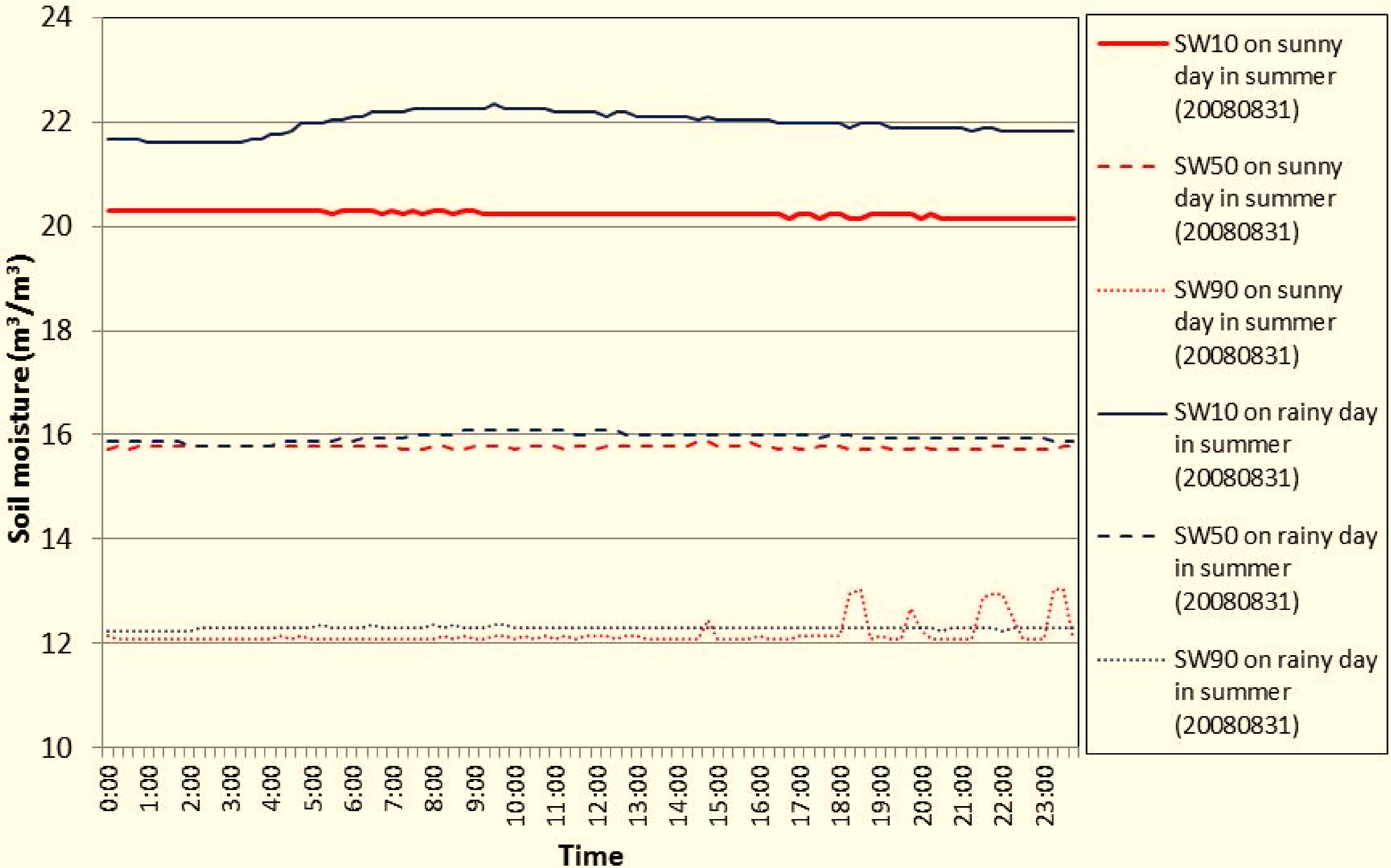
Diurnal woodland canopy and ground temperature in summer



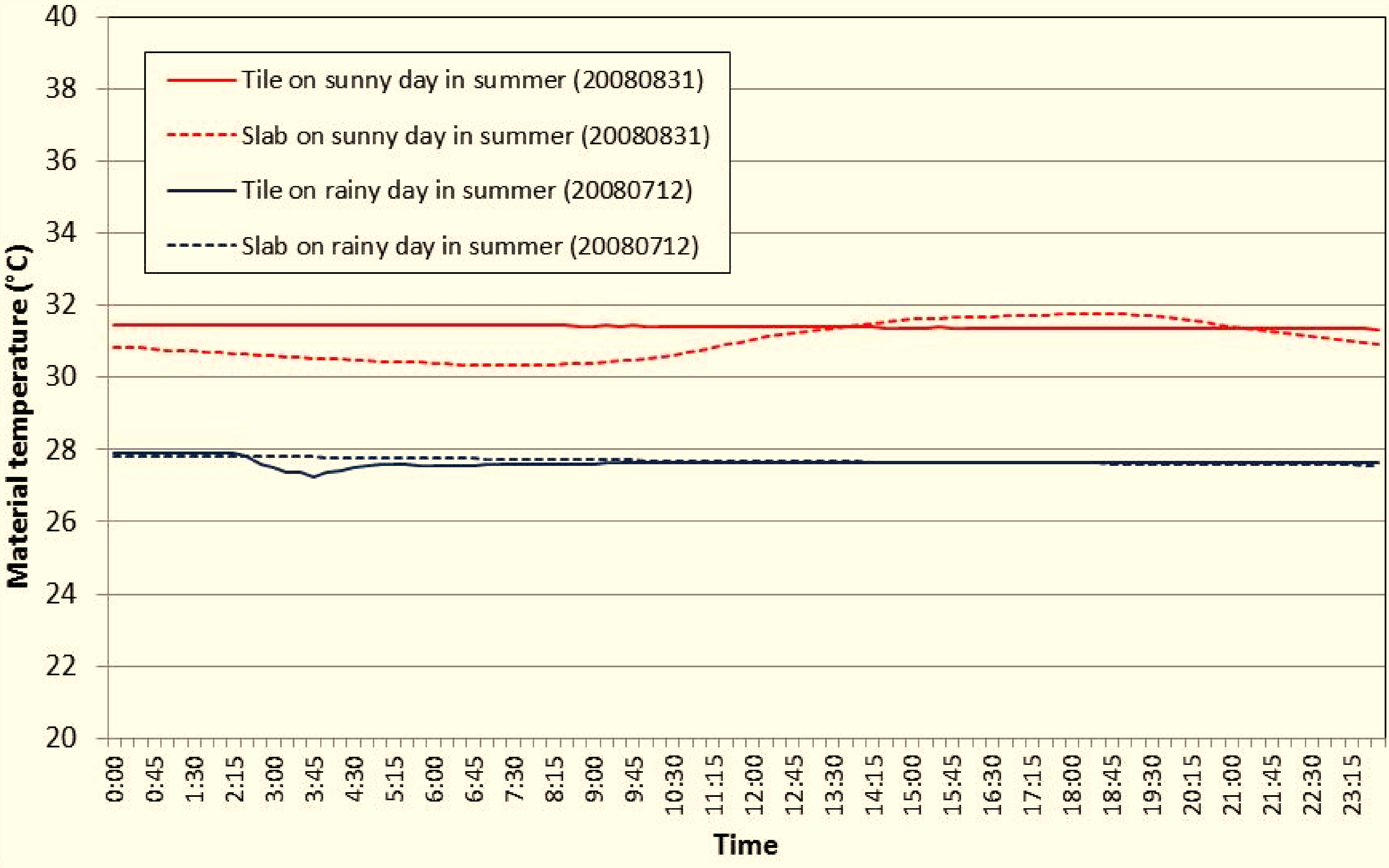
Diurnal soil temperature in summer



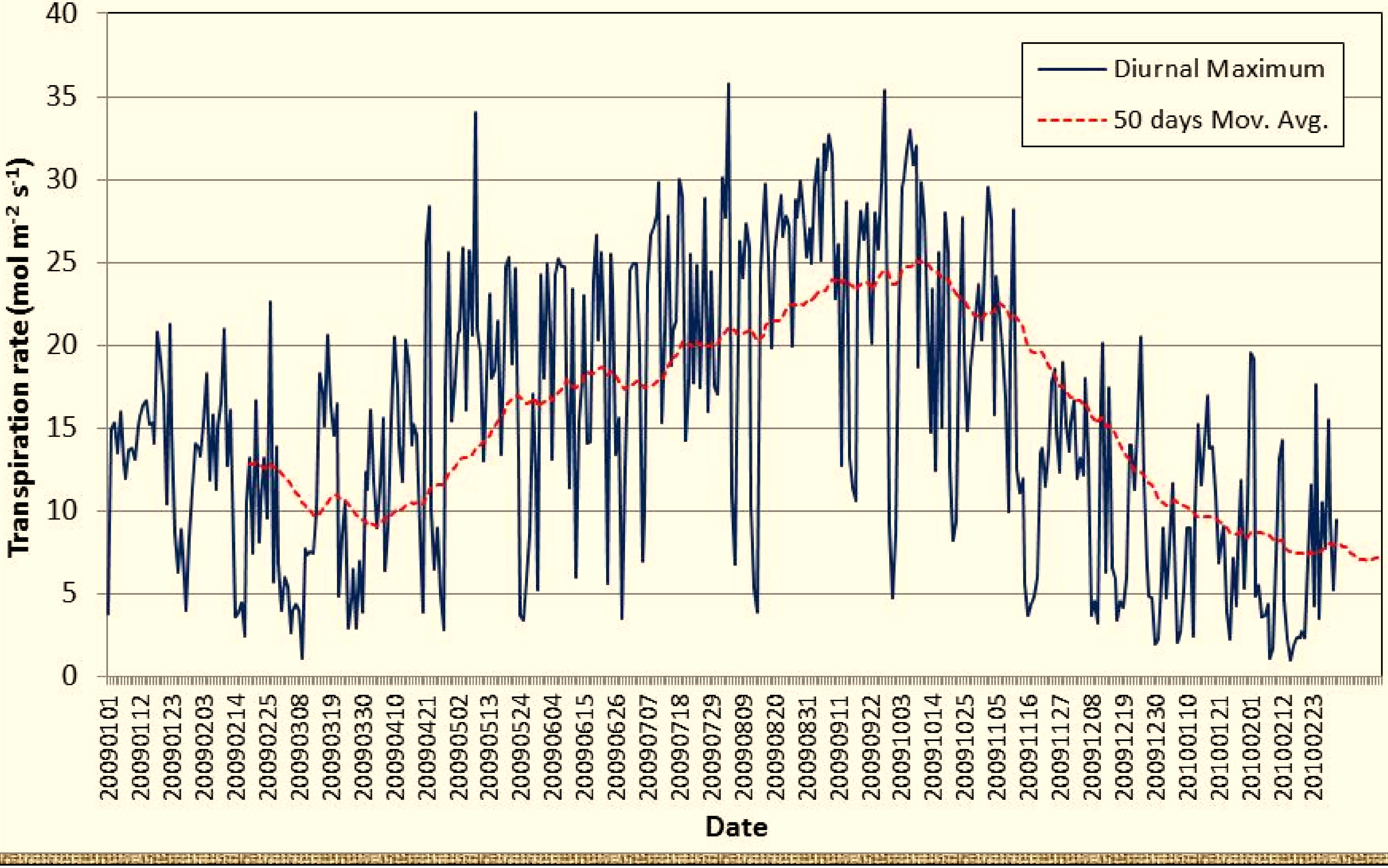
Diurnal soil moisture in summer



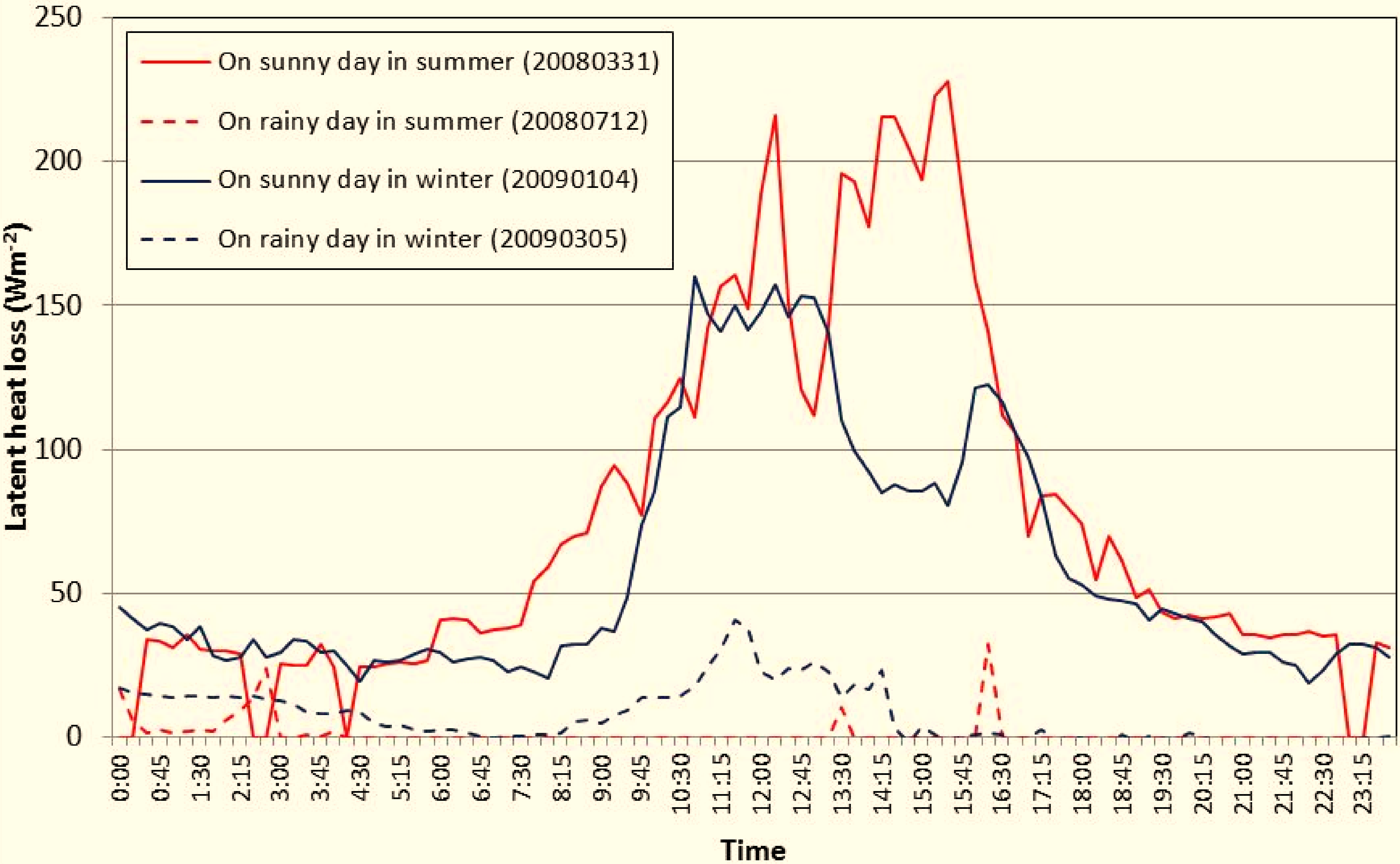
Diurnal tile and concrete slab temperature in summer



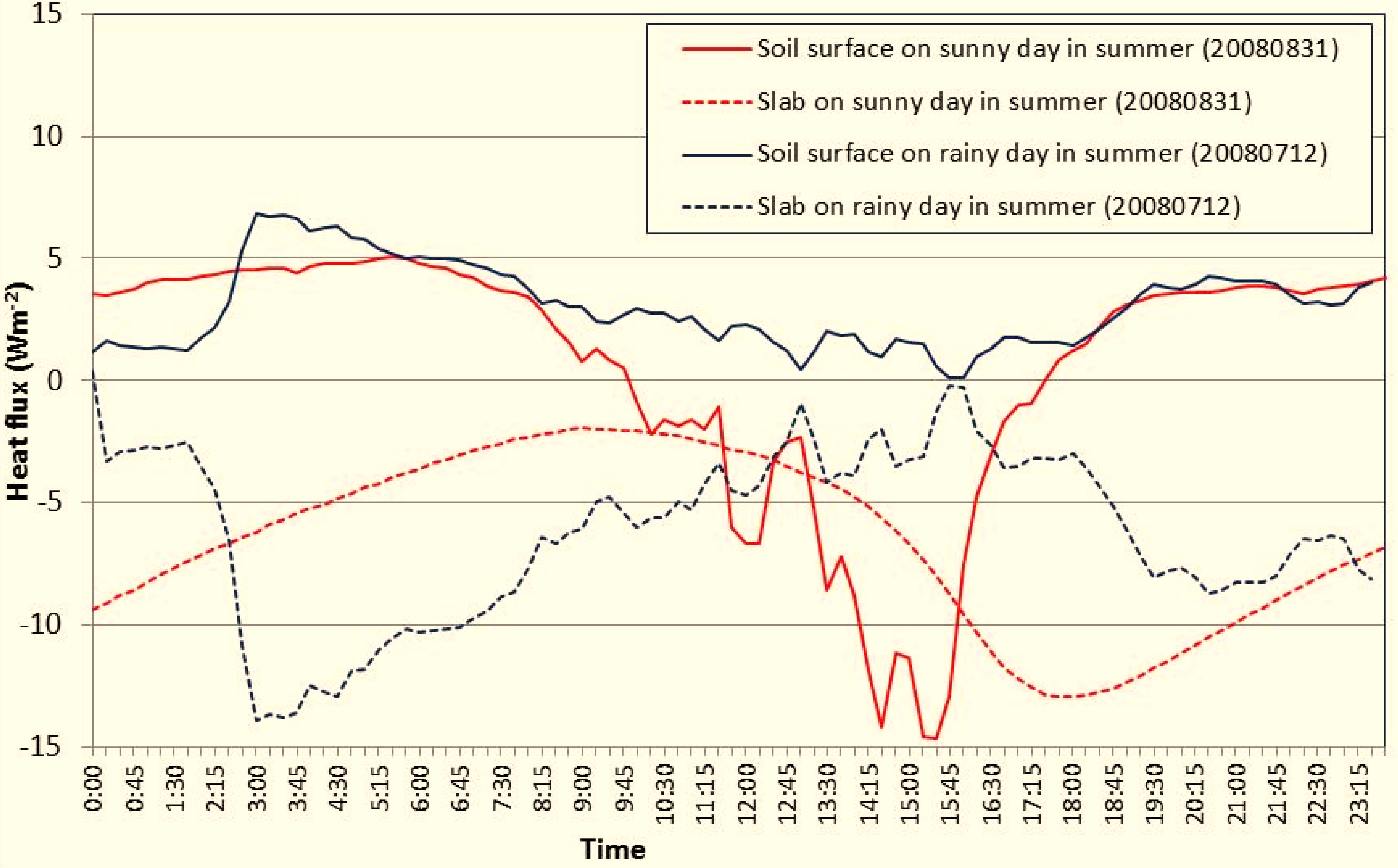
Annual maximum diurnal latent heat loss by transpiration



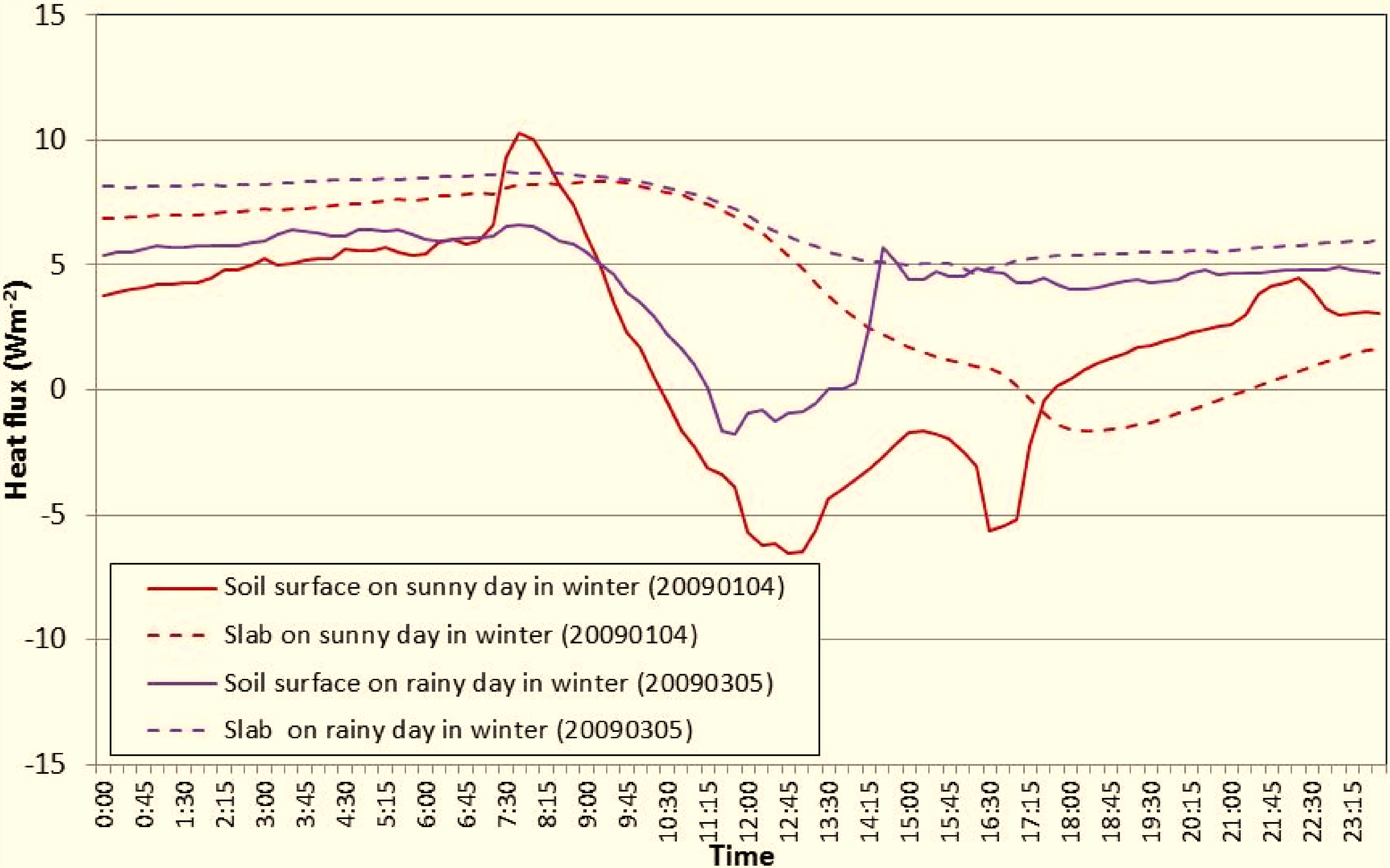
Diurnal latent heat loss in summer



Diurnal heat flux on soil surface and concrete slab in summer



Diurnal heat flux on soil surface and concrete slab in winter



Nature education in accessible and safe site

Major research findings 1/4

1. The seasonal effect is significant for air temperature at different heights, soil surface temperature, soil moisture, tree canopy and ground surface temperature; it is not significant for soil temperature at different depths, tile and concrete slab temperature.

2. The diurnal weather effect is significant for air temperature at different heights, canopy, ground surface, and soil surface temperature; it is not significant for diurnal soil temperature and moisture at different depths (except on the soil surface), tile and concrete slab temperature.

Major research findings 2/4

3. The cooling effect due to transpiration rate (latent heat absorption) varies widely depending on seasonal and weather conditions, and it peaks in early autumn due to rather warm but dry weather condition.

4. The tree canopy layer could reduce solar radiation reaching the soil surface by reflecting some incident solar radiation back to the atmosphere; the air trapped in the canopy could reduce the convective heat loss and increase the air temperature near the soil surface.

Major research findings 3/4

5. The soil substrate layer operates as a large heat sink to reduce temperature fluctuation. The soil absorbs solar radiation on sunny daytime and retains it as storage heat. In nighttime, the storage heat is dissipated as sensible and convective heat.
6. On rainy days, soil absorbs rain water to increase the soil heat capacity to store a considerable amount of energy without increasing the soil temperature to achieve good thermal insulation performance.

Major research findings 4/4

7. The experiment demonstrates that soil thermal insulation performance does not require a thick soil. A thin soil layer of about 10 cm is sufficient to reduce substantially heat penetration into the building.

8. In winter, heat flows notably upwards from the substrate to the ambient air. The warmer indoor air below the roof slab creates a temperature gradient to draw heat upwards into the substrate and hence to dissipate in the air as sensible and latent heat. The resulting cooling of the building interior creates demands for more energy consumption to warm the indoor air. This finding contradicts the temperate latitude studies that point to reduction in heat loss through the roof in winter to lower heating energy consumption.

Conclusion 1/2

- Successful application of ecological concepts and ecological engineering to establish the most complex green roof in HK
  - Feasible to use native trees to create a sky woodland on rooftop
  - Diversified species composition and biomass structure
  - Enhance urban wildlife (birds, butterflies, etc.)
  - Cost-effective green roof installation

Conclusion 2/2

- Fulfil multiples functions
  - Significant cooling effect by evaporation and transpiration
  - Significant insulation effect by vegetation and soil layers
  - Lower indoor temperature and reduce electricity consumption
  - Reduce of stormwater drainage
  - Improve quality of stormwater and reduce water pollution
  - Notable landscape and amenity values for neighbourhood
  - Exemplary demonstration project for HK and the region
  - Findings for technology sharing and transfer

The End
Questions and Comments are Welcome