# ENRICHING THE MAPPING PROCESS UTILIZING THERMAL IMAGERY

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# Purpose Of Research

**GOAL : Classify urban landcover types by extracting their typical thermo-spatio-temporal features**

## Motivation

1. Thermal imagery makes remote sensing practical on certain environmental conditions in which VIS does NOT.

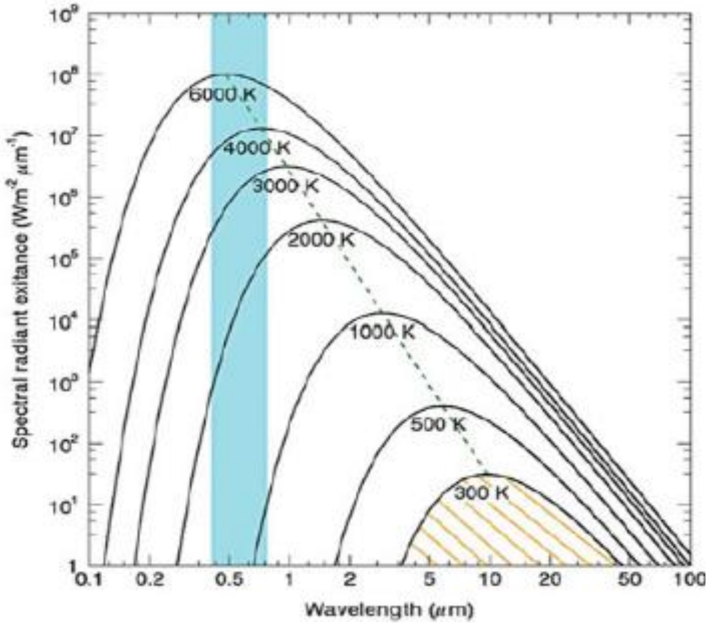
2. When VIS does, two object might share same visual features, but could be distinguished by their radiant temperature values.

3. Real temperature measuring requires material properties.

# Scientific Background – Thermal Radiation

- TIR = Emitted Radiation ; VIS = Reflected Radiation
- Any object above 0 K emits radiant power,

  described by Planck's Law for Blackbody at temp T and wavelength λ :

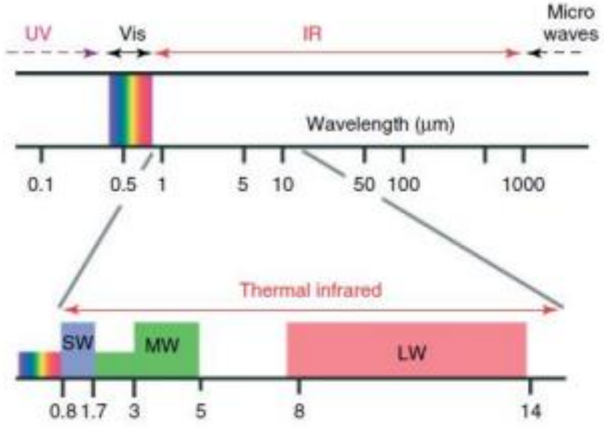


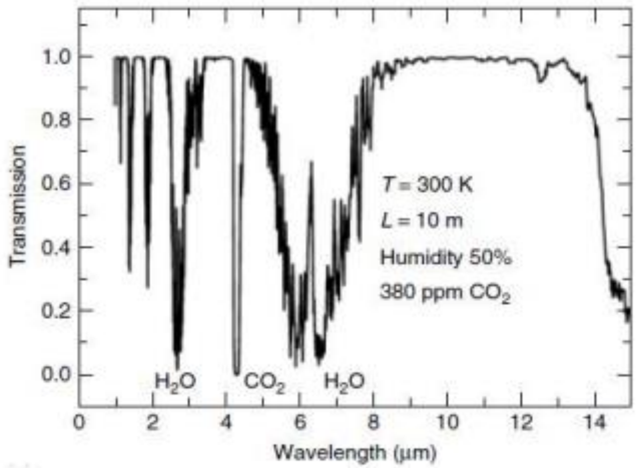

$$M(T,\lambda)_{BB} = \frac{2hC^2}{\lambda^5\left(e^{\frac{hC}{\lambda kT}} - 1\right)}$$

$M_\lambda$ = spectral radiant exitance [W m$^{-2}$ µm$^{-1}$]
h = Planck's constant [6.626 × 10$^{-34}$ J s]
c = speed of light [2.9979246 × 10$^{8}$ m s$^{-1}$]
k = Boltzmann constant [1.3806 × 10$^{-23}$ J K$^{-1}$]
T = absolute temperature [K]
λ = wavelength [µm]

**Wien's Law :**

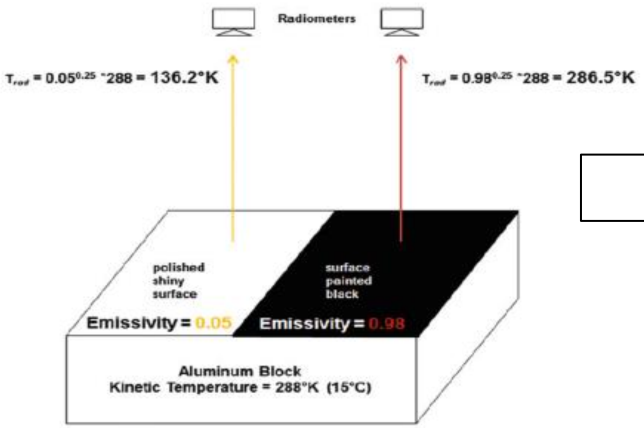
$$\lambda_{max} = \frac{C}{T}$$



# Scientific Background – Radiant Vs. Kinetic Temperature

- TIR Cameras' sensors convert measured radiance into radiant temperature
  - Planck's Law mathematical inverse
- Transition to true (Kinetic) temperature requires Emissivity
  - Emissivity is defined : $\varepsilon_\lambda = \dfrac{R(T,\lambda)}{M(T,\lambda)_{BB}}$
  - Definite value calculation is very complicated (time, environmental variables)




$$\boxed{T_{Kinetic} * \varepsilon^{0.25} = T_{Radiant}}$$

| Surface | Emissivity at 8–14 μm |
|---|---|
| Carbon powder | 0.98–0.99 |
| Water | 0.98 |
| Ice | 0.97–0.98 |
| Plant leaves, healthy | 0.96–0.99 |
| Plant leaves, dry | 0.88–0.94 |
| Asphalt | 0.96 |
| Sand | 0.93 |
| Basalt | 0.92 |
| White paper | 0.90 |
| Wood | 0.87 |
| Granite | 0.83–0.87 |
| Polished metals, averaged | 0.02–0.21 |
| Aluminium foil | 0.036 |

# Literature Review –Radiant Temperature Diurnal Trends

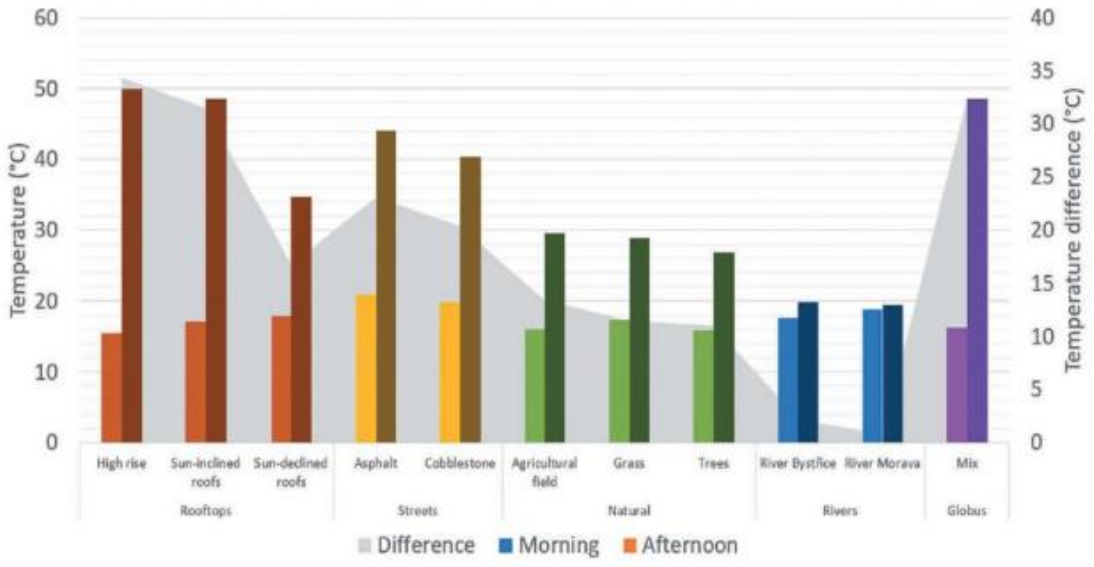



Figure : Thermal regime of urban environment land covers (Pour et al 2019)

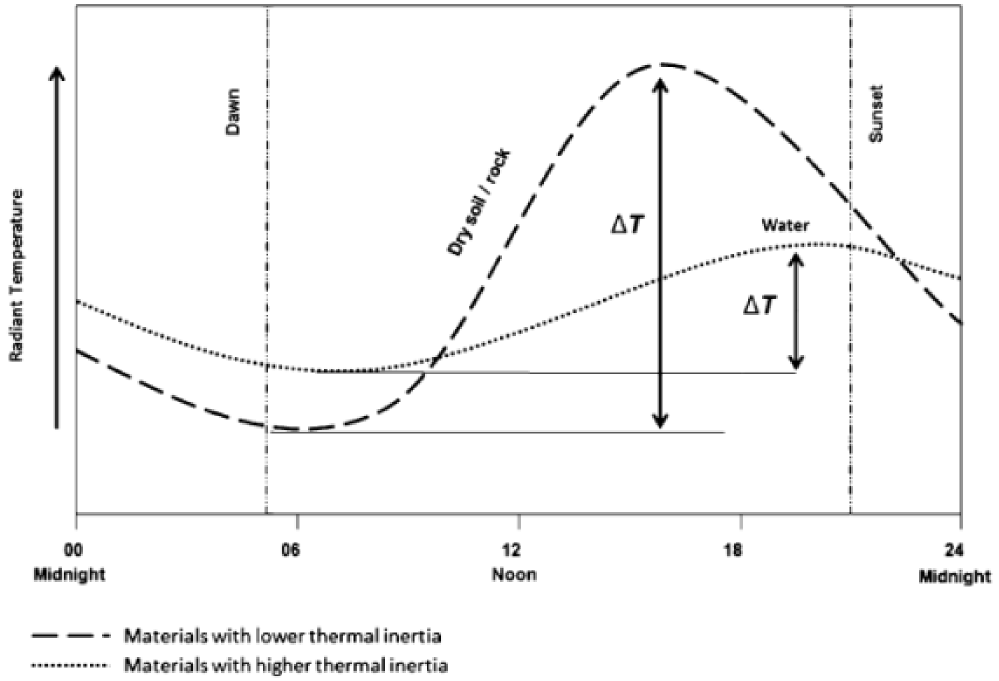



Figure : ΔT values visualization as derived from diurnal curves, for water and dry soil (Lillesand et al 2008)

# Literature Review – The Spatio-Thermal Effect

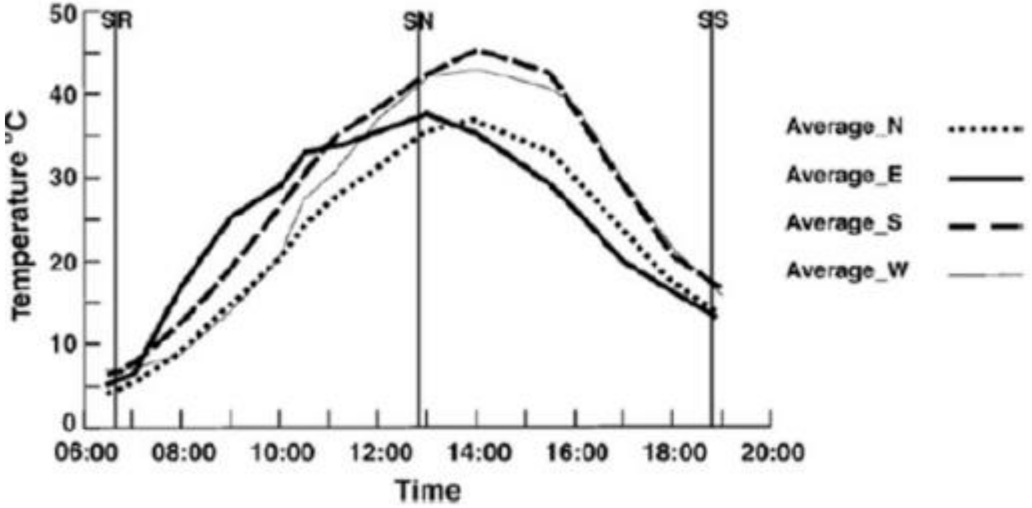
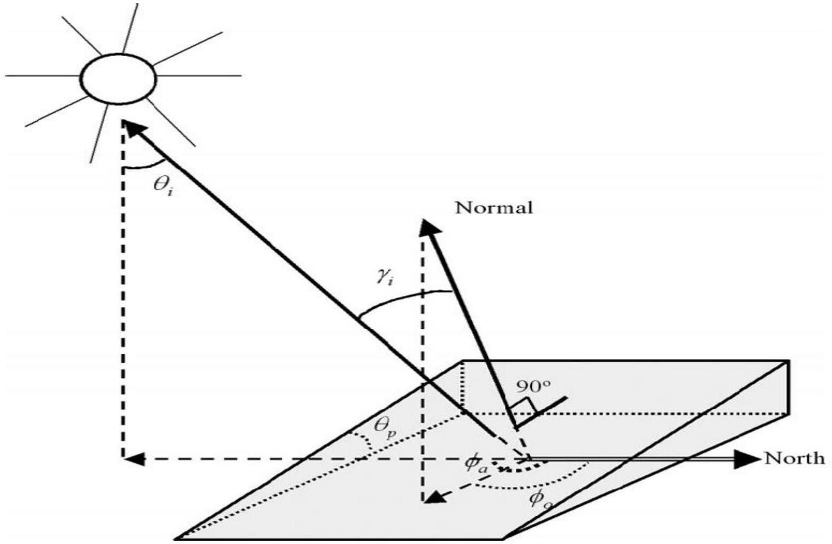



Figure : Diurnal temperature variation of desert sand depending on different aspects – east, south, west and north. (Zhang & Kuenzer 2007)




$$\mathrm{IL} = \cos\gamma_i = \cos\theta_p \cos\theta_z + \sin\theta_p \sin\theta_z \cos(\phi_a - \phi_o)$$

Figure : Spatial solar angles affected by topography (Riano et al 2003)

# Data Collection – Field Experiment Setup

## Area of Interest’s Criteria – Givatayim City, Israel

- An elevated topographic POV allows full 3D scene capturing
- Land cover types variety
- E2W LOS for thermal gradient tracking (summer day)
- Dual TIR+VIS Camera (TIR resolution < 10 cm @100m pixel)



# Data Collection – Image Acquisition

- Dual imagery sets had been acquired from early dawn until late night on 1 hour intervals (A-D VIS;1-4 TIR)
- Example Dual Sets from 21:00 ,15:00 ,11:00 ,05:00 are shown :

(A)

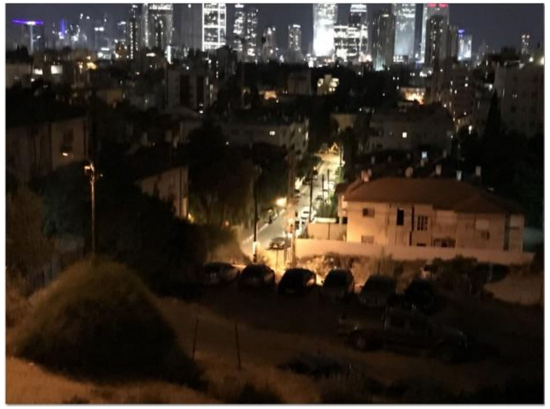

**05:00 AM**

(B)


**11:00 AM**

(C)


**15:00 PM**

(D)


**21:00 PM**

(1)


(2)


(3)


(4)


# Data Validation – Radiant Temperature Consistency

Methodology - Correspondence analysis between:

a) Measured daily radiant temperature pattern of shaded vegetation (ambient temperature representation)

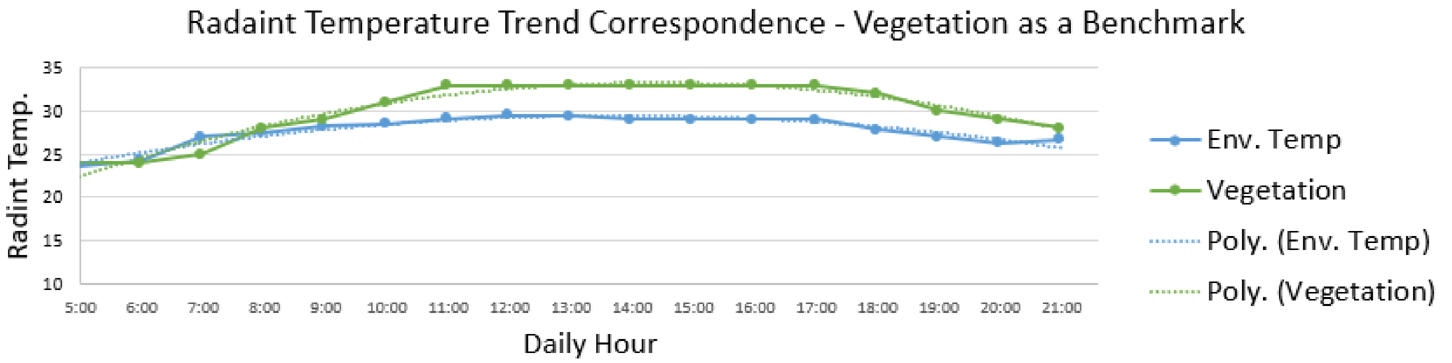
b) Daily temperature reported for the experiment region, on the same day (by the Meteorological Service of Israel)

- Pearson's correlation test :

$$R = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}}$$

- R=0.95 ; p-value≈0

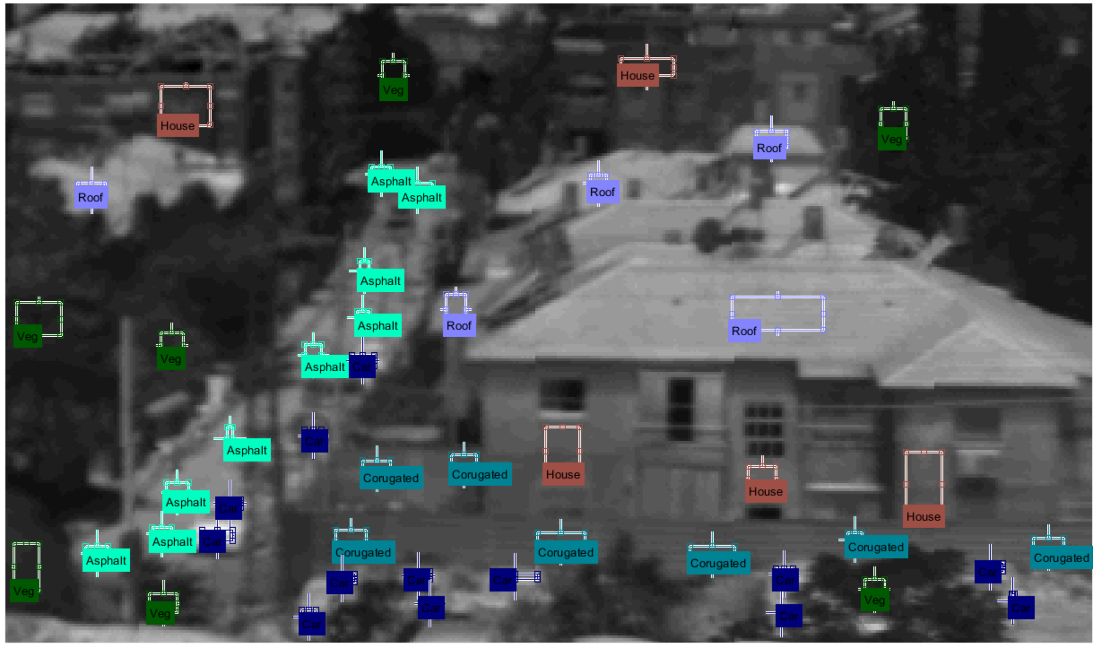
**Radiometry is consistent and reliable**



# Classification Model – Data Labeling

- The Train-Test Dataset was assessed based on manual RGB image interpretation
- Typical urban land cover types includes:
  1. Buildings
  2. Roads
  3. Vegetation
  4. Cars
  5. Roof Tiles
  6. Tin Fence

Pixel Labeling – 5% from image total

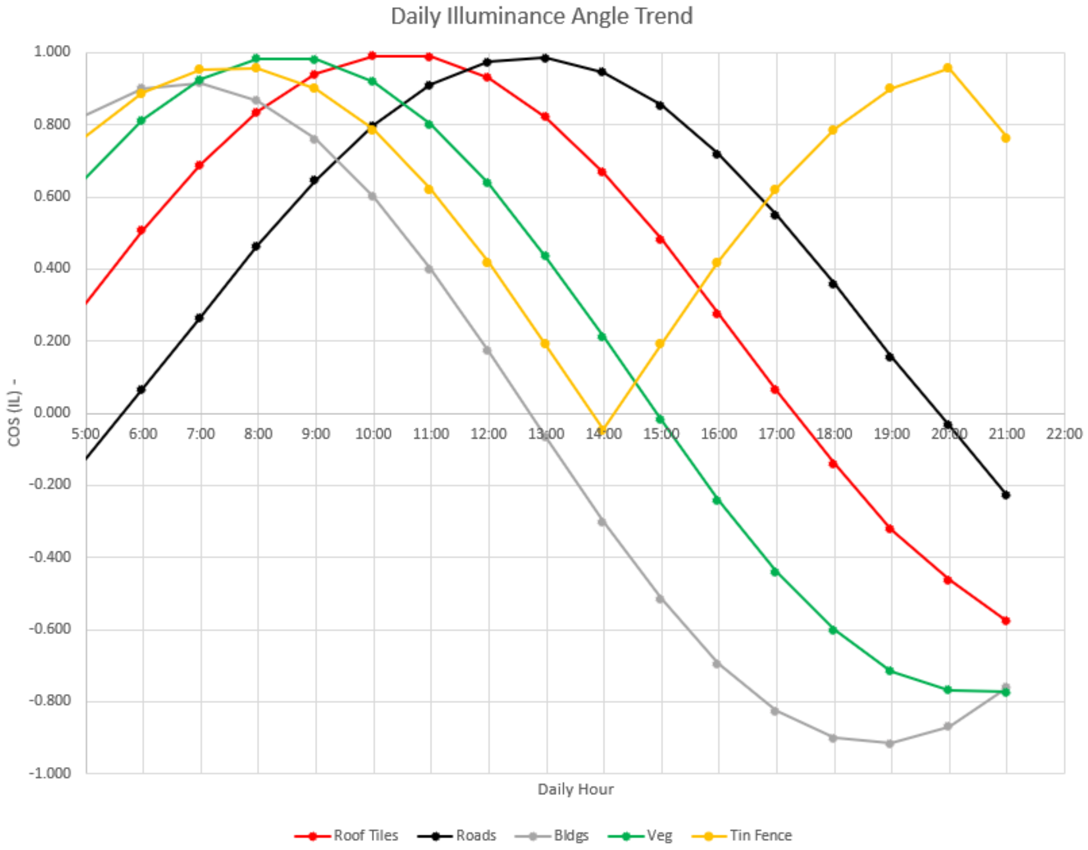


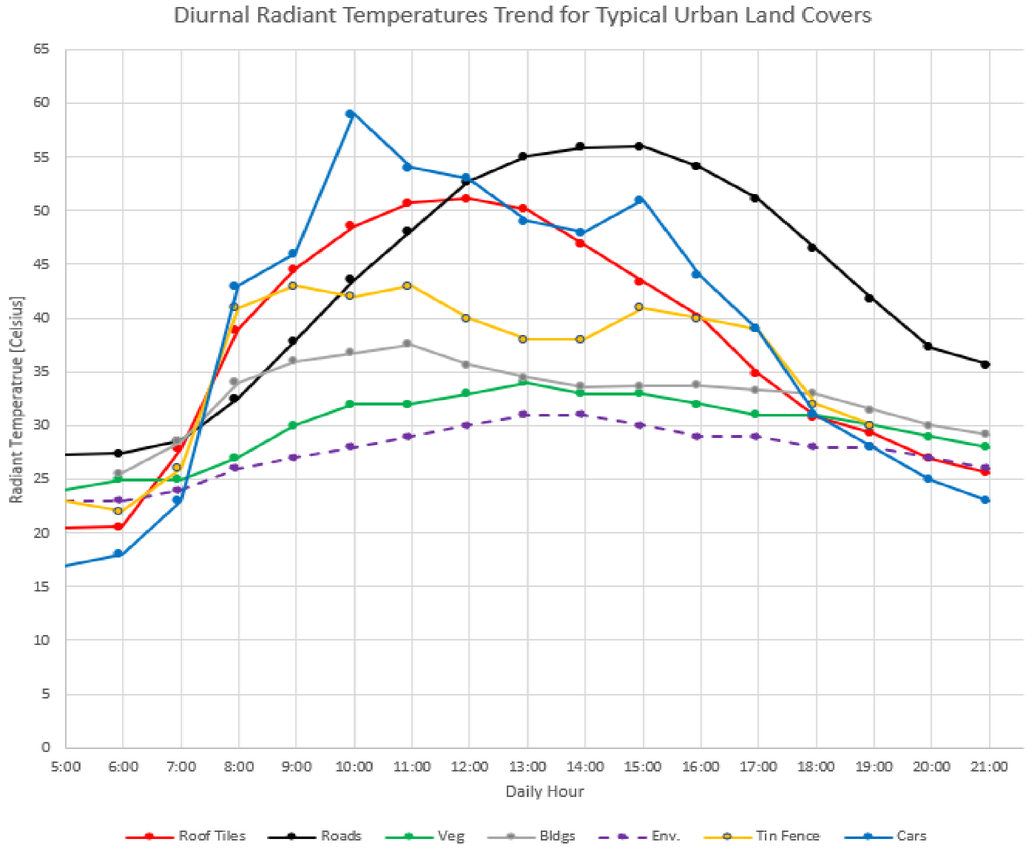
# Classification Model – Feature Set Strategies

- Classification strategies included the following scenarios:

1. All the radiant temperatures from sunrise until sunset
2. Heating gradient-trend based only
3. Cooling gradient-trend based only
4. Relative parameters
5. Three diurnal edge temperatures

# Classification Model – Feature Engineering

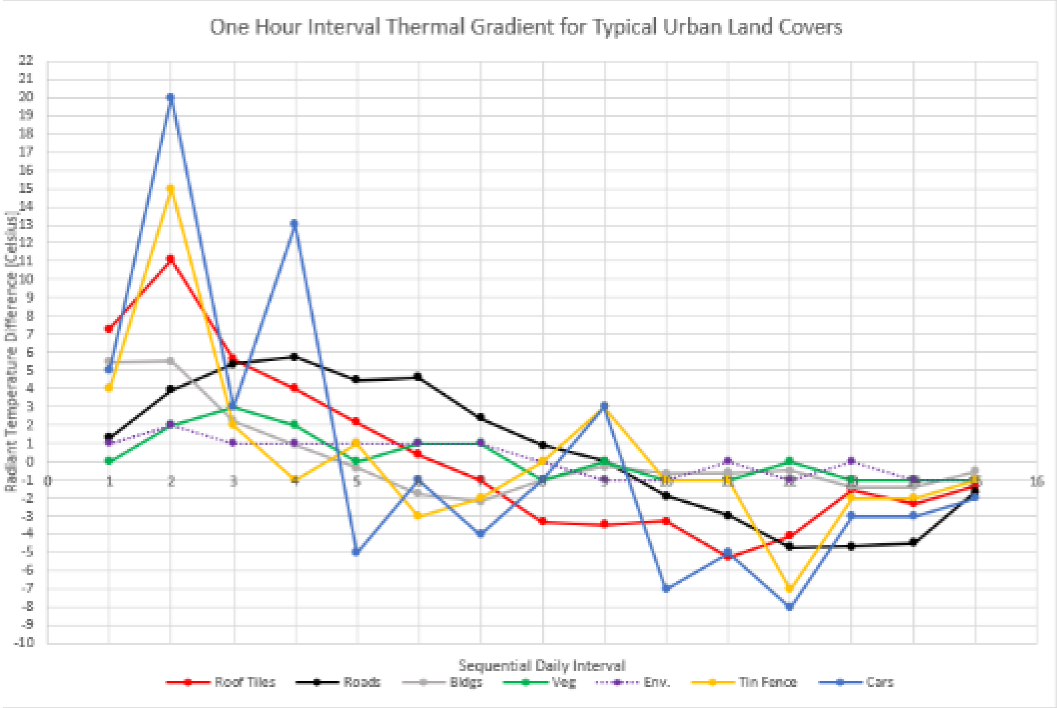


# Classification Model – Feature Engineering

## Sequential Thermal Gradients Patterns for different land cover types

- Transition into slopes (derivatives) space
- Description of a pattern, trend – instead of definite values




- **Thermal Gradient :**

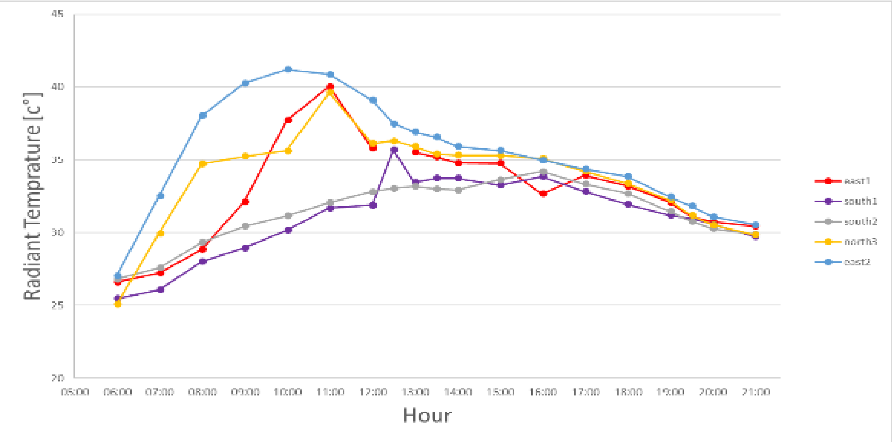
$$\frac{\partial T}{\partial h} = \frac{T_{h_i} - T_{h_{i-1}}}{h_i - h_{i-1}}$$

# Classification Model – Feature Engineering

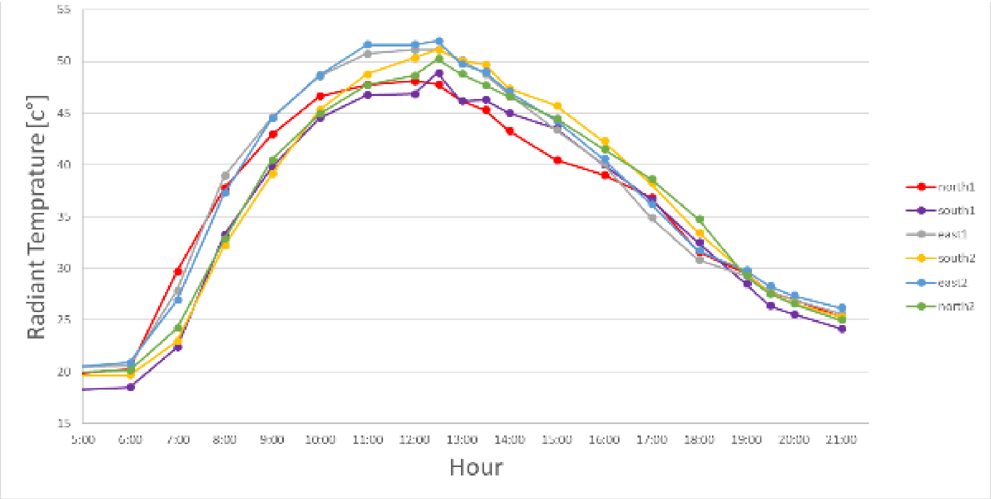
## Diurnal Radiant Temperature for same land cover samples

- Bldgs – Varies pattern, Varies amplitude (highly spatial dependent)
- Roof Tiles – Similar pattern, Varies amplitude (mid spatial dependent)
- Veg – Similar pattern, Similar amplitude (low spatial dependent)

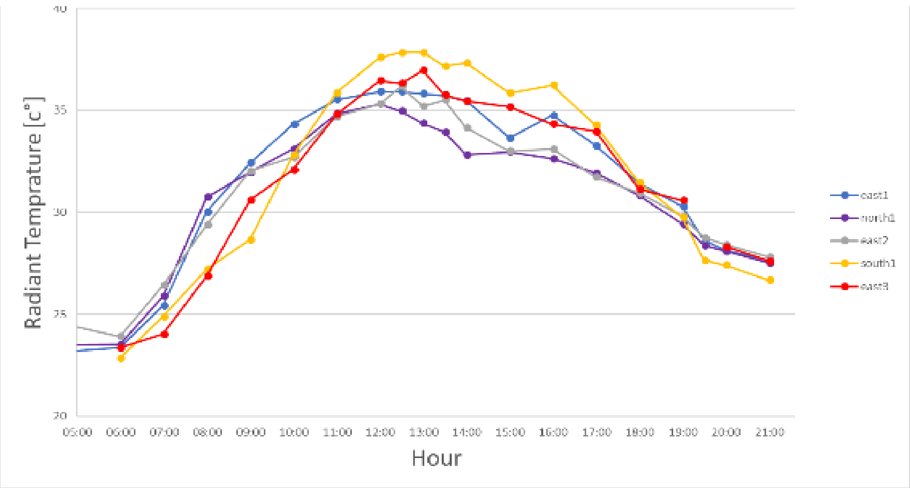
Diurnal radiant temperature patterns for several **building** landcover type observations




Diurnal radiant temperature patterns for several **Roof Tiles** landcover type observations



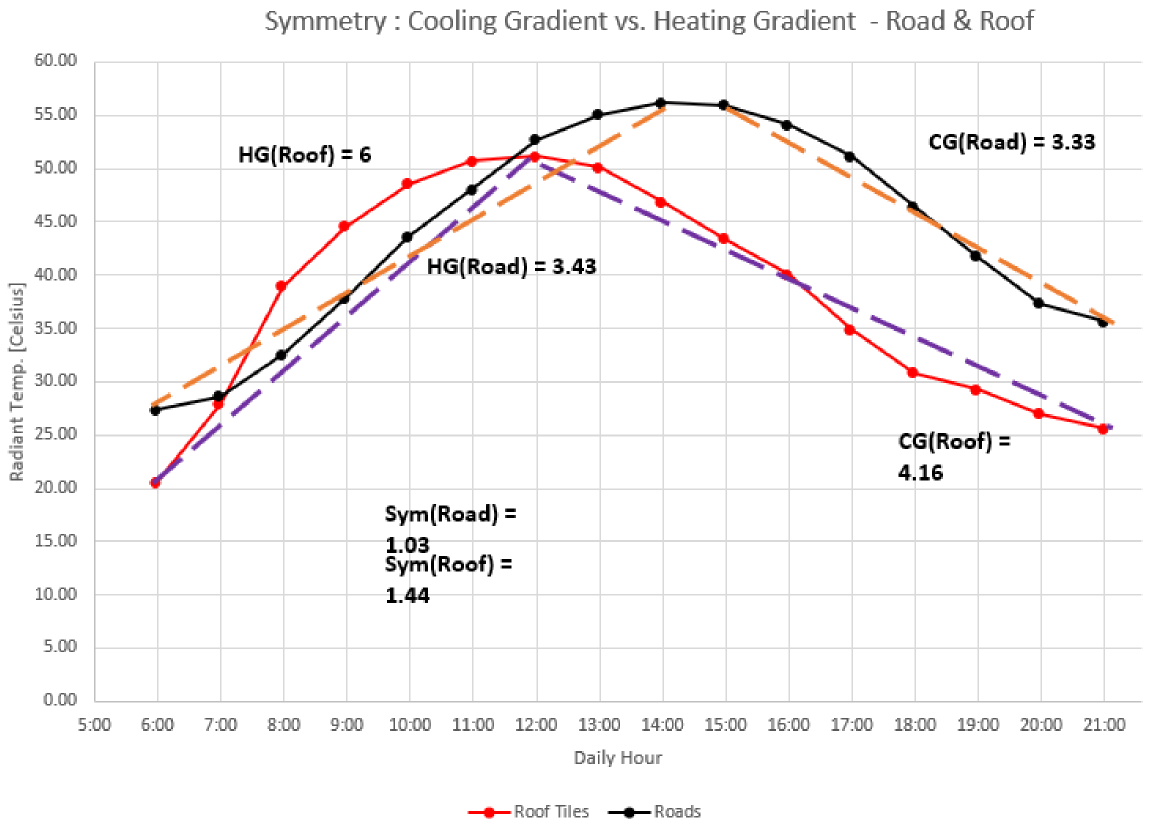

Diurnal radiant temperature patterns for several **Vegetation** landcover type observations



# Classification Model – Feature Engineering

## Heating and Cooling phenomena parametrization

- Generic modeling (all classes)
- Transformation of visual pattern into quantitative values
- Simple method that takes into account 3D spatial orientation




$$Cooling\ Gradient(CG) = \frac{\partial T_{cool}}{\partial h_{cool}} = \frac{T_{max} - T_s}{h_{max} - h_s}\left[\frac{°C}{hour}\right]$$

$$Symmetry = \frac{Heating\ Gradient(HG)}{Cooling\ Gradient(CG)} = \frac{\frac{T_{max} - T_{min}}{h_{max} - h_{min}}}{\frac{T_{max} - T_s}{h_{max} - h_s}}$$

# Classification Model – Feature Engineering

**Amplitude values should be generalized – Relative parameter development**

- Normalized Thermal Gradient Index :

$$NTGI = \frac{T_{max} - T_{min}}{T_{max} + T_{min}}$$

| Label | Av_Max | Av_Min | NTGI |
|---|---|---|---|
| Veg | 34.85 | 23.83 | 0.19 |
| Roof | 51.36 | 20.04 | 0.44 |
| Build | 40.42 | 24.87 | 0.24 |
| Asphalt | 53.39 | 26.58 | 0.34 |
| Fence | 42.20 | 22.01 | 0.31 |
| Car | 52.49 | 18.33 | 0.48 |

- APPARENT THERMAL INERTIA :

$$ATI_{new} = (1 - \mathrm{A})/\Delta T = \varepsilon/\Delta T = 1/\Delta T$$

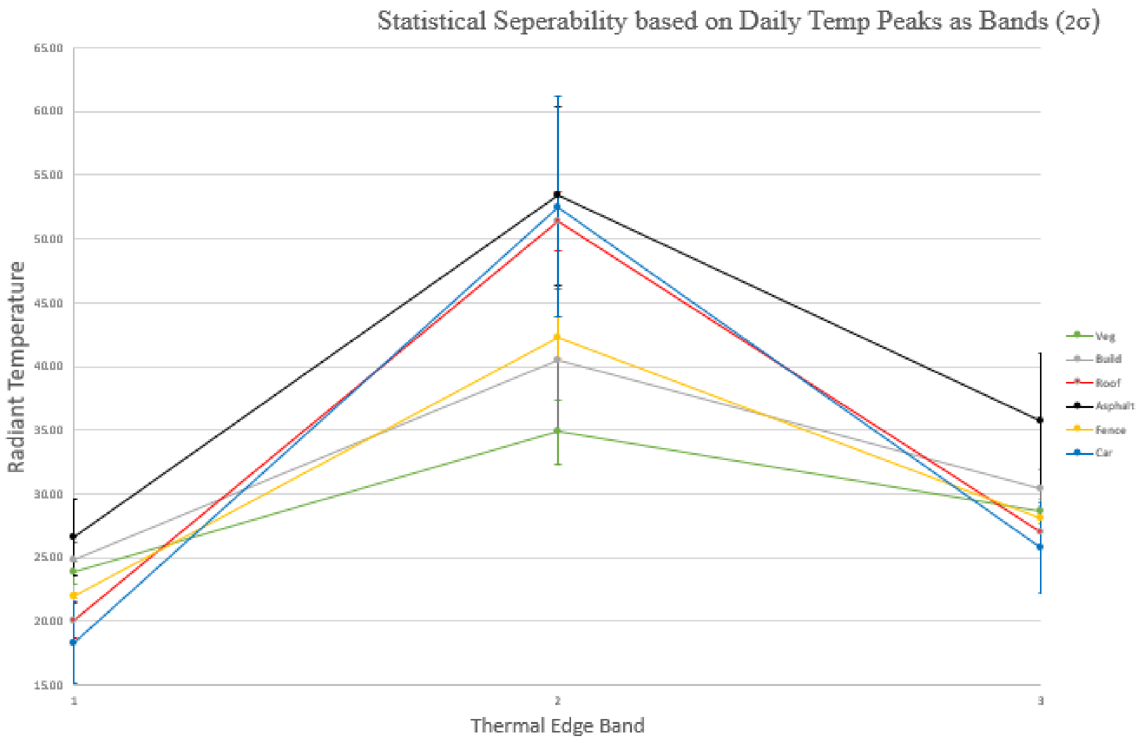
$\Delta$T : Diurnal Radiant Temperatures diff.0

A : Albedo

$\varepsilon$ : Emissivity (at wavelength $\lambda$)

| Label | Avg_Max | Avg_Min | Std_Max | Std_Min | Avg_dT | ATI |
|---|---|---|---|---|---|---|
| Veg | 34.85 | 23.83 | 1.26 | 0.43 | 11.02 | 0.091 |
| Roof | 51.36 | 20.04 | 1.15 | 0.67 | 31.32 | 0.032 |
| Build | 40.42 | 24.87 | 2.79 | 0.65 | 15.56 | 0.064 |
| Asphalt | 53.39 | 26.58 | 3.50 | 1.47 | 26.81 | 0.037 |
| Fence | 42.20 | 22.01 | 0.82 | 0.12 | 20.19 | 0.050 |
| Car | 52.49 | 18.33 | 4.32 | 1.60 | 34.16 | 0.029 |

# Classification Model – Feature Engineering

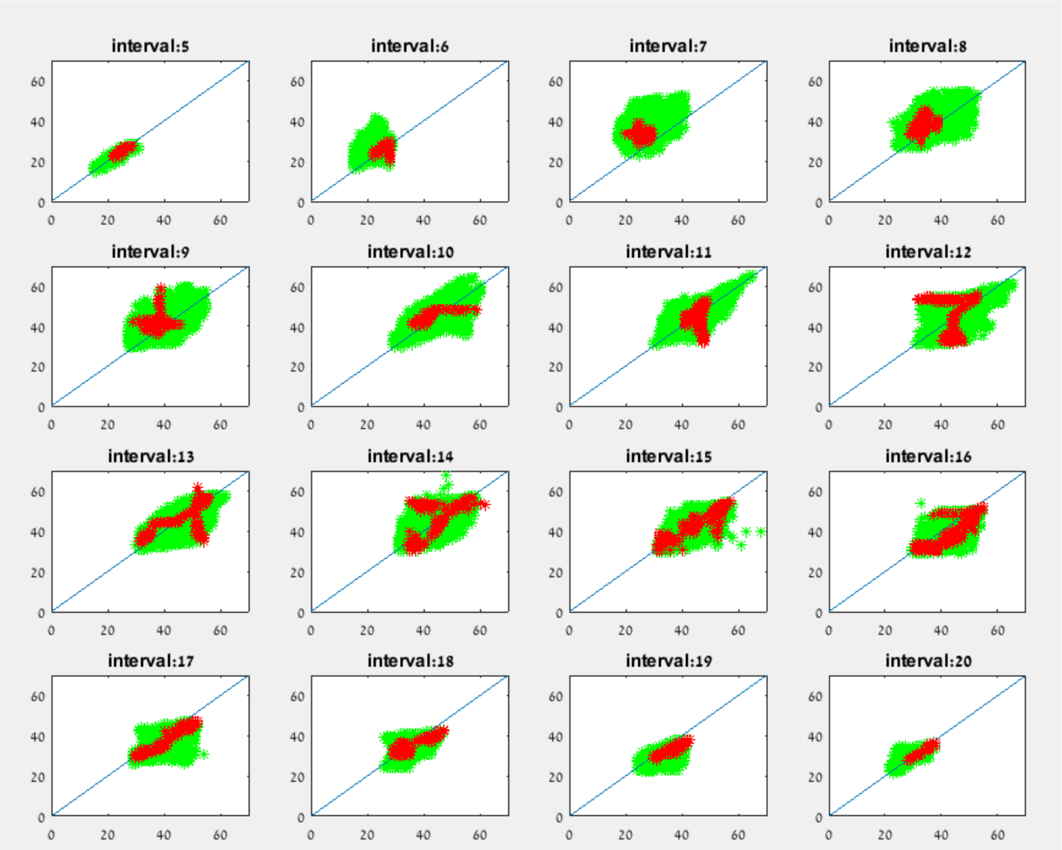



| Label | Av_Max | Av_Min | Av_Ts | Std_Max | Std_Min | Std_Ts |
|---|---|---|---|---|---|---|
| Veg | 34.85 | 23.83 | 28.61 | 1.26 | 0.43 | 0.50 |
| Roof | 51.36 | 20.04 | 27.04 | 1.15 | 0.67 | 0.55 |
| Build | 40.42 | 24.87 | 30.46 | 2.79 | 0.65 | 0.71 |
| Asphalt | 53.39 | 26.58 | 35.77 | 3.50 | 1.47 | 2.61 |
| Fence | 42.20 | 22.01 | 28.02 | 0.82 | 0.12 | 0.17 |
| Car | 52.49 | 18.33 | 25.77 | 4.32 | 1.60 | 1.80 |

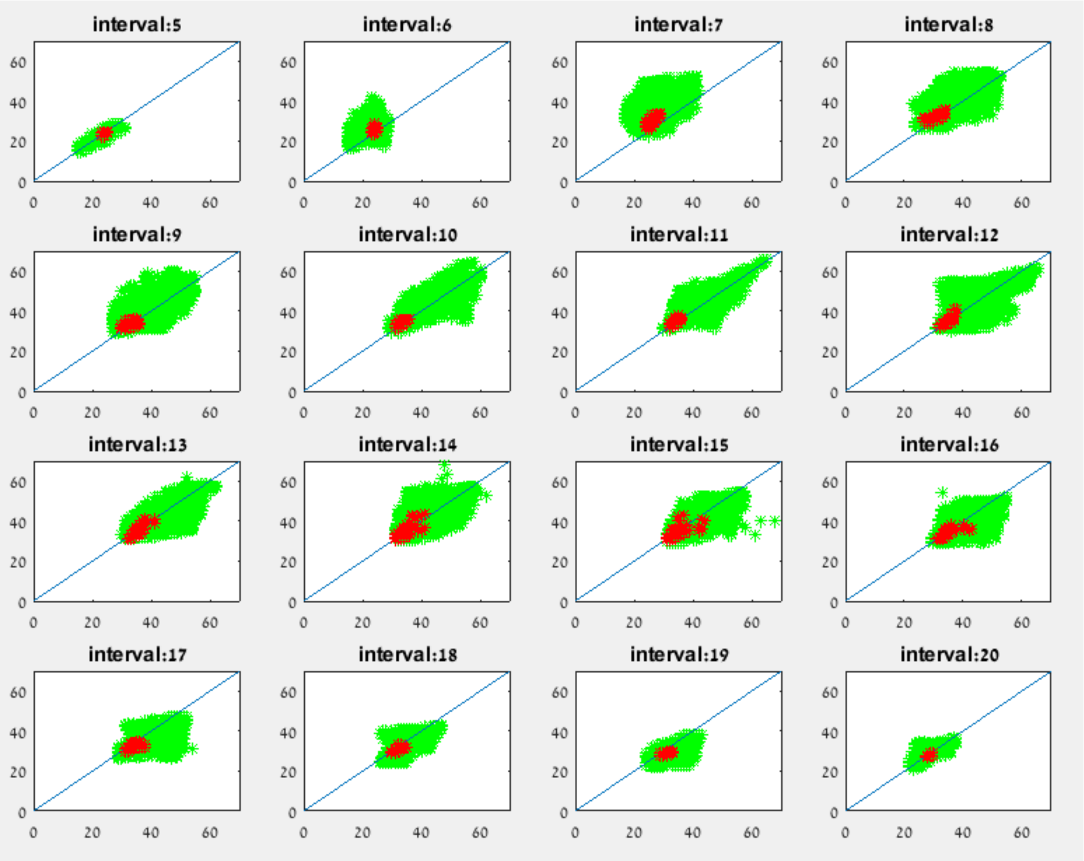
# Classification Model – Time Series Analysis

**Diurnal sequential gradient pairs (Green : All Pixels ; Red : Specific Land Cover Class)**

**Road Pixels (Dynamic-Motion)**

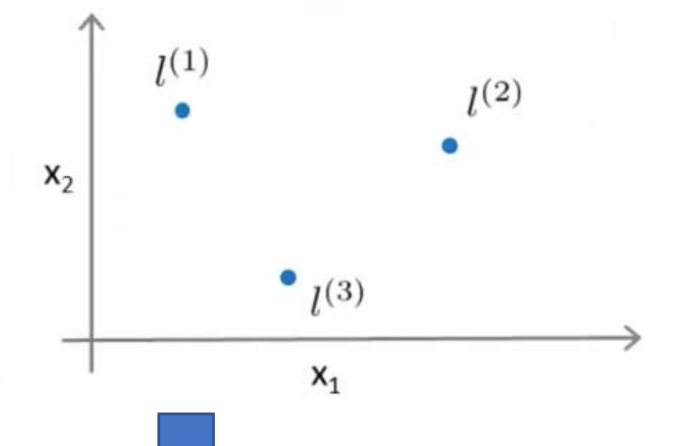



**Vegetation Pixels (Static)**

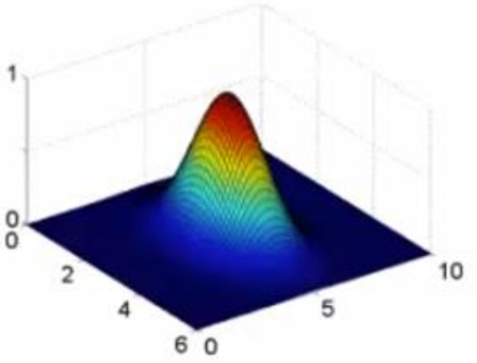


# Classification Model – Algorithm / Classifier

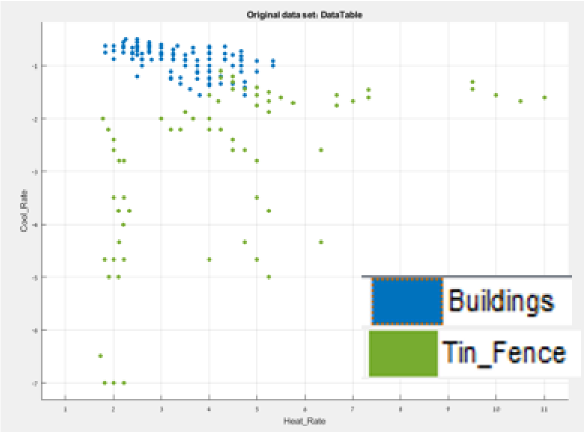
$$f_1 = \text{similarity}(x, l^{(1)}) = \exp\left(-\frac{\|x - l^{(1)}\|^2}{2\sigma^2}\right)$$

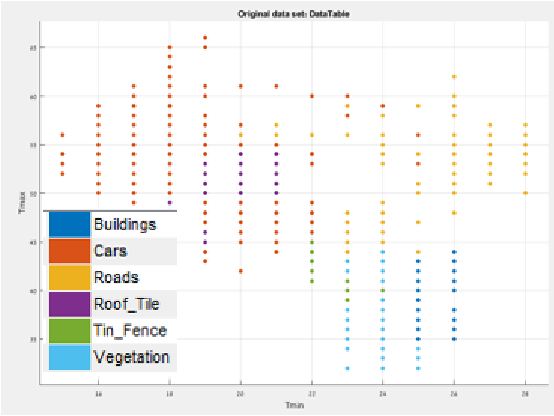


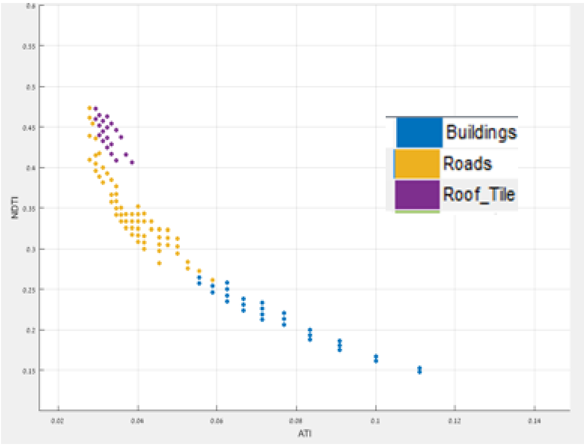

$$\sigma^2 = 1$$

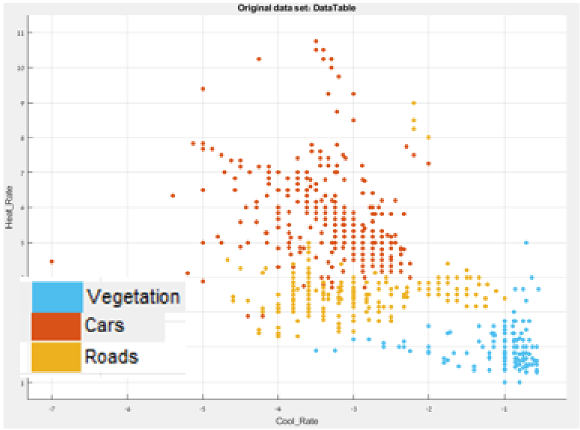



SVM



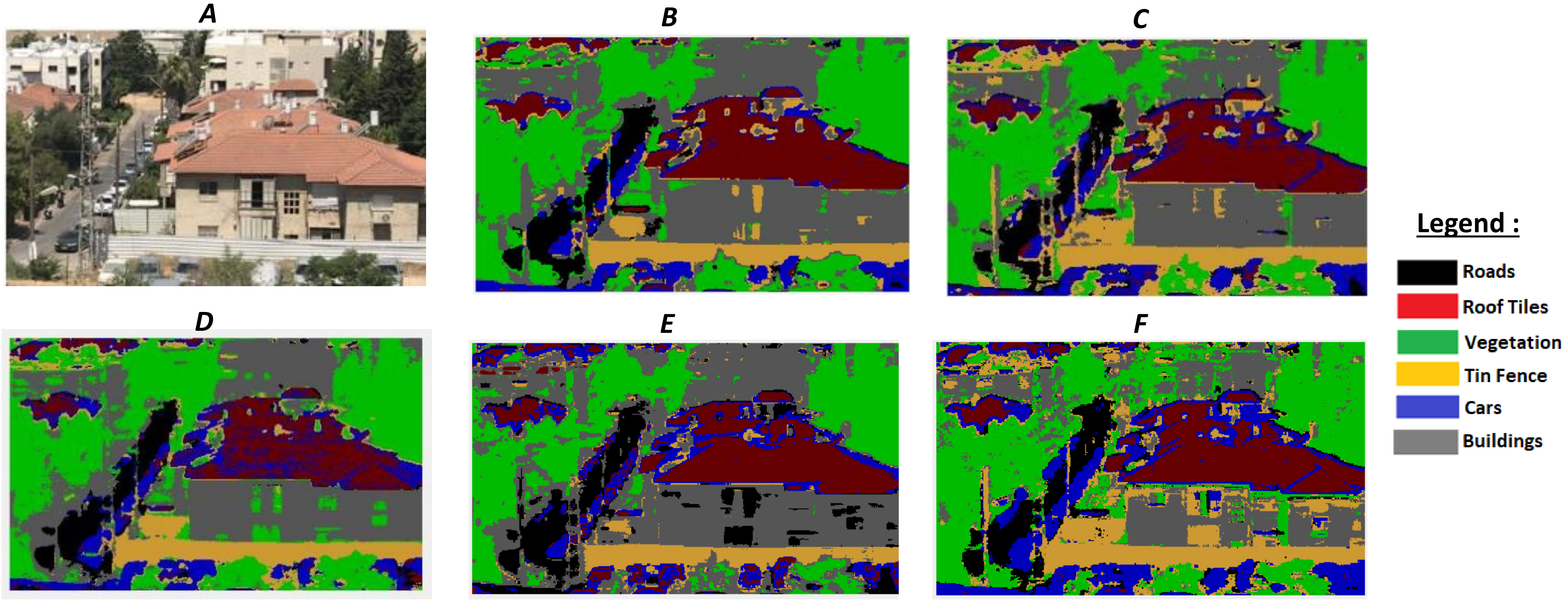



# Classification Model – Goodness of Fit Insights

| Land Cover Type | Veg | | Bldgs | | Raods | | Cars | | Tin Fence | | Roof Tiles | | Overall Accuracy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Test # : | 1775 | Test # : | 2133 | Test # : | 532 | Test # : | 541 | Test # : | 819 | Test # : | 2017 | |
| **Model Features** | TRUE | FALSE | TRUE | FALSE | TRUE | FALSE | TRUE | FALSE | TRUE | FALSE | TRUE | FALSE | |
| **Daily Radiant Values** | 1774 | 1 | 2117 | 16 | 529 | 3 | 511 | 30 | 811 | 8 | 1996 | 21 | 99% |
| **Heating Gradient Based** | 1774 | 1 | 2111 | 22 | 532 | 0 | 507 | 34 | 816 | 3 | 1994 | 23 | 98% |
| **Cooling Gradient Based** | 1728 | 47 | 2087 | 46 | 517 | 15 | 462 | 79 | 815 | 4 | 2012 | 5 | 97% |
| **Relative Parameters** | 1707 | 68 | 2105 | 28 | 527 | 5 | 405 | 136 | 810 | 9 | 2008 | 9 | 96% |
| **3 Edge Values** | 1757 | 18 | 2021 | 112 | 491 | 41 | 385 | 156 | 807 | 12 | 2003 | 14 | 93% |

- Average 84% Recall and Precision (cars..)
- Highest sensitivity - FP cars classifies as roof tiles. (6%)
- Other than car, all classes holds an average of ~95%
- Confusion rates between Vegetation, Buildings. (Still >95%)
- Even though only Radiant Temperatures taken into account (no Emissivity) – high success rates thanks to TRENDS and PATTERNS

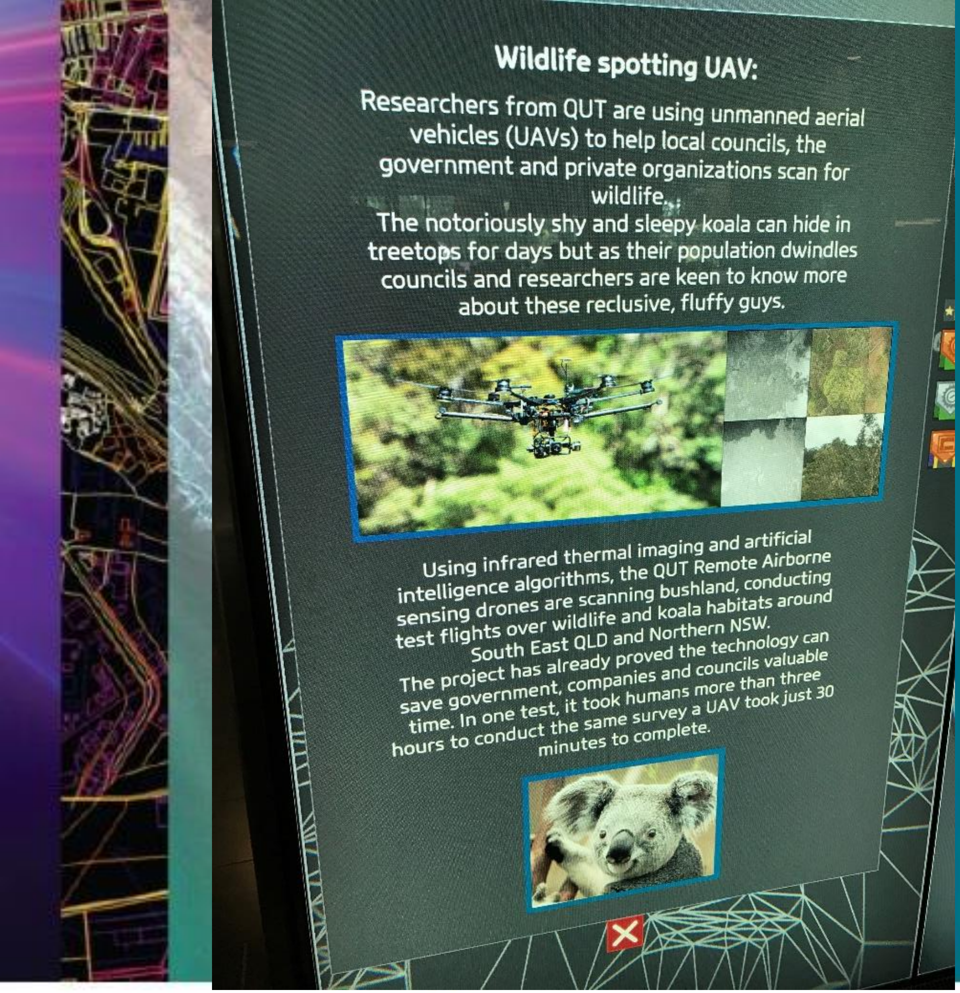
# Classification Model – Fitting Results




A) RGB Image of the scene; B) All the radiant temperatures from sunrise until sunset; C) Heating gradient-trend based only; D) Cooling gradient-trend based only; E) Relative parameters; F) Three diurnal edge temperatures

# Wrap Up & Discussion

- Diurnal radiant temperature pattern facilitated reliable and unique spectral signatures for object classification, including the case of only three extreme measurements - sunrise temperature, maximum temperature and temperature at sunset.
- While heating gradient is highly affected by urban structures orientation, cooling gradient is more correlated with the ambient temperature.
- When a significant gradient is required, it is essential to analyze which of the mentioned features dominates the mapping scene.
- Relative parameters holds a great potential, by getting a robust-close solution, both accuracy and precision wise
- Supervised Thermo-Temporal 3D urban land cover classification results presented in this thesis suggest that thermal imagery may be utilized in enriching common mapping processes.




# Thank You

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