# The role of urban climatology in urban policy

## Can urban models inform policy and become more useful to decision-makers?

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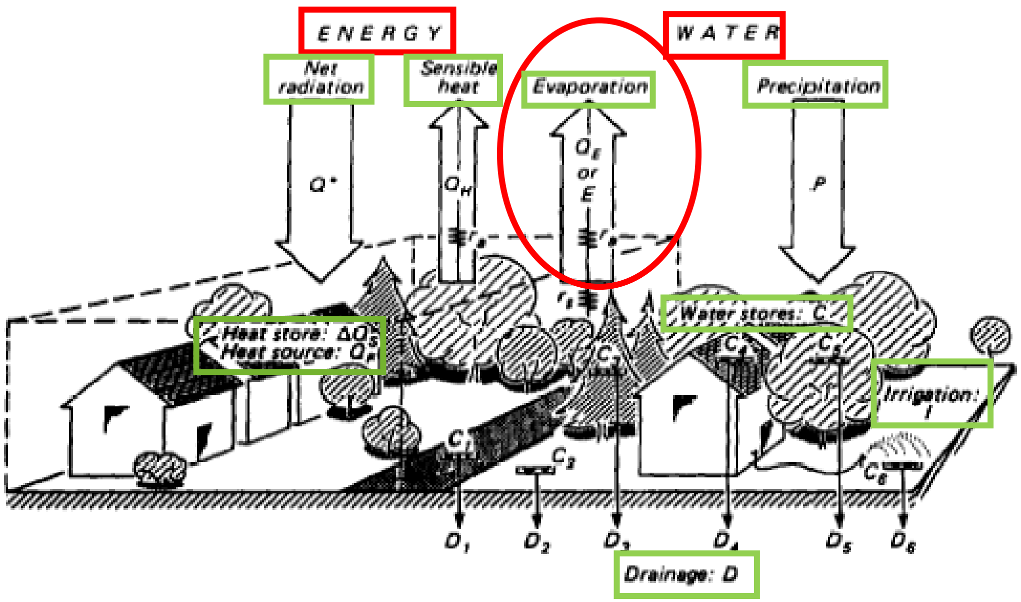


Fig. 1. Schematic of the conceptual framework of the model.

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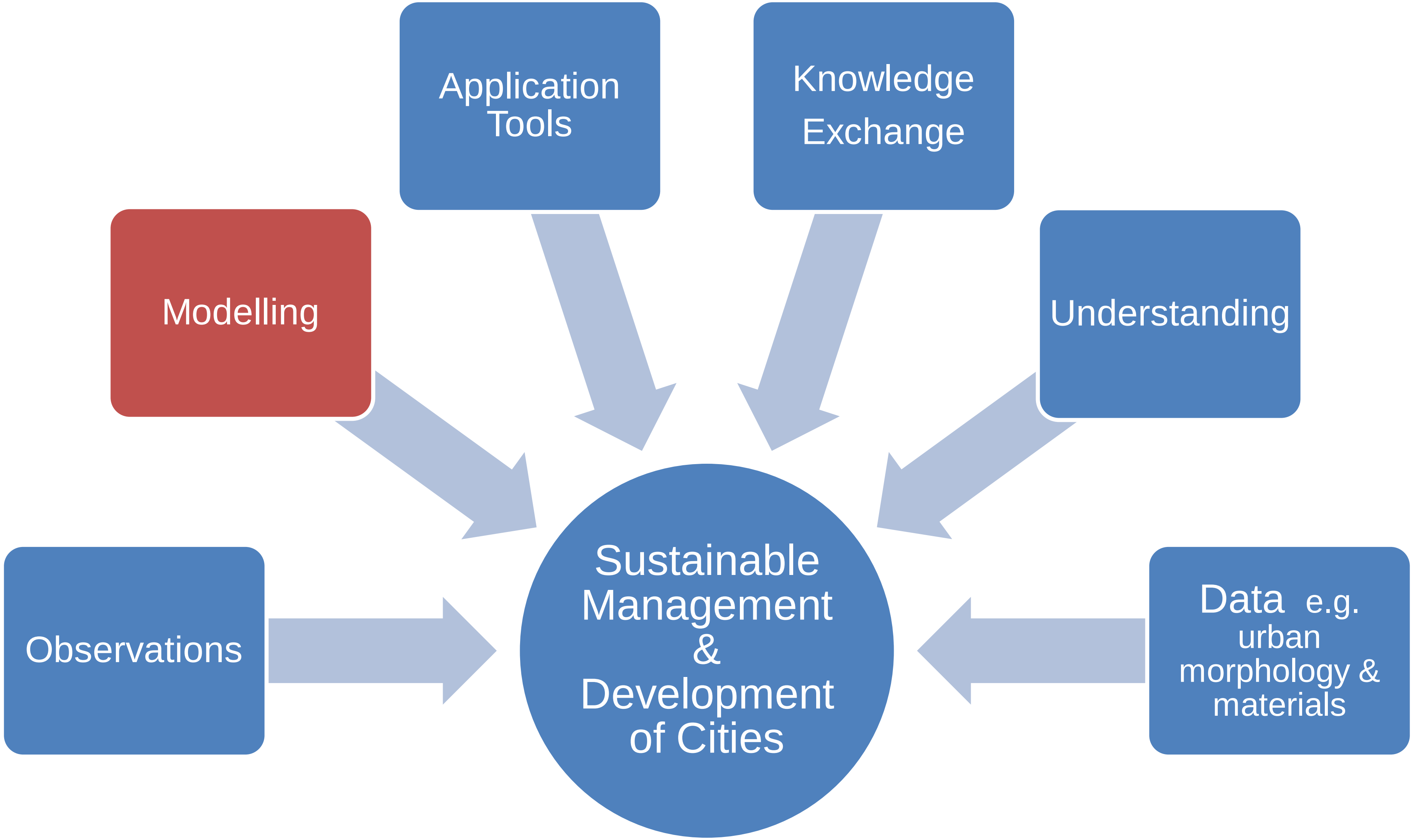
WMO: Sustainable Cities

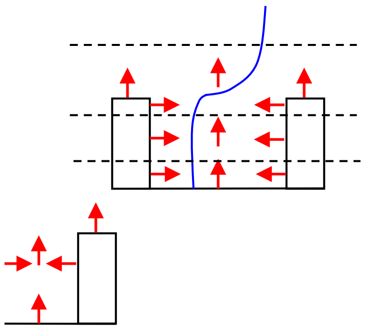


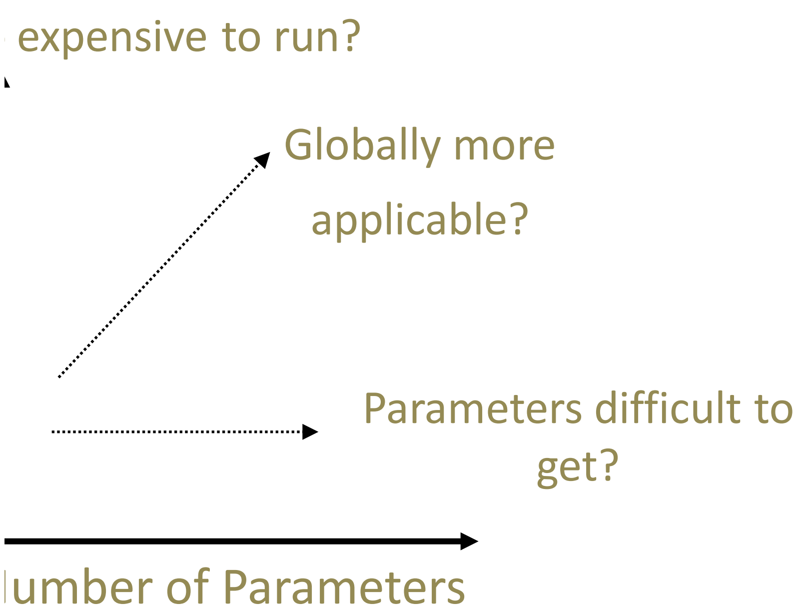

Grimmond et al. (2009) WCC3

# Wide range: Urban Land Surface Schemes

## Wide range of applications

- Standalone models
  - Sensor source areas: TUF2D/ TUF3D
  - Design: GCTTC
- Land surface schemes for
  - Mesoscale models
    - WRF
    - MM5
    - Meso-NH
  - Global Climate models
    - UM
    - CCSM
  - Operational Forecast Models
    - UK Met Office
    - Meteo France
    - Meteo Swiss





# PILPS – Urban: International Urban Energy Balance Model Comparison

| Code | Model Name | References | Versions | Groups |
|---|---|---|---|---|
| **BEP02** | Building Effect Parameterization | Martilli et al. (2002) | 1 | 1 |
| **BEP_BEM08** | BEP coupled with Building Energy Model | Martilli et al. (2002), Salamanca et al. (2009),Salamanca and Martilli (2009) | 1 | 1 |
| **CLMU** | Model - Urban | Oleson et al. (2008a, b) | 1 | 1 |
| **GCTTC** | Green Cluster Thermal Time Constant model | Shashua-Bar and Hoffman (2002; 2004) | 1 | 1 |
| **IISUCM** | Science Urban Canopy Model | Kawamoto and Ooka (2006; 2009a; b) | 1 | 1 |
| **JULES** | Joint Land Environment Simulator | Essery et al. (2003), Best (2005), Best et al. (2006) | 4 | 2 |
| **LUMPS** | Local-scale Urban Meteorological Parameterization Scheme | Grimmond and Oke (2002), Offerle et al. (2003) | 2 | 1 |
| **NKUA** | Model | Dandou et al. (2005) | 1 | 1 |
| **MORUSES** | Met Office Reading Urban Surface Exchange Scheme | Harman et al. (2004 a,b), Porson et al. (2009) | 2 | 1 |
| **MUCM** | Multi-layer Urban Canopy Model | Kondo and Liu (1998), Kondo et al. (2005) | 1 | 1 |
| **NJU--S** | Nanjing University Urban Canopy Model-single layer | Masson(2000), Kusaka (2001) | 1 | 1 |
| **NJUC-UM-M** | Nanjing University Urban Canopy Model-multiple layer | Kondo et al.(2005), Kanda(2005a; b) | 1 | 1 |
| **NSLUCM / NSLUCMK / NSLUCM-WRF** | Noah land surface model/Single-layer Urban Canopy Model | Kusaka et al. (2001), Chen et al. (2004) | 3 | 3 |
| **SM2U** | Soil Model for Submesoscales (Urbanized) | Dupont and Mestayer (2006), Dupont et al. (2006) | 1 | 1 |
| **SNUUCM** | Urban Canopy Model | Ryu et al. (2009) | 1 | 1 |
| **SRUM2/SRUM4** | Single Column Reading Urban Model tile version | Harman and Belcher (2006), Porson et al. (2009) | 4 | 1 |
| **SUEB** | Slab Urban Energy Balance Model | Fortuniak et al. (2004, 2005) | 1 | 1 |
| **SUMM** | Simple Urban Energy Balance Model for Mesoscale Simulation | Kanda et al. (2005a,b; 2007), Kawai et al. 2007, 2009) | 1 | 1 |
| **TEB** | Town Energy Balance | Masson (2000), Masson et al. (2002), Lemonsu et al. (2004) | 1 | 1 |
| **TEB07** | Town Energy Balance 7 | Hamdi and Masson (2008) | 1 | 1 |
| **TUF2D** | Temperatures of Urban Facets 2D | Krayenhoff and Voogt (2007) | 1 | 1 |
| **TUF3D** | Temperatures of Urban Facets 3D | Krayenhoff and Voogt (2007) | 1 | 1 |
| **VUCM** | Vegetated Urban Canopy Model | Lee and Park (2008) | 1 | 1 |

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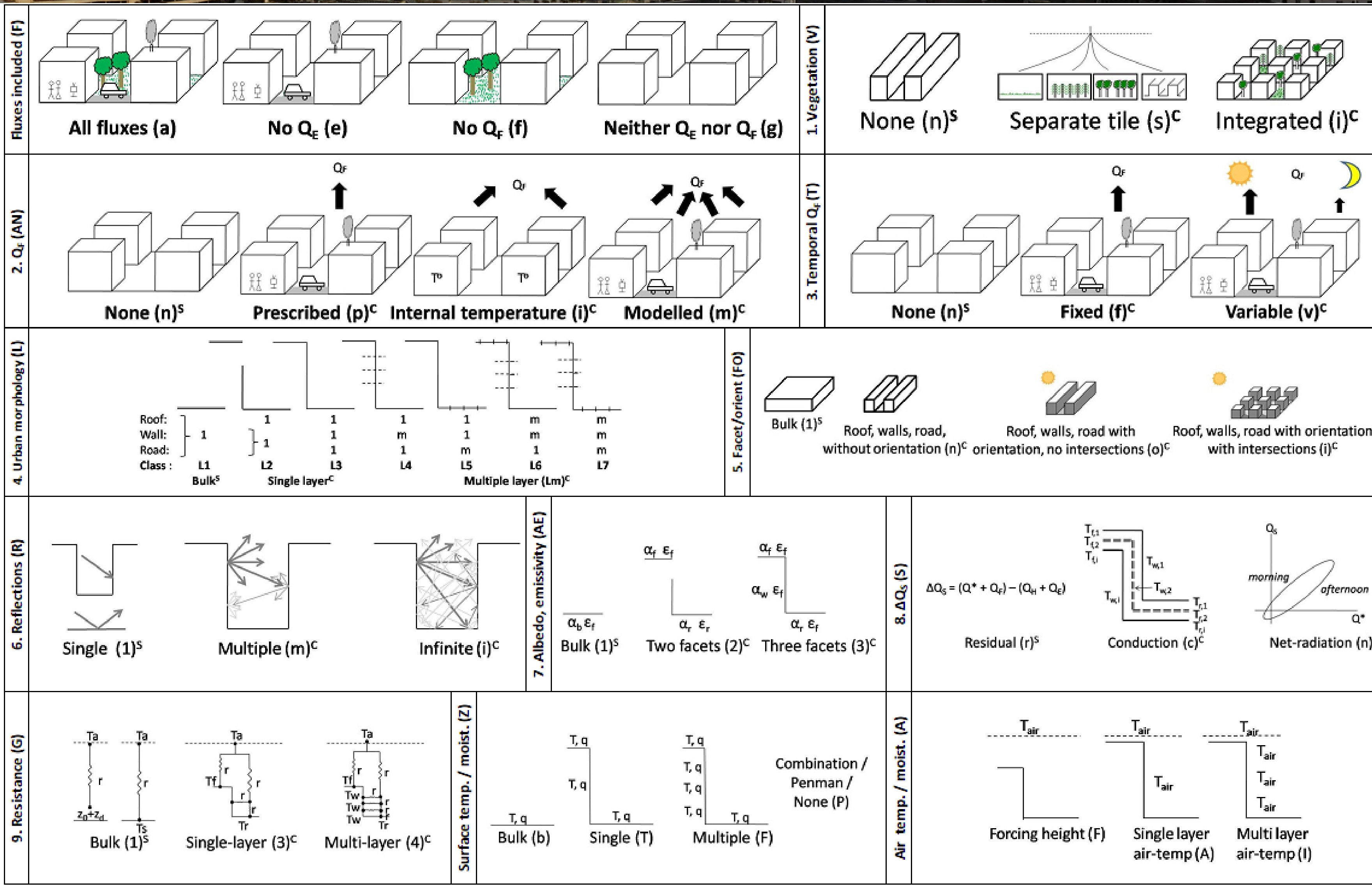
# Approaches Taken: Model Classification

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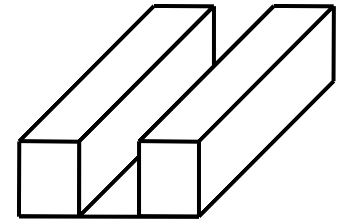
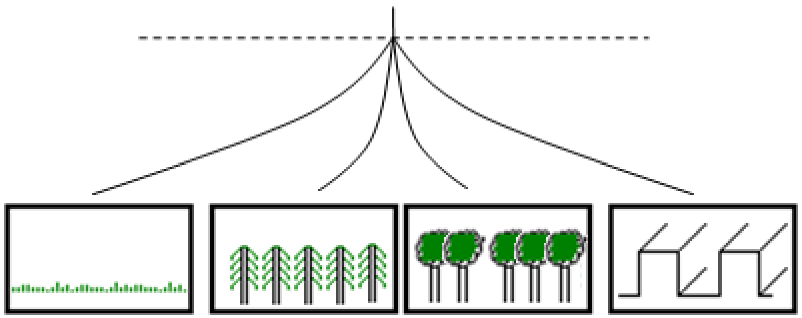
# Vegetation inclusion

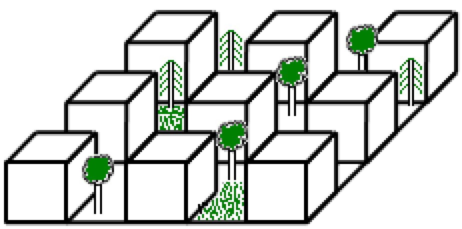
- **None**
  - assumed to be no vegetation present



- **Separate Tile**
  - vegetation and built parts of the surface are treated separately
  - do not interact until a layer above the surface scheme
  - fluxes are a spatially weighted mean



- **Integrated**
  - vegetation is within the tile that has the build facets so can interact/respond to the exchanges associated with this layer of the model



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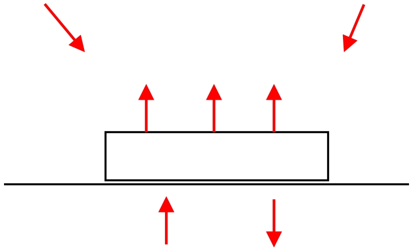
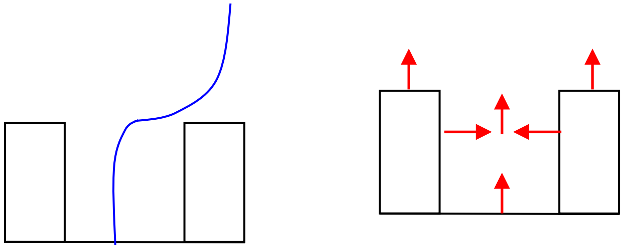
# Layers resolved

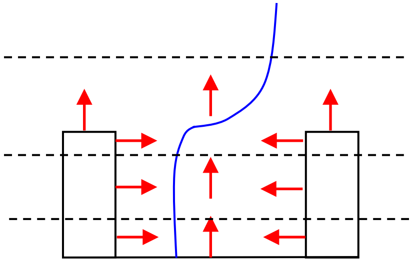
- Slab



- Single layer



- Multi-layer



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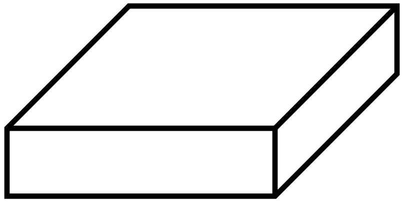
# Facets and aspects resolved

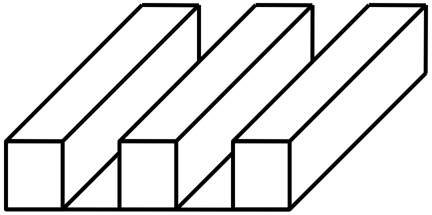
**Whole**

- individual walls, roof, road are not resolved



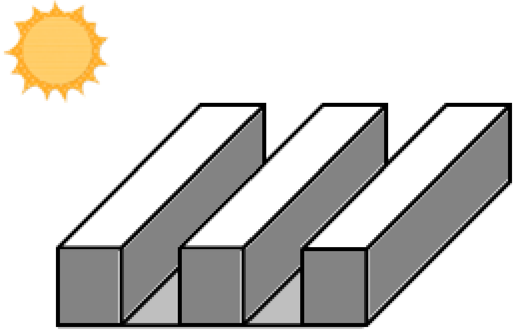
**Roof, Wall and road are resolved but<u>without</u> orientation**

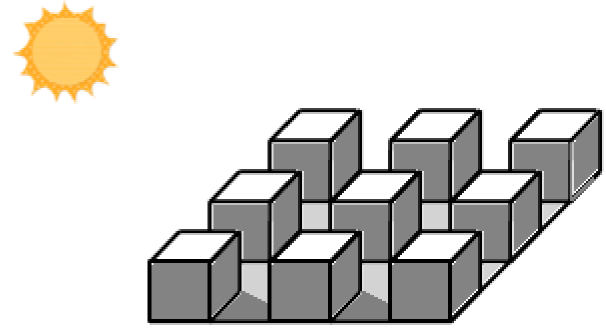
- ⇒ sunlit and shaded facets not resolved



**Roof, Walls and road are resolved <u>with</u> orientation**

- ⇒ during the daytime there maybe sunlit and shaded facets





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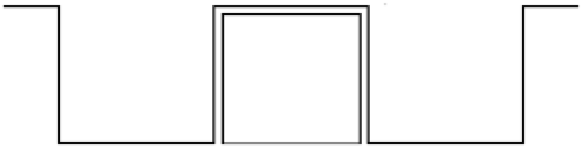
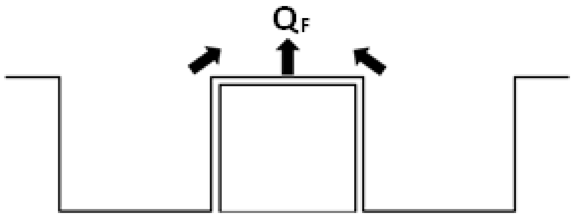
# Anthropogenic heat flux

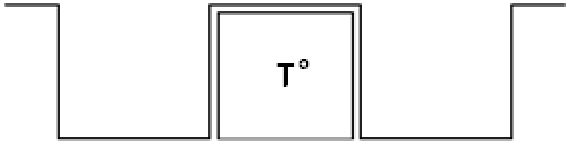
- **None**
  - Flux is assumed to be 0 W m$^{-2}$ or not to exist



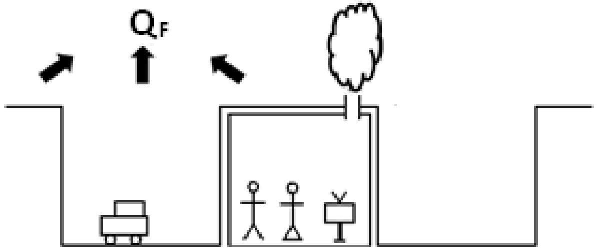
- **Prescribed**
  - Flux value is prescribed, consider either:
    - Some components (partial)
    - All components




- **Internal Temperature**
  - An internal temperature is prescribed which is used to calculate the other fluxes




- **Modelled**
  - All or components of the flux are modelled

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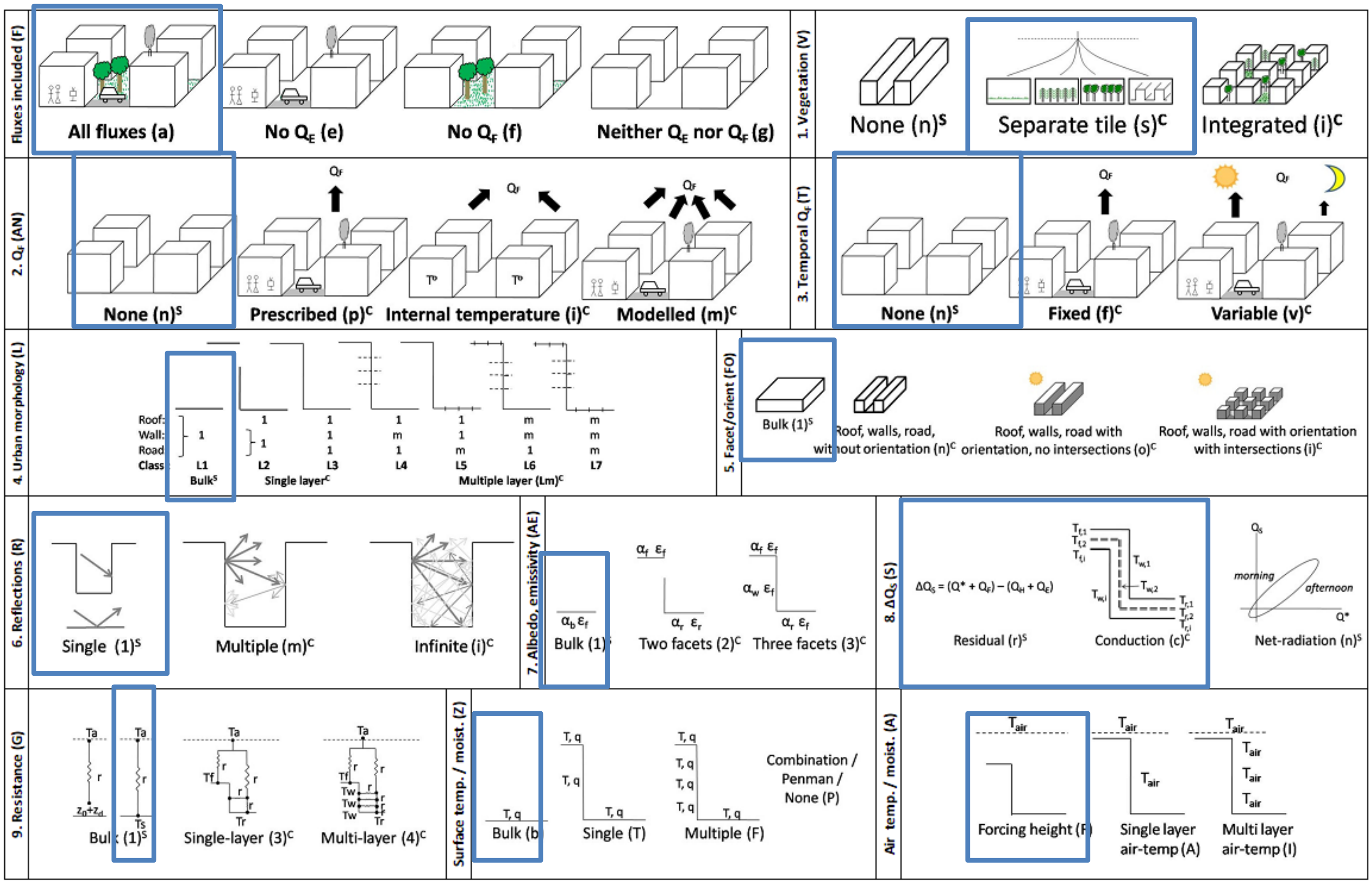
Characteristics of an **Individual Model**

- JULES Urban Tile (Best 2005)

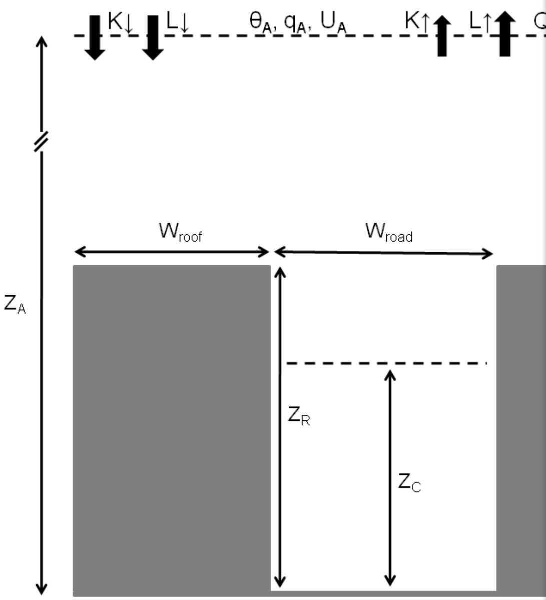


# Models require large number of Input Parameters

**NOAH/SLUCM:**

Total:

68 parameters




| | Parameter | Min | Max | Default | Parameter Definition | Reference (default) |
|---|---|---|---|---|---|---|
| 1 | $Z_R$ | 12.6 | 18.6 | 15.6 | Roof height (m) | LE04 |
| 2 | $W_{roof}$ | 11.2 | 31.2 | 21.2 | Roof width (m) | LE04 |
| 3 | $W_{road}$ | 3.6 | 15.6 | 9.6 | Road width (m) | LE04 |
| 4 | $\sigma_Z$ | 1.0 | 15.0 | 9.0 | Standard deviation of roof height (m) | - |
| 5 | $a_K$ | 0.5 | 2.0 | 1.29 | Empirical coefficient from Kanda et al. (2007) | KA07 |
| 6 | $\alpha_{roof}$ | 0.05 | 0.4 | 0.22 | Roof albedo (-) | LE04,DP06 |
| 7 | $\alpha_{wall}$ | 0.05 | 0.55 | 0.20 | Wall albedo (-) | LE04, DP06 |
| 8 | $\alpha_{road}$ | 0.05 | 0.25 | 0.08 | Road albedo (-) | LE04,DP06 |
| 9 | $\varepsilon_{roof}$ | 0.85 | 0.98 | 0.90 | Roof emissivity (-) | LE04, DP06 |
| 10 | $\varepsilon_{wall}$ | 0.85 | 0.98 | 0.90 | Wall emissivity (-) | LE04, P06 |
| 11 | $\varepsilon_{road}$ | 0.85 | 0.98 | 0.94 | Road emissivity (-) | LE04,DP06 |
| 12 | $k_{roof}$ | 0.19 | 1.5 | 0.90 | Conductivity of roof materials (W $m^{-1}$ $K^{-1}$) | RO06 |
| 13 | $k_{wall}$ | 0.09 | 2.3 | 0.55 | Conductivity of wall materials (W $m^{-1}$ $K^{-1}$) | RO06 |
| 14 | $k_{road}$ | 0.03 | 2.1 | 1.77 | Conductivity of road materials (W $m^{-1}$ $K^{-1}$) | RO06 |
| 15 | $C_{roof}$ | $0.6*10^6$ | $2.3*10^6$ | $1.77*10^6$ | Heat capacity of roof materials (J $m^{-3}$ $K^{-1}$) | RO06 |
| 16 | $C_{wall}$ | $0.4*10^6$ | $2.3*10^6$ | $1.67*10^6$ | Heat capacity of wall materials (J $m^{-3}$ $K^{-1}$) | RO06 |
| 17 | $C_{road}$ | $0.3*10^6$ | $2.3*10^6$ | $1.89*10^6$ | Heat capacity of road materials (J $m^{-3}$ $K^{-1}$) | RO06 |
| 18 | $d_{z,roof}$ | 0.05 | 0.5 | 0.32 | Total thickness of roof layers (m) | RO06 |
| 19 | $d_{z,wall}$ | 0.1 | 1.0 | 0.26 | Total thickness of wall layers (m) | RO06 |
| 20 | $d_{z,road}$ | 0.5 | 2.0 | 1.24 | Total thickness of road layers (m) | RO06 |
| 21 | $d_{zfrac,roof}$ (1) | 0.02 | 0.1 | 0.062 | Fraction of $d_{z,roof}$ covered by layer 1 | RO06 |
| 22 | $d_{zfrac,roof}$ (2) | 0.1 | 0.49 | 0.468 | Fraction of $d_{z,roof}$ covered by layer 2 | RO06 |
| 23 | $d_{zfrac,roof}$ (3) | 0.1 | 0.4 | 0.375 | Fraction of $d_{z,roof}$ covered by layer 3 | RO06 |
| 24 | $d_{zfrac,wall}$ (1) | 0.02 | 0.1 | 0.038 | Fraction of $d_{z,wall}$ covered by layer 1 | RO06 |
| 25 | $d_{zfrac,wall}$ (2) | 0.1 | 0.3 | 0.154 | Fraction of $d_{z,wall}$ covered by layer 2 | RO06 |
| 26 | $d_{zfrac,wall}$ (3) | 0.1 | 0.59 | 0.577 | Fraction of $d_{z,wall}$ covered by layer 3 | RO06 |
| 27 | $d_{zfrac,road}$ (1) | 0.02 | 0.1 | 0.032 | Fraction of $d_{z,road}$ covered by layer 1 | RO06 |
| 28 | $d_{zfrac,road}$ (2) | 0.1 | 0.4 | 0.16 | Fraction of $d_{z,road}$ covered by layer 2 | RO06 |
| 29 | $d_{zfrac,road}$ (3) | 0.1 | 0.49 | 0.4 | Fraction of $d_{z,road}$ covered by layer 3 | RO06 |
| 30 | urb | 0.764 | 0.964 | 0.864 | Urban fraction (-) | LE04 |
| 31 | $R_{cmin}$ | 40 | 400 | 170 | Stomatal resistance (s $m^{-1}$) | CD01 (+DP06) |
| 32 | $R_{gl}$ | 30 | 100 | 100 | Radiation stress parameter (-) | CD01 (+DP06) |
| 33 | $h_S$ | 36.25 | 54.56 | 39.18 | Vapor pressure deficit parameter (-) | CD01 (+DP06) |
| 34 | $\alpha_{veg}$ | 0.10 | 0.30 | 0.23 | Vegetation albedo (-) | CD01 (+DP06) |
| 35 | $\varepsilon_{veg}$ | 0.88 | 0.97 | 0.93 | Vegetation emissivity (-) | CD01 (+DP06) |
| 36 | $z_{0,veg}$ | 0.03 | 1.6 | 0.05 | Roughness length for momentum - vegetation (m) | CD01 (+DP06) |
| 37 | $\Theta_s$ | 0.339 | 0.476 | 0.465 | Maximum soil moisture content ($m^3$ $m^{-3}$) | CD01 (+DP06) |
| 38 | $\Theta_{ref}$ | 0.236 | 0.453 | 0.382 | Reference soil moisture content ($m^3$ $m^{-3}$) | CD01 (+DP06) |
| 39 | $\Theta_w$ | 0.010 | 0.2 | 0.103 | Wilting point ($m^3$ $m^{-3}$) | CD01 (+DP06) |
| 40 | $\Theta_{dry}$ | 0.010 | 0.2 | 0.103 | Dry soil moisture content ($m^3$ $m^{-3}$) | CD01 (+DP06) |
| 41 | LAI | 1.0 | 5.0 | 3.0 | Leaf Area Index ($m^3$ $m^{-3}$) | CD01 (+DP06) |
| 42 | $\sigma_f$ | 0.1 | 0.8 | 0.7 | Green vegetation fraction (-) | CD01 (+DP06) |
| 43 | QTZ | 0.10 | 0.92 | 0.35 | Soil quartz content (-) | CD01 (+DP06) |
| 44 | $C_{soil}$ | $0.5*10^6$ | $4.0*10^6$ | $1.26*10^6$ | Soil heat capacity (J $m^{-3}$ $K^{-1}$) | CD01 (+DP06) |
| 45 | $C_{ZIL}$ | 0.01 | 1.0 | 0.1 | Zilitinkevitch parameter | CH97 |

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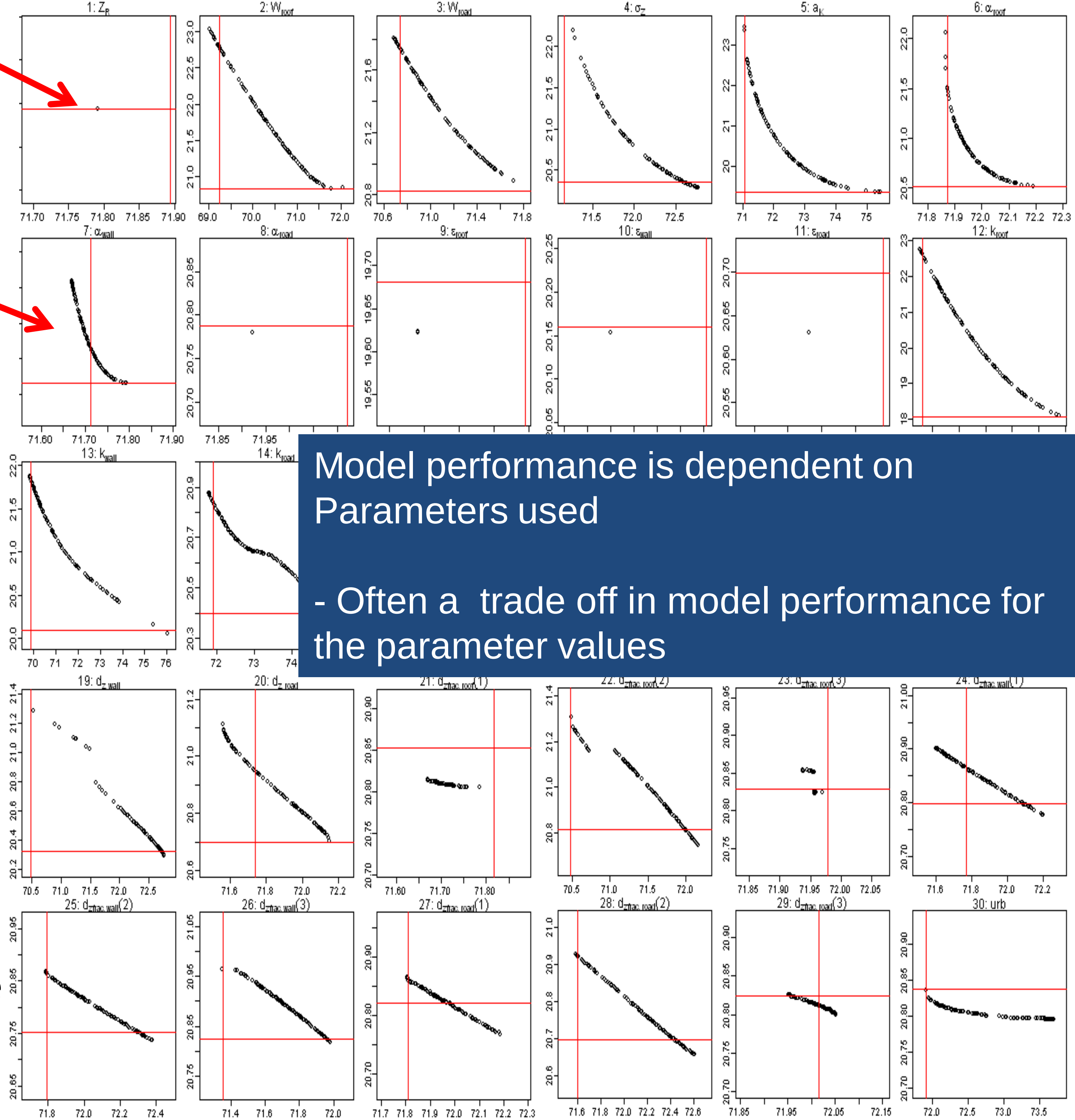
Optimum state: 100 solutions clustered together

No optimum state: ’trade-offs’ in the modelling of the 2 fluxes



Model performance is dependent on Parameters used

- Often a trade off in model performance for the parameter values

Objective space of 100 samples: each point is an optimized model run

RMSE for Q* (W $m^{-2}$)

RMSE for $Q_H$ (W $m^{-2}$)

o Optimized samples

Best *single* objective run (for Q* and $Q_H$)

Loridan et al. (2010) QJRMS

# SLUCM sensitivity

KING'S College LONDON

(a)

| (a) | Parameter | Default | Optimum | Gain in Q* (ΔRMSE) | Impact on $Q_H$ (ΔRMSE) | Impact on $Q_E$ (ΔRMSE) |
|---|---|---|---|---|---|---|
| 1 | $\alpha_{roof}$ | 0.22 | 0.135 | -12.39 | 6.35 | 0 |
| 2 | $a_K$ | 1.29 | 0.529 | -7.60 | 6.17 | 0 |
| 3 | $\alpha_{wall}$ | 0.2 | 0.052 | -6.62 | 0.56 | 0 |
| 4 | $\alpha_{veg}$ | 0.23 | 0.102 | -6.36 | 1.17 | -0.74 |
| 5 | $W_{roof}$ | 21.2 | 11.2 | -3.54 | -2.89 | 0 |
| 6 | $W_{road}$ | 9.6 | 15.6 | -3.21 | -1.03 | 0 |
| 7 | $\varepsilon_{roof}$ | 0.9 | 0.851 | -2.81 | 0.20 | 0 |
| 8 | $f_{urb}$ | 0.864 | 0.764 | -1.66 | 0.64 | -3.73 |
| 9 | $\sigma_Z$ | 9 | 14.946 | -1.62 | 1.06 | 0 |
| 10 | $\varepsilon_{wall}$ | 0.9 | 0.98 | -1.07 | -0.09 | 0 |
| 11 | $k_{wall}$ | 0.55 | 2.299 | -0.97 | -2.22 | 0 |
| 12 | $\varepsilon_{veg}$ | 0.93 | 0.880 | -0.61 | 0.04 | -0.08 |
| 13 | $d_{z,wall}$ | 0.26 | 0.894 | -0.57 | 0.41 | 0 |
| 14 | $k_{roof}$ | 0.9 | 0.363 | -0.53 | 5.81 | 0 |
| 15 | $C_{roof}$ | 1769000 | 604674 | -0.39 | 2.91 | 0 |
| 16 | $\alpha_{road}$ | 0.08 | 0.05 | -0.37 | -0.01 | 0 |
| 17 | $\varepsilon_{road}$ | 0.94 | 0.98 | -0.30 | -0.03 | 0 |
| 18 | $C_{wall}$ | 1676000 | 2299510 | -0.29 | -0.83 | 0 |
| 19 | $d_{z,roof}$ | 0.32 | 0.496 | -0.26 | 1.69 | 0 |
| 20 | Z | 15.6 | 18.599 | -0.24 | -0.15 | 0 |

Rankings for Q* and $Q_H$ :
value change which leads to the best improvement from the default

| (b) | Parameter | Default | Optimum | Gain in $Q_H$ (ΔRMSE) | Impact on Q* (ΔRMSE) | Impact on $Q_E$ (ΔRMSE) |
|---|---|---|---|---|---|---|
| 1 | $k_{roof}$ | 0.9 | 1.495 | -3.38 | 0.78 | 0 |
| 2 | $d_{z,roof}$ | 0.32 | 0.16 | -2.93 | 0.49 | 0 |
| 3 | $W_{roof}$ | 21.2 | 11.2 | -2.89 | -3.54 | 0 |
| 4 | $k_{wall}$ | 0.55 | 2.3 | -2.22 | -0.96 | 0 |
| 5 | $a_K$ | 1.29 | 1.999 | -1.90 | 7.12 | 0 |
| 6 | $\sigma_Z$ | 9 | 3.168 | -1.80 | 7.55 | 0 |
| 7 | $d_{zfrac,roof}(2)$ | 0.468 | 0.228 | -1.62 | 0.17 | 0 |
| 8 | $d_{z,wall}$ | 0.26 | 0.1 | -1.53 | -0.18 | 0 |
| 9 | $R_{cmin}$ | 170 | 40.234 | -1.22 | 0 | -2.25 |
| 10 | $W_{road}$ | 9.6 | 15.6 | -1.03 | -3.21 | 0 |
| 11 | $C_{ZIL}$ | 0.1 | 0.999 | -0.91 | 0 | 0.70 |
| 12 | $C_{wall}$ | 1676000 | 2299910 | -0.84 | -0.29 | 0 |
| 13 | $\alpha_{roof}$ | 0.22 | 0.248 | -0.79 | 5.95 | 0 |
| 14 | $d_{zfrac,wall}(3)$ | 0.57 | 0.146 | -0.69 | -0.14 | 0 |
| 15 | $C_{roof}$ | 1769000 | 2283860 | -0.69 | 0.13 | 0 |
| 16 | $\alpha_{veg}$ | 0.23 | 0.298 | -0.47 | 3.70 | 0.47 |
| 17 | LAI | 3 | 4.995 | -0.46 | 0 | -0.76 |
| 18 | $d_{zfrac,road}(2)$ | 0.16 | 0.1 | -0.42 | -0.06 | 0 |
| 19 | $d_{zfrac,wall}(1)$ | 0.038 | 0.1 | -0.38 | -0.07 | 0 |
| 20 | $d_{z,road}$ | 1.24 | 0.663 | -0.29 | 0.23 | 0 |

Important to know which **parameters** the model is **most sensitive** to

For Policy applications: important to know the model can **respond** to the **appropriate changes** in parameter values

Loridan et al. (2010) QJRMS

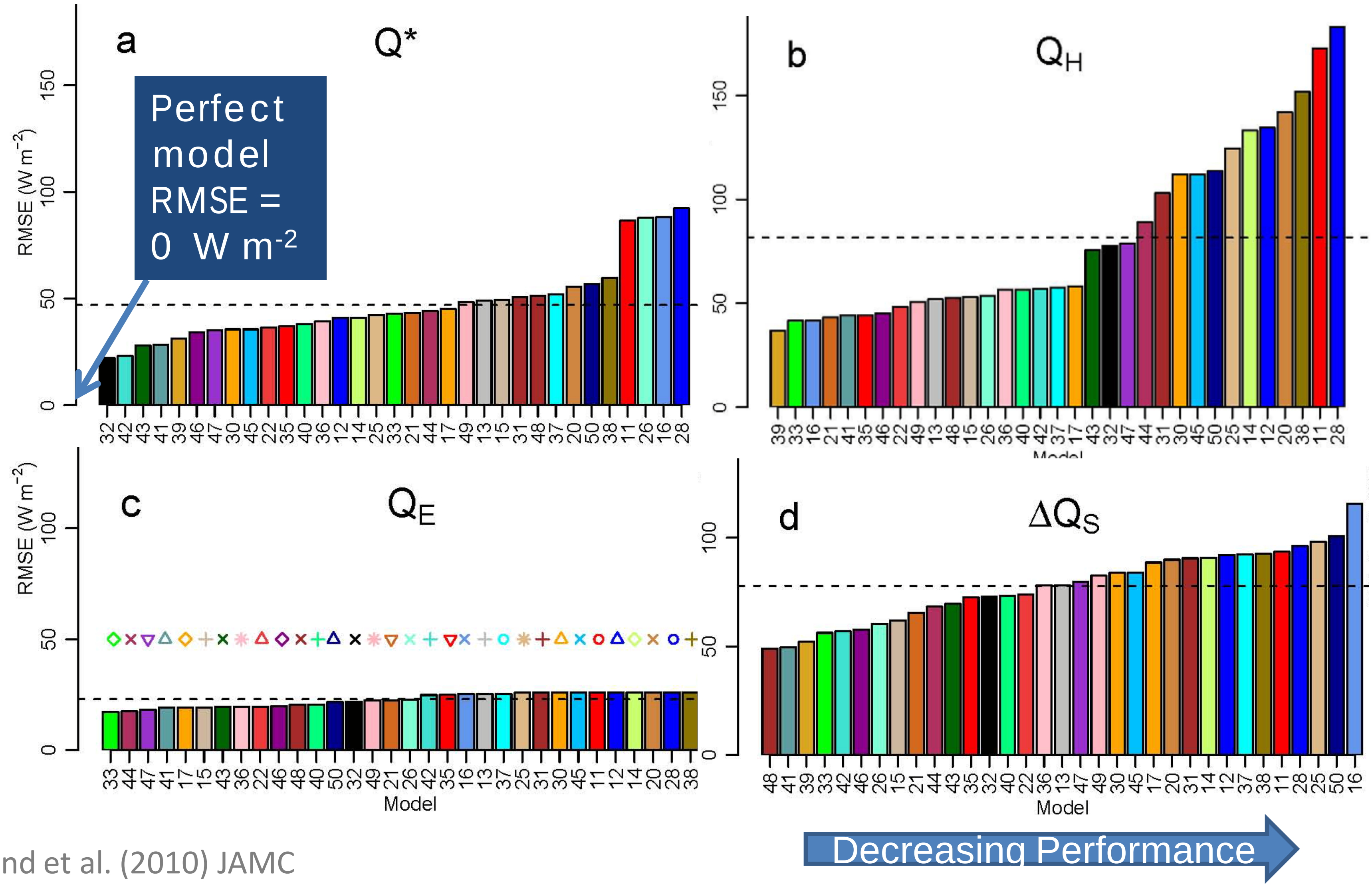
# Noah/SLUCM: Results with Marseille data

- Most sensitive to **roof-related parameters** (a dense European city centre)
  - implications for default values for urban land use
- For **Q***: *albedo* values most critical
- For $\mathbf{Q_H}$: mainly sensitive to *roof* (wall) *conductivities* & *thickness* of roof materials
  - Road characteristics: do not significantly impact model performance
    - higher degree of uncertainty acceptable

- **Difficult to correctly partition turbulent fluxes**: $Q_H$, $Q_E$
  - Vegetation class with a low stomatal resistance (e.g. "cropland / grassland mosaic" or "grassland") recommended
- Scheme appears **mostly sensitive to "objectively determined" parameters**:
  - almost impossible to derive all inputs for every single urban grid cell in a domain → need generic urban classes
  - choice of values to best characterise each class → trade-off

# Models need to be evaluated against observations

VL92: Ranked RMSE, All hours (N=312), Four Fluxes, 33 models

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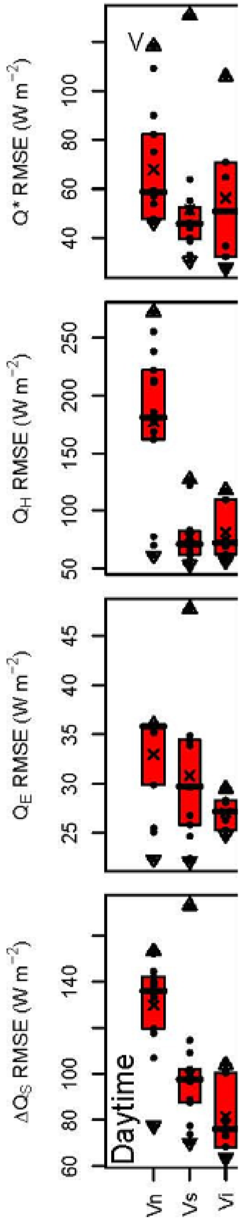
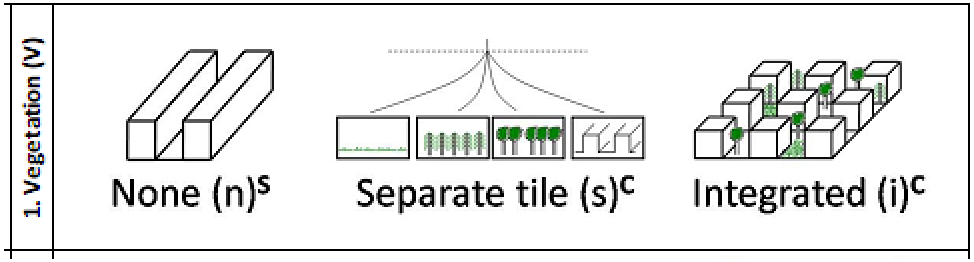
# Modelling Approach can be very important




VL92:

## Model Classes, Daytime RMSE

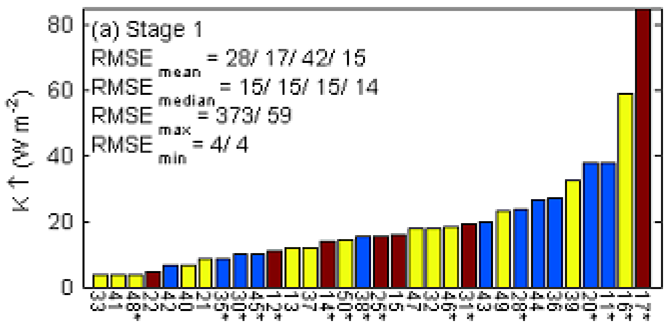



**Vegetation matters – for all fluxes**
**Even in an area with very little vegetation**

Grimmond et al. (2010) JAMC

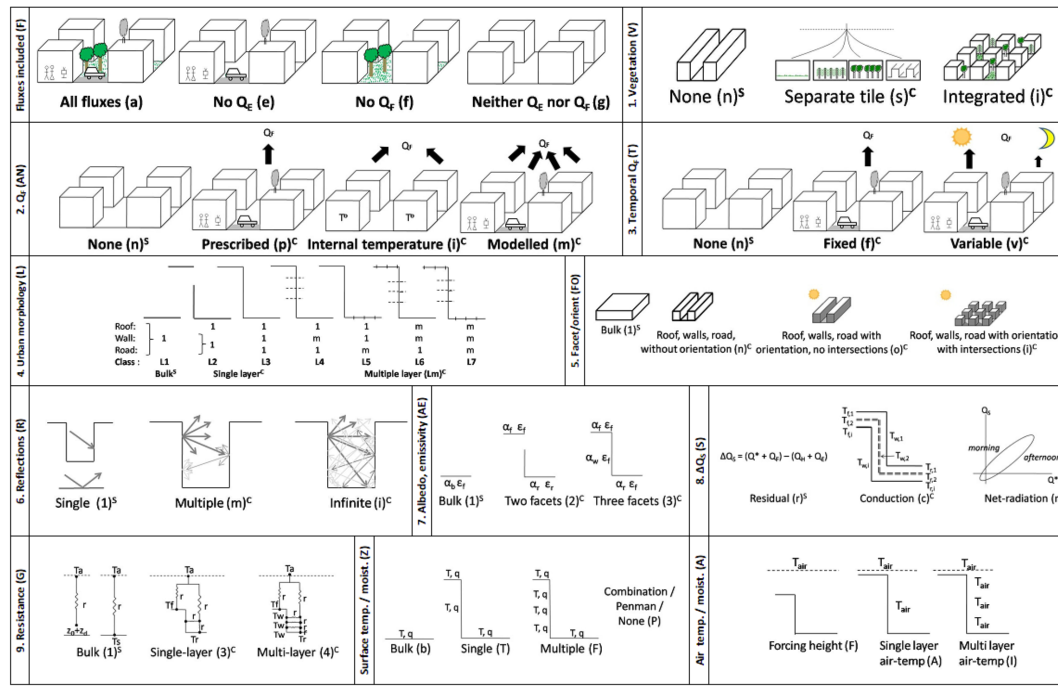
# Overall Models approaches can be classified

Alpha Stage 1, Outgoing Shortwave Radiation



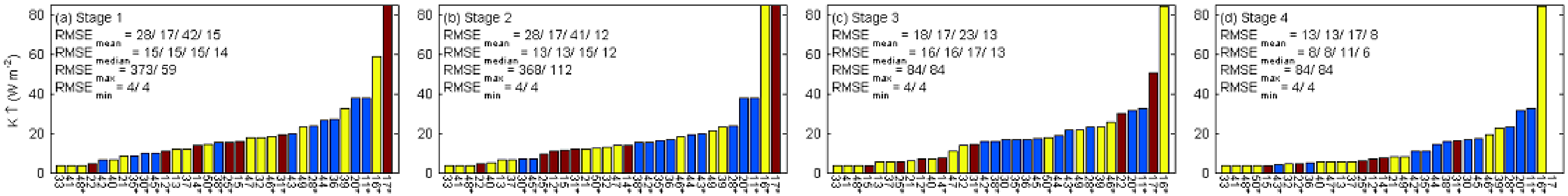

| | |
|---|---|
| Yellow | Simple ( 3 or more simple characteristics) |
| Blue | Medium (1-2 simple characterisitics |
| Crimson | Complex (all characterisitics complex) |

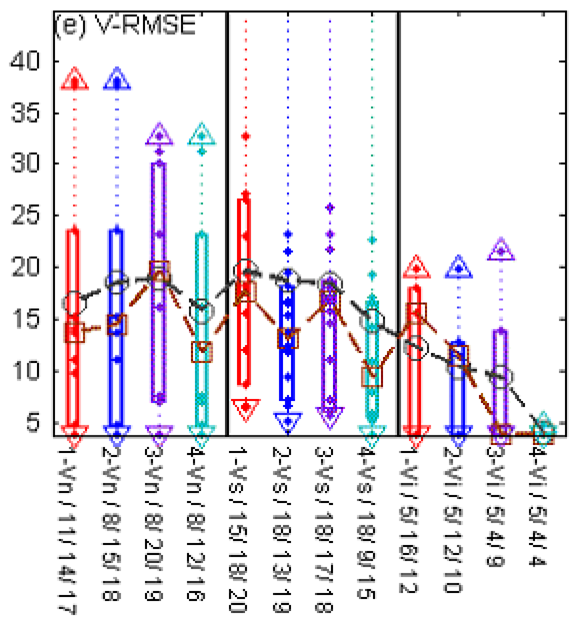
- Mean observed flux: 54.2 W $m^{-2}$
- *models without radiative closure
- N=32/N=31/ w.out closure/ w. closure




Grimmond et al. (2010) IJC in review

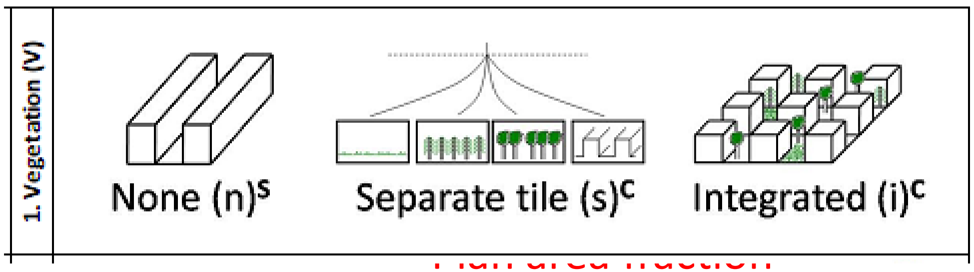
# Amount information that is known about the surface is important




| Yellow | Simple |
|---|---|
| Blue | Medium |
| Crimson | Complex |

## Alpha: Outgoing Shortwave Radiation




Other

- Cut off at 0.4 of maximum RMSE

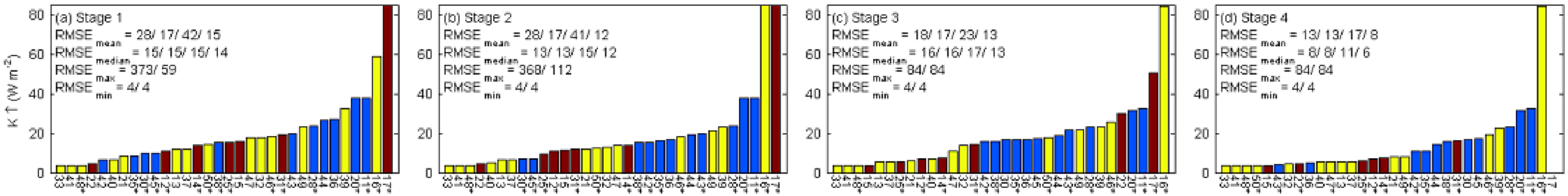
4 Material characteristics

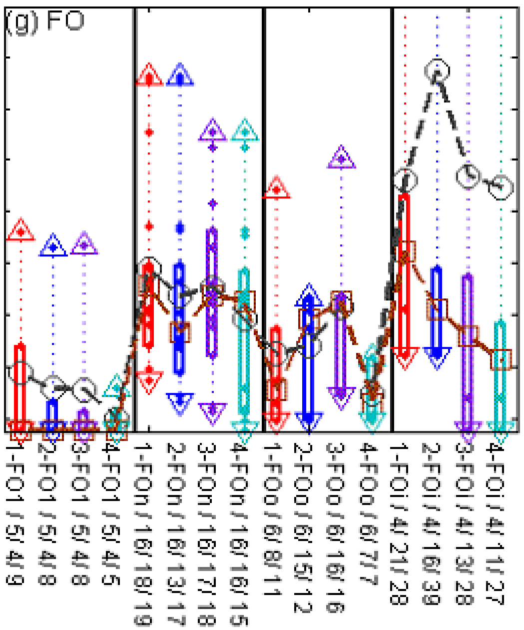
- Number of models
  - Median ⊡

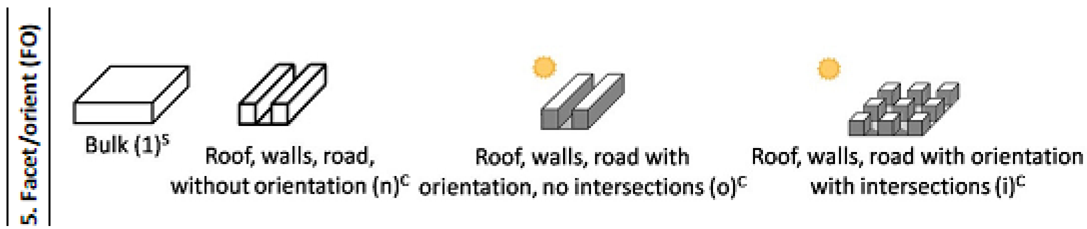
Increasing Information about the site

Grimmond et al. (2010) IJC in review

# Alpha: Outgoing Shortwave Radiation



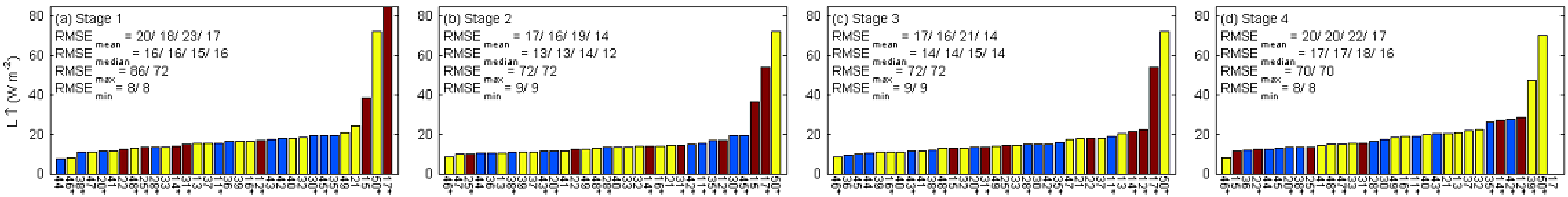

| | |
|---|---|
| Yellow | Simple |
| Blue | Medium |
| Crimson | Complex |

- Cut off at 0.4 of maximum RMSE
- Number of models
  - Median ⊡
    - Mean ⊙

Grimmond et al. (2010) IJC in review

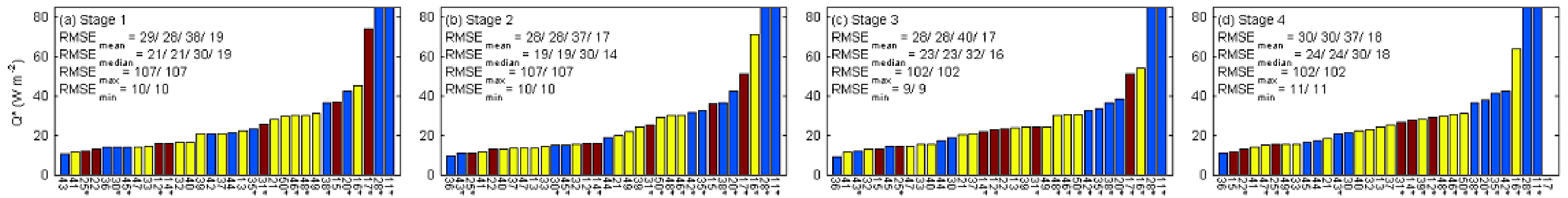
# Alpha: Outgoing Longwave Radiation

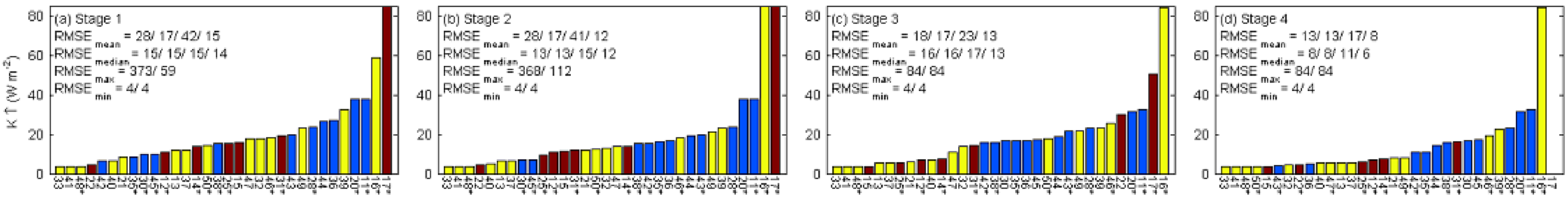
Mean Obs. Flux: 389.6 W $m^{-2}$ All hours 12 months




- Alpha: Net All Wave Radiation

Mean Obs. Flux: 78.9 W $m^{-2}$ All hours 12 months




| | |
|---|---|
| Yellow | Simple |
| Blue | Medium |
| Crimson | Complex |

Grimmond et al. (2010) IJC in review

# Alpha: Turbulent Sensible Heat Flux

Mean Obs. Flux: 37.9 W $m^{-2}$ All hours 12 months

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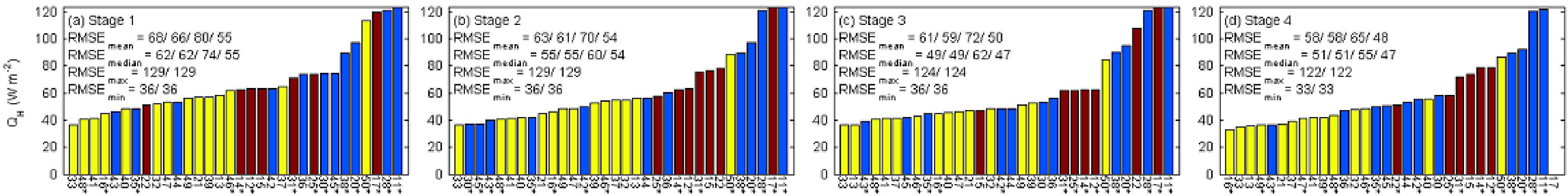
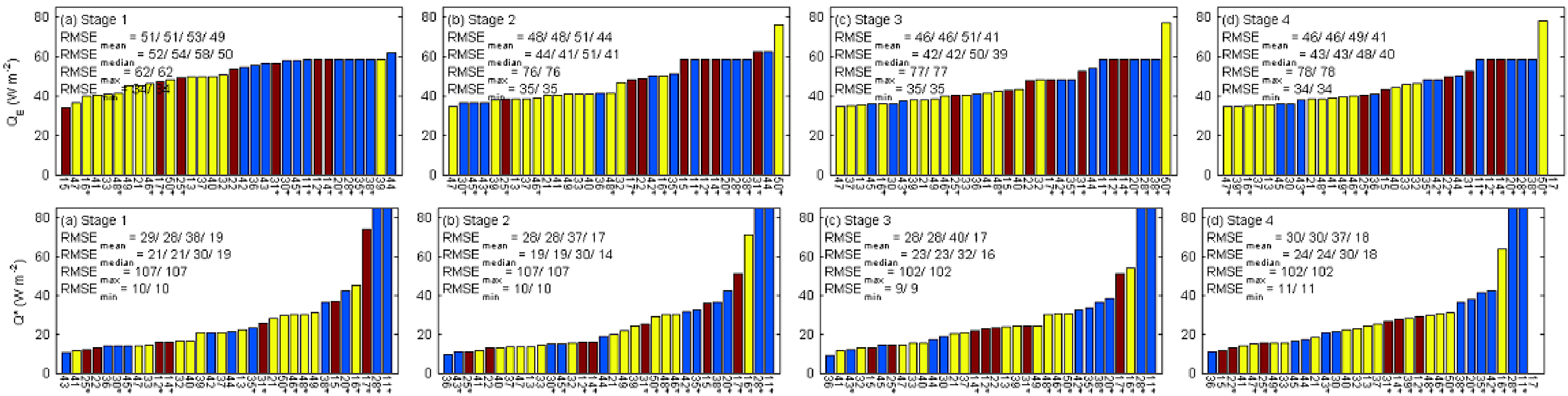



- Alpha: Turbulent Latent Heat Flux

Mean Obs. Flux: 32.5 W $m^{-2}$




| | |
|---|---|
| Yellow | Simple |
| Blue | Medium |
| Crimson | Complex |

Grimmond et al. (2010) IJC in review

# Can urban climate models inform policy and become more useful to decision-makers?

- Yes ... Wide range of models exist (a lot of development is occurring, more is needed)
- Things that need to be considered before use:
- Which is the appropriate model(s) to use for the application?
  - Are all the appropriate processes considered?
  - Does the model(s) perform well relative to observations?
    - For all variables? (If correct for some variables but not others – is it right for the wrong reason?)

- Models require a large number of parameters
  - Does the model respond appropriately?
  - What are the most important to be correctly specified?

- Are the model outputs measurable indicators that Policy makers can use/want?

- Essential to have observations over a wide range of conditions to evaluate models

# Final Comments

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- Significant efforts internationally to develop urban land surface schemes
  - Wide range of approaches taken
  - In general:
    - **Best** ability to model $K_{\uparrow}$ ($Q^*$)
    - **Poorest**: $Q_E$ (even in areas with very low $Q_E$)
    - **Trade off** between flux performance
  - No model clearly performs best/worst
- Model comparison: Developments in a number of the participating models

- Recent past: large number of observations of energy balance fluxes in a variety of urban areas around the world
  - Still wide range of urban areas not represented
  - Few continuous measurements
  - Observational results show wide range of energy flux partitioning (& $CO_2$ fluxes)
  - Need more data to understand the broad range of urban morphologies and land cover variations