Evaluation of building energy use: from the urban to the building scale

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• Introduction

• Objectives

• Methodology

• Results

• Conclusions and future works
Buildings and energy use

Energy consumption by sectors

- Residential: 34%
- Transport: 27%
- Industries: 21%
- Other sectors: 3%

World (IEA, 2012)

- Residential: 27%
- Transport: 28%
- Industries: 11%
- Other sectors: 34%

France (ADEME, 2013)

Energy use inside buildings

- Heating/Air conditioning: 68%
- Sanitary hot water: 10%
- Cooking: 6%
- Specific electricity (light, ...): 16%

France (ADEME, 2013)
Meso-scale models

Rugosity
Influence of obstacles
- Additional term in equations

Buildings / Streets
Solar radiation

WRF (Skamarock et al., 2008)
Meso-NH (Lafore et al., 1997)
FVM (Clappier et al., 1996)

BEP (Martilli et al., 2002)
UCM (Kusaka et al, 2001)
TEB (Masson, 2000)

BEM (Krpo et al., 2010)
(Kikegawa et al. 2003)
Walls, roofs & streets
Window
Cooling/ Heating

Courtesy of N. Blond
Meso-scale – coupling with BEP-BEM

\[ \Delta z_{\text{meso}} \]

WRF model

\[ U_M, \theta_M, Q_M \]

\[ \Delta z_{\text{BEP}} \]

\[ f_u, f_\theta, f_q \]

Momentum loss
Heat fluxes

Courtesy of N. Blond
### Governing Equations

**MOMENTUM**

\[
\frac{\partial U}{\partial t} = \frac{\partial}{\partial z} \left( \mu_t \frac{\partial U}{\partial z} \right) + f_u^s
\]

**HEAT**

\[
\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left( \kappa_t \frac{\partial \theta}{\partial z} \right) + f_g^s
\]

**Diffusion**

\[
\mu_t = C_{\mu} \sqrt{E_l}
\]

**Fluxes**

\[
\frac{\partial E}{\partial t} = \frac{\partial}{\partial z} \left( \lambda_t \frac{\partial E}{\partial z} \right) + P \left( 1 - C_G R_i_f \right) - \mathcal{E} + f_e^s
\]

- ‘M’ – meso-scale value
- ‘c’ – canopy value
- ‘I’ – variable at centre
- ‘U’ – wind speed (ms\(^{-1}\))

- Fluxes
- Diffusion

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\[P = \frac{C_{\mu} \sqrt{E_l}}{Pr}\]
Validation of CIM

Potential temperature (K) at 2m
Validation of CIM – Wind speed

Mauree et al., 2015
Coupling with citysim

Canopy Interface Model

Occ. Vol. & Surf., height

Meteonorm data
Model data …

$U_u$, $\theta_u$, $q_u$

$F_u$, $F_\theta$, $F_q$

Momentum loss
Heat fluxes

Convection coefficient /
Wind speed &
Air temperature

Average geometrical characteristics of buildings

Init.
Calculation of $h_c$

McAdams coefficient

$$h_c = 2.8 + 3U$$

Mirsadeghi et al. 2013

$U$ – wind calculated w.r.t. to attack angle

Then calculate a «pseudo» $h^*_c$ for CitySim that accounts for a more precise wind profile

$$h^*_c = \frac{h_c(\theta_i - \theta_S)}{\theta_n - \theta_S}$$
Experiment

Simulation using a nested domain over Lausanne

Resolution: 45km – 15km – 3km – 1km
Duration: 14 days December 2010
C.f. WRF-CIM and Meteonorm

Temperature (°C)

Wind speed (ms⁻¹)
Energy consumption

- Significant difference in evaluation of energy use

<table>
<thead>
<tr>
<th></th>
<th>Energy consumption (kWh/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meteonorm</td>
<td>19</td>
</tr>
<tr>
<td>WRF+CIM</td>
<td>25</td>
</tr>
<tr>
<td>Difference (%)</td>
<td>30</td>
</tr>
</tbody>
</table>
Conclusions

• Proper evaluation of energy use needed to define more precise development / planning scenarios

• Enhance capability of existing tools to give enhance estimation at the neighborhood scale

• Evaluation of building energy use with real meteorological data could help understand processes regulating the energy consumption from the building to urban scale
Future work

- Two-way coupling with feedback to meso-scale model
- Full year analysis of energy consumption
- Increase from one building to whole neighbourhood
  - Implementation of methodology to account for varying building height
- Evaluate the possibility of Renewable Energy integration in urban areas
Thank you!

Questions?

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Climate change

Carbon dioxide concentration at Mauna Loa Observatory from 1960 to 2011

Evolution of the world energy production (IEA, 2010)
Urbanization

World urban and rural population evolution

Urban energy use:
70% of world energy consumption
INTERACTIONS AT DIFFERENT SCALES

GLOBAL
Seasonal variations

MESO
Topography, Land uses
Urban-Rural Interaction

NEIGHBORHOOD
Obstacle effects
Urban canopy – atmosphere interaction

BUILDING
Building energy use

Domain size
+1000KM | +100KM | 1KM | 10M
Meso-scale – coupling with CIM

WRF model

Canopy Interface Model

Δz
meso

Δz
CIM

Δz
BEP

Δz
CIM

U_M

θ_M

Q_M

U_u

θ_u

q_u

F_u, F_θ, F_q

Momentum loss
Heat fluxes

Diffusion process

Courtesy of N. Blond
Coupling with CitySim
COUPLING WITH CITYSIM – WIND ON TOP

Wind speed (ms⁻¹)

Time (h)

Data
CIM from LEO
Coupling with Citysim – Wind / PT AT 2M

Data

CIM from LESO