PARTICULATE EMISSIONS FROM RESIDENTIAL WOOD COMBUSTION: IMPROVING ESTIMATIONS IN DENMARK AND PORTUGAL

INTERNATIONAL CONFERENCE ON CARBONACEOUS PARTICLES
BERKELEY, USA

Ricardo L. Carvalho, Ole M. Jensen, Luís A. Tarelho, Helge R. Olesen
Danish Building Research Institute, Aalborg University, Denmark
Centre for Environmental and Marine Studies, Aveiro University, Portugal
Danish Centre for Environment and Energy, Aarhus University, Denmark

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA
How to improve PM emission estimations from RWC in Europe?

Over 240 million people is relying on heating fireplaces and inefficient WBSs and boilers in the cold season.

Global health risk

- Household heating is a major cause of premature deaths in Europe, North America and China.
- *Fireplaces and wood-burning stoves* (WBSs) in more than 20% of the European households.
- Secondary heating systems in areas with developed district heating grids.
HOUSEHOLD HEATING AND PM EMISSIONS IN WESTERN EUROPE
(two case studies and new methods in the EU28)

Heating typical
a single family house
with NG
Costs 10% more
In 2015 than in 2008
(ERSE, 2015)

Primary energy supply for heat
(high wattage and natural vent.)

Portugal
10,4 Mo (40% rural)
92,212 km²

Low fuel loads
& high tightness

Well developed heating grid
So, part of culture...
20-50% of wood heat

Secondary energy for cozyness
(low wattage and mechanical vent.)

Denmark
5,6 Mo (12% rural) = 42,916 km²

43% of people (<10% rural)
32% of area
(of California)

High fuel loads
& low tightness

Local resilience...
Up to 100% of wood heat

1.5 Mo units

RWC units per dwelling

750,000 units

42%

25%

43% of people
(=10% rural)

32% of area
(of California)
OLD TRADITIONAL WBSs

Fireplace in Europe
Open fire, 2014

Closed stove in Spain
Carvalho, 2015
NEW & NEW MODERN WBS

Wood stove (NEW, before 2008) in Portugal
Carvalho, 2014

Swan labelled stove (NEW MODERN, after 2008) in Denmark
Carvalho, 2014
Residential wood boiler in Denmark
Perthshire biofuels, 2015

Wood cooking boiler in Portugal
Lareiras Pacinha, 2015
RWC in Denmark/Nordic region

~1.6Mo users per ~3.0Mo dwellings

27%

73%

~770,850 installations
21.920 TJ

T1: Lab to field studies, 2014

Old closed
New closed
Modern
Boilers and cookers


RWC in Portugal/Mediterran region

~3.6 Mo users
Over ~3.4 Mo dwellings

~1.2 Mo installations
35.342 TJ +60% than DK!

## AVAILABLE EMISSION INVENTORIES AND GAPS
### (PHONE SURVEYS)

\[ E_{PM} = \sum_{i=0}^{n} W_c \cdot EFs \]

### Denmark
- Survey (2015) for ONLY 2133 people and 4 types of stoves…
- Average Efs on condensed particles with a controlled pressure chimney draft (Norwegian method)
- Spatial distribution from housing registration system (BBR)

### Portugal
- Survey (2012) for ONLY 2400 people and 2 types of systems…
- Standard Efs on condensed particles but with uncontrolled pressure chimney draft (prEN4711)
- Spatial distribution from one single study [1]

---


EPM = \sum_{i=0}^{n} Wci \cdot EFsi

DANISH VS. PORTUGUESE PM2.5 EMISSION FACTORS?
(FIREPLACES, WOOD-LOG AND PELLET STOVES)


MAIN GAPS ON OFFICIAL EMISSION FACTORS?

\[ E_{PM} = \sum_{i=0}^{n} Wc \cdot EFs \]

- Wet wood used in real-life NOT CONSIDERED...
- Typical fuel loads vary from mean values...

Denmark

- Approaches to mainstream emissions, not representing:
  - Uncontrolled stove venting and household ventilation (underpressure in real world)?

Portugal

- Lab tests under ideal conditions do not represent situations where:
  - Uncontrolled stove venting and household ventilation (under or over pressure in real world)?


RECALCULATIONS OF ANNUAL PM2.5 EMISSIONS?

\[ E_{PM} = \sum_{i=0}^{n} W_C \cdot EFs \]

<table>
<thead>
<tr>
<th>PM2.5 emissions</th>
<th>kton PM2.5 year-1</th>
<th>kg PM2.5 per capita</th>
<th>kton PM2.5 year-1</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Countries</td>
<td>RWC</td>
<td>RWC</td>
<td>All sources</td>
<td>%</td>
</tr>
<tr>
<td>Denmark</td>
<td>17,3?</td>
<td>3,1?</td>
<td>28,3</td>
<td>61%?</td>
</tr>
<tr>
<td>Portugal</td>
<td>11,0?</td>
<td>1,1</td>
<td>36,3</td>
<td>30%?</td>
</tr>
</tbody>
</table>

Underestimated emissions for Portuguese fireplaces?
Overestimated emissions for new Danish stoves?


SPATIAL DISTRIBUTION OF PM2.5 EMISSIONS PER CASE

\[ E_{PM} = \sum_{i=0}^{n} W_c \cdot EFs \]

T1: Lab to field studies, 2014

T2: Field to lab. studies, 2015


T1a. A PIONEER LAB-TO-FIELD TEST ON EFs IN DANISH DWELLINGS
(by Glausius et al., DCE, Aarhus University, 2005)

(real-life measurements in 13 houses in Denmark)


Users behaviours can be the main reason of variations on the PM2.5 Efs!
WOODUSE: Slagslunde: 400 houses, 201 with wood stoves or boilers

**T1b**: TEOM measured [PM$_{2.5}$] increment due to wood combustion during the 6-weeks period


**TEOM** (tapered element oscillating microbalance) is a continuous measurement method of atmospheric particles
**T1: WOODUSE** computated increment due to wood combustion for an average for 6-week period

Average at the monitor:
- Measured: 1.97 µg/m³
- Modelled (OML): 4.2 µg/m³

\[
\text{correction factor} = \frac{\text{measured} \, \text{av}}{\text{modelled} \, \text{av}} = \frac{1.97 \, \text{av}}{4.2 \, \text{av}} = 0.47
\]


OML is an atmospheric dispersion model
**T1b WOODUSE: LAB-TO-FIELD AIR QUALITY STUDY IN A DANISH VILLAGE**

*(DCE, , Aarhus University, 2007/12)*

\[ \text{corr. av. } EF = 0.47 \cdot 935 \sim 440 \text{ gPM/GJ} \]

Dilution tunnel and dust-track  
Testing convection installation

For the dry softwood Pinus Pinaster (wood type on RWC in Portugal):

- Variations on fuel load may increase particulate emissions by more than 3 times comparing to official emission factors used in previous inventories "5.2±4.3 g/kgF"
- These variations might be even larger if we consider a common bottom ignition during lightning!

For the dry hardwood Fagus Sylvatica (typical fuel in Spain):

- Such operating practices did not change significantly…

**IAQ TEST:** indoor [PM$_{2.5}$] during one week in the Autumn when testing a wood stove (*CESAM, Aveiro University, 2014*).

Indoor particules increase due to underpressure:

- Transport of particules from outdoors to indoors
- Indoor emissions when lightning (insufficient draft)...

Conclusions and recommendations

• The current estimations are rather uncertain due to:
  • Few available surveys with few respondents...
  • Little knowledge of representative Efs...
  • Limited knowledge on the spatial distribution...

• Improve activity data in conjunction with national chimney sweepers associations
• New testing methods and studies to determine real emissions, especially for old types of appliances (larger uncertainties) by:
  Bringing the lab to field (quite expensive…)  
  Bringing the field to lab (economic, deep investigation on burning practices)
  Modelling real-life household savings and mitigation effects
PARTICULATE EMISSIONS FROM RESIDENTIAL WOOD COMBUSTION: IMPROVING ESTIMATIONS IN DENMARK AND PORTUGAL

INTERNATIONAL CONFERENCE ON CARBONACEOUS PARTICLES
BERKELEY, USA

Ricardo L. Carvalho, Ole M. Jensen, Luís A. Tarelho, Helge R. Olesen
Danish Building Research Institute, Aalborg University, Denmark
Centre for Environmental and Marine Studies, Aveiro University, Portugal
Danish Centre for Environment and Energy, Aarhus University, Denmark
WBS use in Denmark and Portugal

Denmark

21.920 TJ

- Old closed: 31%
- New closed: 42%
- Modern: 27%

Portugal

35.342 TJ

- Fireplace: 53%
- Old closed: 24%
- New closed: 23%

References:


### SURVEYS (2012/13): REAL WOOD CONSUMPTION AND TRANSITIONS (T)?

\[
E_{PM} = \sum_{i=0}^{n} W_{ci} \cdot EF_{si}
\]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Countries</td>
<td>All</td>
<td>All</td>
<td>All</td>
<td>All</td>
<td>All</td>
<td>Users</td>
<td>Fireplace</td>
<td>Old closed</td>
<td>New closed</td>
<td>Modern</td>
<td>All</td>
</tr>
<tr>
<td><strong>Denmark 2013</strong></td>
<td>Number (Mo)</td>
<td>2.133 x10^3</td>
<td>(3,0/10,4) x10^6</td>
<td>0,8 x10^6</td>
<td>27%</td>
<td>1,5 x10^6</td>
<td>-</td>
<td>202.500</td>
<td>315.000</td>
<td>232.500</td>
<td>750.000</td>
</tr>
<tr>
<td><strong>Portugal 2012</strong></td>
<td>Number (Mo)</td>
<td>2.387</td>
<td>(3,4/5,6) x10^6</td>
<td>1.5 x10^6</td>
<td>34%</td>
<td>3,6 x10^6</td>
<td>645.818</td>
<td>282.903</td>
<td>294.333</td>
<td>-</td>
<td>1.161.221</td>
</tr>
</tbody>
</table>


T1: Lab to field studies, 2014

T2: field to lab studies, 2015