DEVELOPMENT & BENCHMARKING OF WHOLE BUILDING HYGROTHERMAL MODEL

F. Tariku, K. Kumaran & P. Fazio

April 12th, 2010
OUTLINE

- Background
- Objective
- Development of Whole-Building Hygrothermal model (HAMFitPlus)
- Benchmarking
- Conclusion
FUNCTION OF A BUILDING

- Isolated space
- Indoor environment
ASSESSMENT TOOLS

- Performance of building envelope components
- Indoor humidity conditions
- Energy efficiency
DURABILITY ASSESSMENT

- LWR
- Sheathing Board
- Sheathing membrane
- Air space
- Cladding
- Dry wall
- Vapor Barrier
- Insulation

Outdoor
T
RH
Wind

Indoor
T
RH
DURABILITY MODEL

- Indoor boundary condition
  - Constant or seasonal variable
  - Variable: heat and mass balance in the room
INDOOR HUMIDITY ASSESEMENT

- Indoor humidity
  - Moisture generation
  - Ventilation

- Limitations:
  - Moisture buffering effects
    - 1/3 moisture absorption (El Diasty et al. 1993)
  - Construction moisture source (Christian 1994)
ENERGY PERFORMANCE ASSESSMENT

- Indoor Temperature & Energy demand

- Limitations: Moisture effect in energy calculation

- Construction
  - Thermal properties (ASHRAE 2005, Mendes et al. 2003)
  - Phase change

- Indoor
  - Latent heat load (Isetti et al. 1988)
OBJECTIVE

- Develop a model to alleviate the shortcomings of the stand-alone models

- Assess building performance in an integrated manner
  - Durability of building envelope
  - Indoor air condition and comfort
  - Energy efficiency
WHOLE BUILDING HYGROTHERMAL MODEL
APPROACH

- Develop
- Validate
- Integrate
- Validate

Climate
- Temperature
- Relative humidity
- Wind
- Solar radiation
- Precipitation
- Cloud cover

Material Properties
- Density
- Sorption isotherm
- Vapor permeability
- Liquid diffusivity
- Thermal conductivity
- Heat capacity
- Air permeability

Building Envelope Model
- Mass Energy Momentum Balance

Indoor Model
- Mass Energy Balance

HVAC system
- Heating
- Cooling
- Ventilation
- Humidification
- Dehumidification

Heat and Moisture gains
- Human Activities
  - Solar gain
  - Evaporation
  - Condensation
  - Moisture buffering

Climate
- Relative humidity
- Wind
- Solar radiation
- Precipitation
- Temperature

Background
Objective
WBHGM
Development
Benchmarking
Conclusion

11
Moisture Balance:

$$\Theta \frac{\partial \phi}{\partial t} = \text{div} \left( D_\phi \text{div} \phi + D_T \text{div} T \right) - \text{div} \rho_a V C_c \tilde{P} \phi$$

Energy Balance

$$\rho_m C_{p_{eff}} \frac{\partial T}{\partial t} + \rho_a V C_{p_a} + \omega C_{p_v} \text{div} T + \text{div} -\lambda_{eff} \nabla T = \dot{Q}_p$$

Darcy equation:

$$-\text{div} \delta_a \text{div} P = 0$$
INDOOR MODEL

- **Humidity balance:**

\[ \rho_a \tilde{V} \frac{d \omega}{dt} = \dot{Q}_b^m + \dot{Q}_v^m + \dot{Q}_m^m + \dot{Q}_e^m + \dot{Q}_c^m + \dot{Q}_o^m \]

- **Energy balance:**

\[ \rho_a \tilde{V} \frac{d h}{dt} = \dot{Q}_b^h + \dot{Q}_v^h + \dot{Q}_m^h + \dot{Q}_e^h + \dot{Q}_f^h + \dot{Q}_o^h \]
WBHG MODEL (HAMFitPlus)

- **Zone Enclosure**
- **Windows**
- **Internal Heat & Moisture source/sink--Lumped system**
- **Internal Heat & Moisture source/sink--Bulk system**

**Mechanical Systems & Heat and Moisture Gains**

- 8 inputs
- 24 inputs
- 2 inputs
- 2 inputs
- num of Furn x 2 inputs
- 36 plus inputs

**INDOOR AIR MODEL**

- 1/z

**Background**

**Objective**

**WBHGM Development**

**Model**

**BuildingEnv. Model**

**Indoor Model**

**WBHG Model**

**Benchmarking**

**Conclusion**
HVAC & HEAT and MOISTURE GAINS
HAMFitPlus OUTPUTS

- Building envelope
  - Moisture content
  - Temperature
- Indoor environment
  - Indoor air temperature
  - Indoor air relative humidity
- Energy
  - Heating, cooling and latent loads
  - Heat loss: Ventilation, construction
IEA/ANNEX 41 (2008)  
TEST CASE (CMEX 1)

- Density (kg/m$^3$): 650  
- Conductivity (W/mK): 0.18  
- Heat Capacity (J/kgK): 840  
- Water vapour permeability (kg/m.s.Pa): Function of RH  
- Sorption curve (kg/m$^3$): Function of RH

U = 3.0 W/(K.m$^2$)

150 mm Aerated concrete
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volume</strong></td>
<td>129.6 m³</td>
</tr>
<tr>
<td><strong>Ventilation rate</strong></td>
<td>0.5 ACH</td>
</tr>
<tr>
<td><strong>Heating/Cooling System</strong></td>
<td>100%</td>
</tr>
<tr>
<td>(Infinite capacity)</td>
<td>Convection</td>
</tr>
<tr>
<td><strong>Indoor temperature</strong></td>
<td>20-27°C</td>
</tr>
<tr>
<td>(Thermostat Controlled)</td>
<td></td>
</tr>
<tr>
<td><strong>External boundary condition</strong></td>
<td>Copenhagen Weather</td>
</tr>
<tr>
<td><strong>Solar and long wave radiation</strong></td>
<td>Considered</td>
</tr>
<tr>
<td><strong>Initial condition: Cons. &amp; Indoor air</strong></td>
<td>20°C &amp; 80 %</td>
</tr>
</tbody>
</table>
RESULTS

INDOOR CONDITIONS
(July 5th)

Indoor Temperature

Indoor Relative humidity
RESULTS (Cont’d)

BUILDING ENVELOPE (July 5th)

Roof surface Temperature

Roof surface Relative humidity

All other models

HAMFitPlus

BM #1

BM #2

Conclusion

Background

Objective

WBHGM Development

Benchmarking
RESULTS (Cont’d)

ENERGY DEMAND
(July 5th)

Heating load
<table>
<thead>
<tr>
<th>Hours</th>
<th>Heating load (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>6</td>
<td>0.20</td>
</tr>
<tr>
<td>12</td>
<td>0.40</td>
</tr>
<tr>
<td>18</td>
<td>0.60</td>
</tr>
<tr>
<td>24</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Cooling load
<table>
<thead>
<tr>
<th>Hours</th>
<th>Cooling load (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-8.00</td>
</tr>
<tr>
<td>6</td>
<td>-7.00</td>
</tr>
<tr>
<td>12</td>
<td>-6.00</td>
</tr>
<tr>
<td>18</td>
<td>-5.00</td>
</tr>
<tr>
<td>24</td>
<td>-4.00</td>
</tr>
</tbody>
</table>
Field experiment (Holm and Lengsfeld, 2007)

Two rooms with identical geometry, orientation, BC
- Volume: 48.49 m³
- Floor area: 19.34 m²
- Indoor temperature: 20±0.2°C
- Reference and Test rooms

Differences
- Interior layer
  - Reference room—latex paint (walls & ceiling)
  - Test room—unpainted gypsum walls & alum. foil ceiling
- Ventilation
  - Reference room—0.63 ACH
  - Test room—0.68 ACH
MOISTURE GAIN (2.4 kg/day)

- Diurnal moisture production rate (g/hr)
- Hours of a day
BENCHMARKING #2
RESULTS

Reference Room
Indoor Relative Humidity

Test Room
Indoor Relative Humidity

Reference Room
Indoor Relative Humidity on Feb 17th

Test Room
Indoor Relative Humidity on Feb 17th
CONCLUSIONS

- HAMFitPlus model are developed & benchmarked
- Indoor boundary conditions for durability assessment
- Moisture buffering effects in indoor humidity predictions
- Effect of moisture in energy demand calculation, and equipment size
- Optimized building performance by integrated analysis of durability, indoor air and energy consumption
THANK YOU
FOR
YOUR ATTENTION!