Detailed simulation of the indoor environment as a tool to design ventilation systems in low energy houses

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Introduction

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Policies to reduce building energy consumption

More insulation

\+

More air tightness

=

Possible indoor environment issues

Example

IAQ problems were found in 8 newly built homes in Northern Ireland due to inadequate ventilation (McGill et al. 2015).

Methodology

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Scenarios

Ventilation strategy

+

Occupants' behaviour

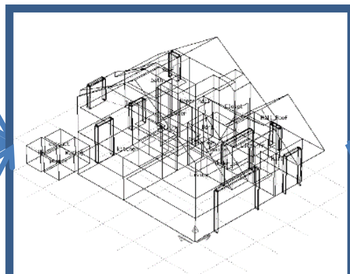
+

Pollutant sources

Measured data

Check

Model



Case Study: 2-bedroom Passivhaus located in Dormont, Lockerbie (Scotland)

Results

CO_2 Concentration

Other pollutants (formaldehyde, PM, NO2)

Temperature

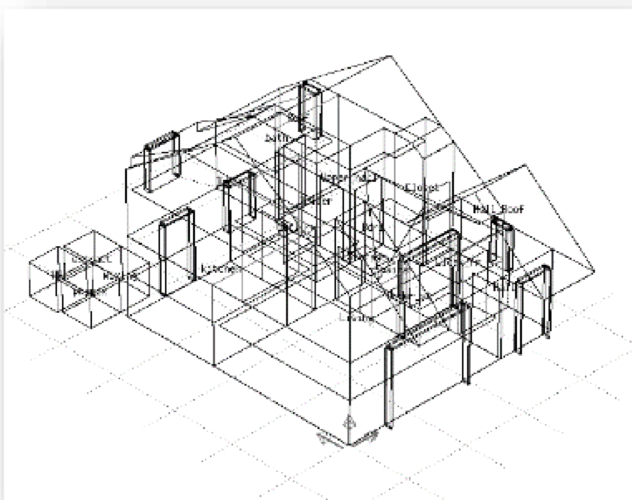
Relative Humidity

Deliverables

Recommendations

Modelling - Tools

Case Study: 2-bedroom Passivhaus located in Dormont, Lockerbie (Scotland)



ESP-r Model

ESP-r

- ✓ Detailed **thermal** simulation tool and ability to model several pollutants
- ✗ Emission models are limited

Modelling

Formaldehyde emission model

University of Strathclyde Glasgow

The numerical model developed by **Huang and Haghighat (2002)** was implemented in ESP-r

- **Emission rate**, R(t) ($\mu g/m^2 s$):

$$R(t) = h\left(\frac{C_m(b,t)}{k} - C_a(t)\right)$$

Material/air partition coefficient:
$$\boldsymbol{k = f(T)}$$
(Zhang et al. 2007)

- **Concentration at the material surface**, C_m (b,t) ($\mu g/m^3$):

$$\left(\frac{D_m}{\delta y} + \frac{\Delta y}{\Delta t} + \frac{h}{k} - \frac{Lh^2\Delta t}{k(N\Delta t + Lh\Delta t + 1)}\right)C_m(b,t)$$
$$= \frac{D_m}{\delta y}C_m(b-\delta,t) + \frac{\Delta y}{\Delta t}C_m(b,t-\Delta t) + \frac{h}{(N\Delta t + Lh\Delta t + 1)}C_a(t-\Delta t)$$

Initial emittable concentration:
$$\boldsymbol{C_0 = f(T, RH)}$$
(Liang et al. 2016)

Diffusion coefficient of the material:
$$\boldsymbol{D_m = f(T)}$$
(Deng et al. 2009)

Modelling

PM deposition and resuspension model

The model used by CONTAM was implemented in ESP r:

$$R_{PM}(t) = k_d V_z \rho_{air} C_{PM}(t)$$

$$S_{PM}(t) = r A_r L_{PM}(t)$$

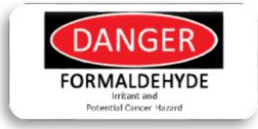
where $R_{PM}(t)$ is the removal rate (kg_{PM}/s), k_d is the deposition rate (s^{-1}), V_z is the zone volume (m^3), ρ_{air} is the density of the air (kg/m^3), $C_{PM}(t)$ is the PM concentration (kg_{PM}/kg_{air}), S_{PM} is the resuspension rate (kg_{PM}/m^2), r is the resuspension rate (s^{-1}), Ar is the resuspension surface area (m^2), $L_{PM}(t)$ is the concentration of PM on the deposition surface (kg_{PM}/m^2) and t is time.

Modelling

Questions Analysed

- **Question 1** - Does an MVHR system without summer bypass lead to overheating periods? How does its impact on indoor temperature compare with a MVHR system with summer bypass?

- **Question 2** - What is the impact of a failure of the MVHR system? What are the peak concentrations of pollutants that could arise? How long after the fault is the acceptable IAQ threshold surpassed? Could window opening solve the IAQ issue?



- **Question 3** - What is the impact on IAQ of a kitchen hood? What is the energy penalty of the unbalanced ventilation system?

- **Question 4** - Do trickle vents with Mechanical Extract Ventilation (MEV) supply enough ventilation for good IAQ? How does its performance compare with a MVHR system?

- **Question 5** - How does a constant ventilation rate compare with the use of different types of ventilation control?

Modelling

Scenarios

Question 5

How does a constant ventilation rate compare with the use of different types of ventilation control?

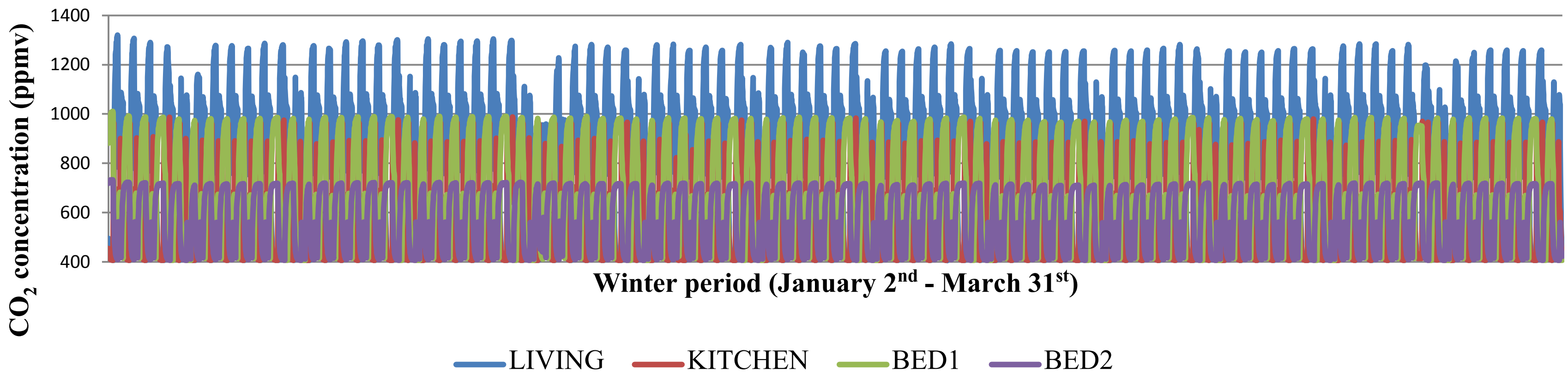
- **Scenario 5A** – MVHR with constant ventilation rate
- **Scenario 5B** - MVHR with boost control based on RH
- **Scenario 5C** - MVHR with boost control based on CO_2
- **Scenario 5D** - MVHR with boost control based on RH and indoor temperature
- **Scenario 5E** - MVHR with boost control based on CO_2 and indoor temperature
- **Scenario 5F** - MVHR with boost control based on RH and window opening based on adaptive thermal comfort
- **Scenario 5G** - MVHR with boost control based on CO_2 and window opening based on adaptive thermal comfort

- All the scenarios were defined for two different situations; one assuming internal doors are open and another one assuming internal doors remain shut.
- Two different emission scenarios were considered for PM and NO_2 sources: a low emission rate scenario and a high emission rate one.

Simulation Results

CO_2

- **Doors open** → CO_2 concentrations < 1000 ppm independently of the control strategy used.
- **Doors shut:**
  – MVHR with constant ventilation rate → CO_2 conc. > 1000 ppm for **70 %** of the time in the **living room**
  – T & CO_2 boost control → high CO_2 levels in the **living room** for **35 %** of the time.



Formaldehyde

- Formaldehyde concentrations stay below 0.034 mg/m^3 (LEED v4 recommended limit) in all cases and therefore, do not present an IAQ issue for any of the scenarios simulated.

Simulation Results

PM_{10}

- **Doors open:**

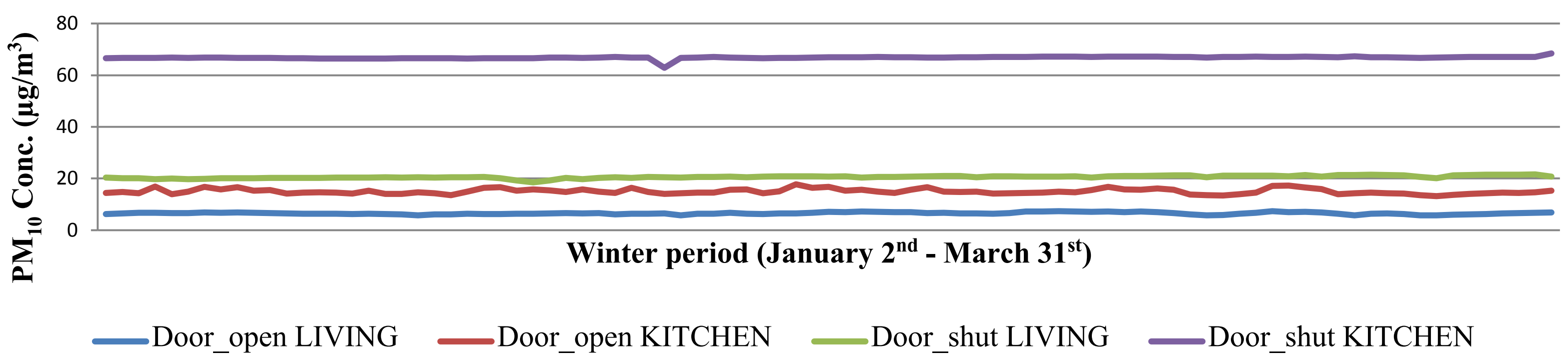
– The WHO 24-h mean recommended concentration (50 μg/m^3) is not exceeded.

– The mean concentration ~ 22 μg/m^3 > the WHO annual mean recommended level (20 μg/m^3), in the **living room** (high emission scenario)

- **Doors closed:**

– PM_{10} 24-h mean > 50 μg/m^3 **all the time** in the **kitchen** for the low emission scenario and also, in the **living room** for the high emission one.

– The T & RH/CO_2 control strategy does not make a significant difference.



$PM_{2.5}$

- An analogous situation is found.

Simulation Results

NO_2

- **Doors open →** 1-h mean levels > 200 $\mu g/m^3$ (WHO recommended limit) for **4 %** of the time in the **living room** and **6 %** of the time in the **kitchen.**
- **Doors shut →** 1-h mean concentrations above the threshold **8 %** of the time in the **kitchen.**

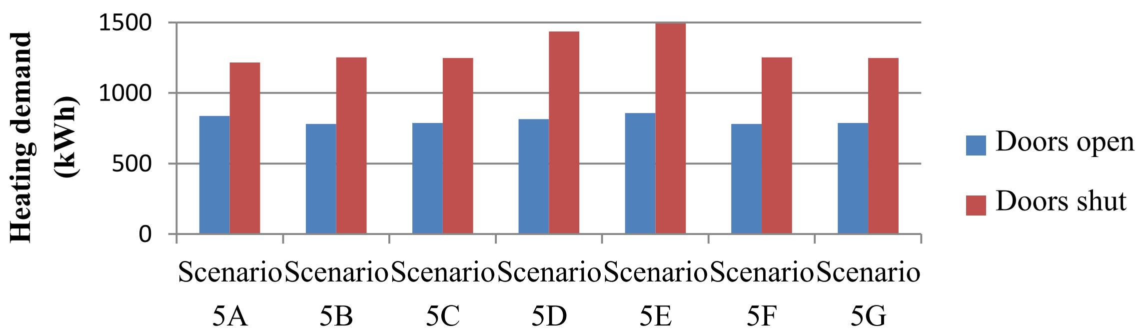
RH

- **Doors open →** Air mainly dry in **all rooms**
- **Doors closed →** Comfortable periods for **50 %** of the time in the **living room** and the **kitchen**. However the air remains dry in the **bedrooms** for around **80 %** of the time.

Temperature

- Overheating is not an issue for any of the scenarios simulated in this case.

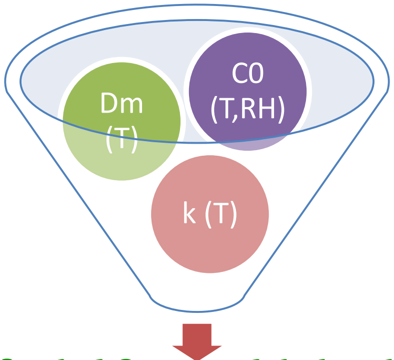
Heating demand



Conclusions

- **Emission modelling**, taking into account prevailing **temperatures and RH**, resulted in significant variations compared to the emission rates obtained assuming constant environmental conditions, especially, temperature.

- A **comprehensive** database that compiles correlations between emission parameters (**C_0, D_m and k**) and indoor conditions **(temperature and RH)** is needed.



Model formaldehyde emissions accurately

- **Large variations** of temperature and IAQ were found **in different rooms** within the house. Therefore, a simple one-zone model simulation could provide misleading results.

- **Indoor door opening** results in improved thermal comfort and IAQ.

Thank you!

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