Large differences in real life IAQ- and Energy Performance of Code Compliant Residential Ventilation Systems
MONICAIR: MONItoring & Control of Air quality in Individual Rooms

MONICAIR is a pre-competitive field research project into the real-life IAQ- and Energy Performance of ventilation systems in Dutch residential dwellings.

Final goal:
Further improvement of residential ventilation systems, building codes and energy assessment methods

By:
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Projectleader MONICAIR
MONICAIR CONSORTIUM

Participating parties:

Manufacturers:

Consulting agencies:

Research institutions:
MONICAIR PROJECT FUNDING

Total project costs : 1,57 million euro

Contribution Dutch Ministry of Economic Affairs* : 0,86 million euro

Contribution Consortium Members : 0,63 million euro

Contribution Housing Corporations : 0,08 million euro

* Within the framework of TKI (Top Consortia for Knowledge & Innovation)
PROJECT RATIONAL

Lack of data on the real-life IAQ- and Energy Performance of residential ventilation systems

Ventilation systems are selected, based on:

1. Compliance with Building Codes
2. Purchase, installation & operating costs
3. Assessment of the energy performance acc. EPBD
4. Estimates & simulations on IAQ-performance

Insufficient real life data
PROJECT RATIONAL

Energy-performance of ventilation systems is *estimated* (based on EPBD-calculation methods).

IAQ- performance is *assumed*, and estimated equal for all code compliant ventilation systems.

**MONICAIR** collects **real-life data** on the IAQ- & Energy Performance of code compliant ventilation systems, in order to gain knowledge and improve systems & assessment methods.
DETAILS MONITORING PROJECT

- 62 terraced / semi detached houses
- 10 ventilation systems, tuned to building codes
- Monitoring of CO$_2$, RH, Temperature and Presence in all rooms
- Monitoring of power consumption of all mech. ventilation units
- Sampling frequency: 5 minutes
- Meteorological data imported from most nearby weather stations
- Period: 2 heating seasons, one summer season

Resulting in a MONICAR database of over 100 million data-points
# TYPE OF VENTILATION SYSTEMS

**Type A:**
Natural supply in all rooms
Natural exhaust wet rooms

**Type C:**
Natural supply hab. rooms
Mech. exhaust wet rooms

<table>
<thead>
<tr>
<th>System type</th>
<th>Section of house that is served</th>
<th>Air exchange provisions</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Whole house</td>
<td>Nat. extraction in wet-rooms</td>
<td>Stnrd nat.supply vents in all rooms</td>
</tr>
<tr>
<td>C.1</td>
<td>Whole house</td>
<td>Mech. extraction in wet-rooms</td>
<td>Stnrd nat.supply vents in hab.rooms</td>
</tr>
<tr>
<td>C.2c</td>
<td>Whole house</td>
<td>Mech. extraction in wet-rooms</td>
<td>Wind contrl. nat. supply in hab.rooms</td>
</tr>
<tr>
<td>C.4a</td>
<td>Whole house</td>
<td>Mech. extraction in wet-rooms</td>
<td>Wind contrl. nat. supply in hab.rooms</td>
</tr>
<tr>
<td>C.4c</td>
<td>Whole house</td>
<td>Mech. extraction in all rooms</td>
<td>Wind contrl. nat. supply in hab.rooms</td>
</tr>
</tbody>
</table>
## TYPE OF VENTILATION SYSTEMS

**Type D:**
- Mechanical supply
- Mechanical exhaust
- Heat Recovery

### Type D Systems

<table>
<thead>
<tr>
<th>System type</th>
<th>Section of house that is served</th>
<th>Air exchange provisions</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.2</td>
<td>Whole house</td>
<td>Mech. extraction in wet-rooms</td>
<td>Mech. supply in hab.rooms</td>
</tr>
<tr>
<td>D.5a</td>
<td>Whole house</td>
<td>Mech. extraction in wet-rooms</td>
<td>Mech. supply in hab.rooms</td>
</tr>
<tr>
<td>D.5b</td>
<td>Whole house</td>
<td>Mech. extraction in all rooms</td>
<td>Mech. supply in hab.rooms</td>
</tr>
<tr>
<td>D.x</td>
<td>Whole house</td>
<td>Mech. extraction in all rooms</td>
<td>Mech. supply in con.spaces</td>
</tr>
</tbody>
</table>
### Type of Ventilation Systems

**Type X1/C and X1/A**

A combination of systems:
- Living section: Mechanical supply & exhaust per room with HR
- Sleeping section: System C of system A

<table>
<thead>
<tr>
<th>System type</th>
<th>Section of house that is served</th>
<th>Air exchange provisions</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Exhaust</td>
<td>Supply</td>
</tr>
<tr>
<td>X1/C</td>
<td>Living section: D</td>
<td>Mech. extraction in hab. rooms</td>
<td>Mech. supply in hab. rooms</td>
</tr>
<tr>
<td>X1/A</td>
<td>Living section: D</td>
<td>Mech. extraction in hab. rooms</td>
<td>Mech. supply in hab. rooms</td>
</tr>
<tr>
<td></td>
<td>Sleeping section: A</td>
<td>Nat. extraction in wet-rooms</td>
<td>Wind contrl. nat. supply in bedrooms</td>
</tr>
</tbody>
</table>
INDICATOR IAQ-PERFORMANCE

Purpose of ventilation systems: to exchange polluted indoor air by cleaner outdoor air in all rooms of a dwelling, thus diluting the concentrations of all possible indoor contaminants.

The IAQ-performance of ventilation systems is based on their ability to – under all kinds of real life circumstances – achieve the requested air exchange rates in each individual room.

For habitable rooms: CO$_2$-concentration
The CO$_2$-concentration is generally accepted as indicator, not only for hygienic thresholds, but also for the actually occurring air-exchange-rates in a room during presence

For wet rooms: RH
Since dwell time in wet rooms is limited, RH is used as indicator for the IAQ-performance in wet rooms
INDICATOR IAQ-PERFORMANCE

Indicator for the IAQ-performance of ventilation systems in habitable rooms

Over a whole heating season:
- duration CO₂-conc. > 1200 ppm multiplied by degree of excess

In formula:
\[
IAQ\text{-performance} = \sum_{d=1}^{212} (t_{>1200} \times (C_{\text{CO}_2 >1200} - 1200)) / 1000 \text{ in kppm/h/s}
\]

Indicator for the IAQ-performance of ventilation systems in wet rooms

Over a whole heating season: average nr. of hours per day with RH > 70%
INDICATOR ENERGY-PERFORMANCE

1. Determine hourly mech. ventilation volume flow (air exchange)
2. Calculate hourly difference in thermal energy content of exchanged air (based on hourly averages on $\Delta T_{\text{in-out}}$, $\Delta R_{\text{Hin-out}}$, and air pressure) : $Q_{\text{th};h}$
3. Correct $Q_{\text{th};h}$ for average heating system efficiency (85%) : $Q_{\text{th};h} / 85$
4. Determine hourly power cons. vent. units (converted to primary) : $Q_{\text{elec};h} / 40$
5. Totalize all hourly data of heating season, resulting in : $Q_{\text{vent;prim}; \text{ht.ssn}}$
6. Divide $Q_{\text{vent;prim}; \text{ht.ssn}}$ by heated surface of the dwelling : $A_h$

In formula

$$\text{Energy-performance} = \sum \left( \frac{Q_{\text{th};h}}{85\%} + \frac{Q_{\text{elec};h}}{40\%} \right) / A_h \text{ in MJ/m}^2/\text{ht.ssn}$$
**RESULTS**

**Total average ventilation rate per dwelling $m^3/h/m^2$**

- System C2c
- System C4a
- System C4c
- System D2
- System D5a
- System D5b
- System Dx
- System X1/C

**Average ventilation rate per dwelling in $m^3/h/m^2$:**

- Total average ventilation rate per dwelling $m^3/h/m^2$

**Ventilation system type:***

- System C2c
- System C4a
- System C4c
- System D2
- System D5a
- System D5b
- System Dx
- System X1/C

**Overall averages:**

- $1.00 \, m^3/h/m^2 \, A_{heated}$
- $0.40 \, dm^3/s/m^2 \, A_{habitable}$

**All dwellings/systems:**

Well above $35 \, m^3/pp/h$
RESULTS

Some examples CO₂-levels system C2c (nat.supply & exhaust in hab.rooms)
RESULTS

Some examples CO$_2$-levels system C4c (nat.supply & mech.exhaust in hab.rooms)
Some examples CO₂-levels system D2 (mech.supply & nat.exhaust in hab.rooms)
RESULTS

Average CO\textsubscript{2}-excess doses per person = IAQ-performance vent. system

- Living (& kitchen)
- Sleeping section
- Separate kitchen

Bedrooms are critical

Results not corrected for temporarily switched off mech. ventilation in hab. rooms:

What is a proper IAQ-performance? 50 kppmh/pp/hs?
RESULTS

Some examples RH-levels

- **RH bathroom in dwelling C4a-3; 2 inhabitants** (Tuesdays in heating season)
  - RH [%]

- **RH bathroom in dwelling D2-2; 5 inhabitants** (Wednesdays in heating season)
  - RH [%]
RESULTS

Average Nr. of hours per day RH > 70% per dwelling section

- Living (& kitchen)
- Sleeping section
- Separate kitchen
- Bathroom

Humidity wet rooms generally okay, except in some bathrooms with natural exhaust.
RESULTS


CO2-excess doses versus primary energy consumption

- Systeem C1
- Systeem C2c
- Systeem C4a
- Systeem C4c
- Gemiddelde C1, C2c, C4a
- Gemiddelde C4c

Averages system C1, C2c, C4a:
- 122 MJ/m² and 290 kppmh/pp/hs

Averages system C4c:
- 82 MJ/m² and 72 kppmh/pp/hs
RESULTS

Energy & IAQ Performance Central and Local mech. systems with HR

CO2-excess doses versus primary energy consumption

Primary energy consumption during heating season with real life HR-efficiency =80% in [MJ/m²]
(Results are not corrected for temporarily switched off units)

Averages system D2, D5a, Dx:
29 MJ/m² and 89 kppmh/pp/hs

Averages system X1/C:
Living section: 9 MJ/m² and 30 kppmh/pp/hs
Sleeping sect.: 94 MJ/m² and 145 kppmh/pp/hs
<table>
<thead>
<tr>
<th>Ventilation systems</th>
<th>$Q_{\text{vent;prim}}/m^2$</th>
<th>$\eta$ HR = 80%</th>
<th>$CO_2$ excess dose kppmh/pp/hs</th>
<th>Stnrd Dev. kppmh/pp/hs</th>
</tr>
</thead>
<tbody>
<tr>
<td>System A</td>
<td>No data</td>
<td></td>
<td>442</td>
<td>438</td>
</tr>
<tr>
<td>System C1</td>
<td>No data</td>
<td></td>
<td>349</td>
<td>276</td>
</tr>
<tr>
<td>System C2c</td>
<td>119</td>
<td></td>
<td>244</td>
<td>216</td>
</tr>
<tr>
<td>System C4a</td>
<td>144</td>
<td></td>
<td>271</td>
<td>389</td>
</tr>
<tr>
<td>System C4c</td>
<td>82</td>
<td></td>
<td>72</td>
<td>78</td>
</tr>
<tr>
<td>System D2</td>
<td>40</td>
<td></td>
<td>68</td>
<td>32</td>
</tr>
<tr>
<td>System D5a</td>
<td>25</td>
<td></td>
<td>105</td>
<td>156</td>
</tr>
<tr>
<td>System D5b</td>
<td>103</td>
<td></td>
<td>183</td>
<td>32</td>
</tr>
<tr>
<td>System Dx</td>
<td>23</td>
<td></td>
<td>76</td>
<td>199</td>
</tr>
<tr>
<td>System X/C (living / sleeping section)</td>
<td>9 / 94</td>
<td>30 / 145</td>
<td>33 / 103</td>
<td></td>
</tr>
</tbody>
</table>
RESULTS

Main findings of MONICAIR:

1. Average flow rates of ventilation systems are very close to flows corresponding with setting 1 of ventilation switch
2. For all dwellings/systems average flows are well above 35 m3/h/pp
3. Large differences in IAQ-performance of code compliant ventilation systems (0 – 853 kppmh/pp/ht.ssn)
4. Large differences in standard deviation of IAQ-performance (32 – 438 kppmh)
5. Bedrooms are critical
6. Differences in real-life energy performance and EPBD assessment methods
7. Inhabitants do not react on high CO2-levels (> 3000 ppm CO2)
8. Noise and draught are reasons to temporarily switch off mech. vent. units
9. Leaks in dwellings façade or roof do not improve the IAQ
10. For dwellings with only natural air-supply and extract provisions in habitable rooms, an increase in flow rate does not improve the IAQ
11. Correlation between IAQ and flow rate is strongest for systems with mechanical air exchange provisions and IAQ-sensors in habitable rooms
CONCLUSIONS

1. Compliance with Buildings Codes does not guarantee the IAQ-performance of the ventilation system

2. Code compliant ventilation systems largely differ in their IAQ-performance

3. An assessment of the Energy Performance of ventilation systems is meaningless without an assessment of its key-function “the ability to exchange air in all rooms under all circumstances”

4. Building codes, assessment methods and standards can be further improved to overcome this omission

5. Ventilation systems can be further improved to guarantee a proper IAQ-performance
RECOMMENDATIONS

3. Assessment of the energy performance acc. EPBD
   - Include real-life tests in the assessment of the Energy Performance of ventilation systems
   - Further refine Buildings codes, assessment methods and applicable standards
   - Perform more monitoring studies to further substantiate the findings of MONICAIR

4. Estimates & simulations on IAQ-performance
   - Include real-life tests in the assessment of the IAQ-Performance of ventilation systems
   - Set guidelines for proper IAQ-performance levels of ventilation systems
Thank you for your attention

Full report (in Dutch & English) can be downloaded from: www.monicair.nl