Objective

- To critically examine, whether available epidemiological data do provide reliable evidence on ventilation-health relationship
- To examine, what can be learnt from the published literature and what are the limitations
- To examine, whether published epidemiological data can be used for regulative purposes when defining ventilation requirements in non-industrial environments
Background: Ventilation requirements through history

1825
Tredgold
1836
Meikleham
1854
Bilings 1895 comfort

Adapted from Li (2013)
Previous reviews on the relationship between ventilation and health

<table>
<thead>
<tr>
<th>Study</th>
<th>Main results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mendell (1993) [13]</td>
<td>Acute health (SBS) symptoms of office workers were associated with air-conditioning, carpets, more workers in a space, VDT use, and ventilation rates at or below 10 L/s per person.</td>
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<tr>
<td>Godish and Spengler (1996) [14]</td>
<td>Limited evidence suggests that increasing the ventilation rate up to 10 L/s per person may be effective in reducing prevalence of acute health (SBS) symptoms and occupant dissatisfaction with air quality. Because of complex relationships between ventilation rates, contaminant levels, and building-related health complaints, the use of ventilation as a mitigation measure for air quality problems should be tempered with an understanding of factors that may limit its effectiveness.</td>
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<tr>
<td>Seppänen et al. (1999) [15]</td>
<td>Ventilation rates below 10 L/s per person in all building types were associated with statistically significant worsening in one or more health or perceived air quality outcomes. Some studies determined that increasing ventilation rates above 10 L/s per person up to approximately 20 L/s per person, were associated with a significant decrease in the prevalence of acute-health symptoms or with a significant improvement of the perceived air quality. The risk of acute health (SBS) symptoms continued to decrease significantly with decreasing carbon dioxide concentrations below 800 ppm.</td>
</tr>
<tr>
<td>Wargocki et al. (2002) [16]</td>
<td>Ventilation rates below 25 L/s per person increase the risk of acute health (SBS) symptoms, increase short-term sick leave, and decrease productivity.</td>
</tr>
<tr>
<td>Seppänen et al. (2006) [102]</td>
<td>A 1–3% improvement in average performance was associated with an increase in ventilation rate by 10 L/s per person. The performance increase was statistically significant when ventilation rates increased up to 15 L/s per person (95% confidence interval, CI) and up to 17 L/s per person (90% CI). The performance increase per unit increase in ventilation rates below 20 L/s per person and almost negligible with ventilation rates over 45 L/s per person.</td>
</tr>
<tr>
<td>Li et al. (2007) [23]</td>
<td>There is strong and sufficient evidence substantiating the association between ventilation, air movements in buildings and the transmission/spread of infectious diseases such as measles, tuberculosis, chickenpox, influenza, smallpox and SARS. There is insufficient data to clearly define the ventilation rates that can reduce the risk of the spread of infectious diseases via the airborne route for hospitals, schools, offices, homes and isolation rooms. Overcrowding is a risk factor that may be related to the ventilation of buildings but it also increases transmission via direct contact.</td>
</tr>
<tr>
<td>Fisk (2009) [103]</td>
<td>As the ventilation rate is reduced from 10 to 5 L/s per person, the relative prevalence of acute health (SBS) symptoms increases by ca. 23% (12%–32%). As the ventilation rate is increased from 10 to 25 L/s per person, the relative prevalence of symptoms decreases by 29% (15%–42%).</td>
</tr>
<tr>
<td>Sundell et al. (2011) [25]</td>
<td>Higher ventilation rates in offices, up to about 25 L/s per person, were associated with reduced prevalence of acute health (SBS) symptoms. Ventilation rates in homes above 0.5 air changes per hour are associated with a reduced risk of allergic manifestations among children in Nordic climates.</td>
</tr>
</tbody>
</table>
Previous reviews on ventilation-health relationship

- More than dozen
- Multiple health outcomes associated with changes in ventilation rates
- Increasing ventilation rates will reduce health outcomes
- Ventilation rates >10 L/sp, >15-17 L/sp or even >25 L/sp are needed to reduce acute health symptoms
- Non-linear relationship between ventilation and acute symptoms (10 to 5 L/sp increases prevalence by 23%) and between ventilation and cognitive performance (doubling ventilation rate results in 1-3% higher performance)
- Ventilation rates >0.5 h⁻¹ in homes reduce infestation of HDMs in moderate and cold climates
- Strong evidence on the link between ventilation and infectious diseases but no ventilation rate can be recommended due to other influencing factors
- Maintenance of ventilation systems - an important confounding factor
- The use of ventilation rates as a mitigation measure should be tempered before the complex relationship between ventilation, contaminants and exposure is understood

Mendell (1993); Godish and Spengler (1996); Seppänen et al. (1999;2006); Wargocki et al. (2002); Li et al. (2007); Fisk (2009); Sundell et al. (2011)
Current ventilation standards

- Do not adequately address the health relevant aspects of indoor air quality
- Ventilation rates based on sensory comfort (different classes of comfort), not based on “hard” health data
- Requirements are defined for different classes of building users (visitors and occupants) and modified based on the strength of pollution sources (classes of building materials)
- Ventilation rates not defined on target values for exposures
- There have been no (formal) requirements for air used for ventilation (ambient air assumed to be clean) and there are no requirements for compliance with the requirements in the standard
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What does the scientific literature tell us about the ventilation–health relationship in public and residential buildings?

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ABSTRACT

Objective of this paper is to examine whether the available epidemiological evidence provides information on the link between outdoor air ventilation rates and health, and whether it can be used for regulatory purposes when setting ventilation requirements for non-industrial built environments.

Effects on health were seen for a wide range of outdoor ventilation rates from 6 to 7 L/s per person, which were the lowest ventilation rates at which no effects on any health outcomes were observed in field studies, up to 25–40 L/s per person, which were in some studies the lowest outdoor ventilation rates at which no effects on health outcomes were seen. These data show that, in general, higher ventilation rates in many cases will reduce health outcomes and that there are the minimum rate.
Review, methodology

Literature search (2000-2011)

168

Screening titles and abstracts

68

Review (2 reviewers /paper)

48 Papers relevant and conclusive

Link ventilation rate-health

23

Respiratory, asthma and allergy symptoms

Acute health symptoms

Airborne infectious diseases

Performance and learning

Link ventilation type and maintenance-health

26

Maintenance

Ventilation system type
## Results: Ventilation rate and health

<table>
<thead>
<tr>
<th></th>
<th>Respiratory, asthma and allergy symptoms</th>
<th>Acute health symptoms</th>
<th>Airborne infectious diseases</th>
<th>Performance and learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homes and dorms</td>
<td>5 (↑↑↑→→)</td>
<td>2 (↑→)</td>
<td>1 (↑)</td>
<td>0</td>
</tr>
<tr>
<td>Schools</td>
<td>0</td>
<td>2 (↑↑↑)</td>
<td>2 (↑↓)</td>
<td>3 (↑↑↑)</td>
</tr>
<tr>
<td>Offices</td>
<td>0</td>
<td>3 (↑↑↓)</td>
<td>3 (↑↑→)</td>
<td>2 (↑↑)</td>
</tr>
</tbody>
</table>

2 studies negative effect (↓) --- 4 studies no effect (→) --- 17 studies positive effect (↑)
Results: no-effect level vs. exposure-response relationship

- Estimate of change in risk – exposure response relationship: ORs or absence rate or performance change per change in ventilation rate, e.g.
  - 1.25 L/sp higher ventilation rate results in 10-20% lower risk for respiration symptoms (Erdmann et al.)
  - 1 L/sp higher ventilation rate results in 1.6% lower absence rate (Mendell et al.)
  - Doubling ventilation rate results in 8-14% higher performance of schoolwork (Wargocki et al.)

- Estimate of ventilation rate at which no effect was seen (cut-off point), e.g.
  - 0.32 vs. 0.37 h\(^{-1}\) to examine risk of asthma and allergy (Bornehag et al.)
  - <5 L/sp - higher risk of self-reported infections (Sun et al.)
  - >0.4 h\(^{-1}\) – no increase in acute health symptoms (Engvall et al.)
Results: minimum ventilation rate for no effect

For health, the minimum no-effect rate ca. 6-7 L/sp
For schoolwork and office work, the minimum no effect rate 16-24 L/sp
Results, exposure

- Wide range of ventilation rates over which outcomes change (6-7 L/sp to 25-40 L/sp)
- Likely indication of exposure-related rather than the ventilation rate-related rate

6-7 L/sp (???) or 25-40 L/sp (???) => neither (???)
Results: maintenance and the type of ventilation system

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<tbody>
<tr>
<td>Mechanical ventilation</td>
<td>8 (↑↑↑↑→↓↓↓↓)</td>
<td>8 (↑↑↑↑↑↓↓↓↓)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Air conditioning</td>
<td>3 (↓↓↓↓)</td>
<td>1 (↓)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

AC elevates the risk (↓) --- MV inconsistent, but mainly reduces the risks (↑)
Results, moisture, infectious diseases

- Ventilation vs. moisture control – yes in moderate and cold climate but only when absolute humidity levels outdoors low (winter)
- Data insufficient to document efficacy
- WHO considers moisture as risk, but no limits are defined
- Ventilation vs. infectious disease – yes, most likely but only as a modifier, many other factors involved
Limitations of the available epidemiological data

- Limited epidemiological evidence (< three scores)
- Incomparable or difficult to compare
- Improper characterization of buildings and exposures
- Lack of data on indoor pollution sources including maintenance of ventilation systems
- Assumption of clean (unpolluted) outdoor air
- Weak characterization of health outcomes (mainly self-estimated acute symptoms, no chronic outcomes)
- Weak (poor) characterization of ventilation, and crude ventilation measurements
- Poor or no characterization of exposed population and its sensibility
- Weak experimental designs
Major problems related with ventilation measurements

- **Inadequate reporting**, eg. “We measured ventilation rates and they were xx m$^3$/h.” with no information whatsoever on how, when, where, accuracy, number of repetitions, verification and whether instruments were calibrated – difficult to assess the quality of measurements

- **High level of uncertainty** of ventilation measurements in naturally ventilated buildings, measurements depending on the outdoor weather conditions and occupant behavior

- **No ventilation measurements**, assumed by the engineer or nominal/design values are used.

- Measurements **do not capture true variability** in ventilation (representative for the period when made, usually a point in time, weekly averages (at maximum), recently few measurements with period of up to 2 years)

- **No description of the ventilation system design or operation**, important to understand measurement results
Some potential (serious) errors associated with the measurements of ventilation rates

- Tracer gas methods: a point in time measurements (eg., SF6, R134a) and average ventilation over the period (eg., PFT, CO₂)
  - Requires uniform concentration (full mixing)
  - Influenced by unmarked air (transit air)

- Measurements of CO₂ as a proxy of ventilation efficiency to remove pollutants
  - Requires assumptions regarding generation of CO₂
  - Average CO₂ concentrations are meaningless

- Duct traversal methods
  - Neglects infiltration
  - Neglects air distribution
Other “default” problems related with the assessment of ventilation effectiveness

- **Default** assumption that outdoor air is *fresh* and clean. No information on actual air quality outdoors, where main intakes located, how far from exhaust outlet, outdoor weather conditions during measurements, etc.

- **Default** assumption that ventilation system is clean and that the quality of air delivered to the space is at least equal to the quality of the outdoor air, if not better.

- **Default** assumption that air is fully mixed in the space (neglecting ventilation efficiency and air distribution) or that the clean air is delivered to the occupied zone.
Limitations, characterization of health outcomes

- Mostly self-estimated acute health symptoms
- Different recall periods
- Some reporting frequency and some intensity
- Acute health symptoms very prevalent in general population so in case of low prevalence there is no chance for establishing causal relationship
- No chronic health outcomes (as in case of Burden of Disease estimations), only few studies with the objective medical measurements
Limitations, characterization of exposure

- No causal link due to lack of proper (or no) characterization of exposures
- Both outdoor and indoor exposures poorly characterized
- No information on measures taken to reduce exposures (source control, other methods to reduce emissions)
- In many building smoking either occurred or curtailed, but still the third-hand tobacco smoke could influence the exposures
- No characterization of ventilation systems, their performance, maintenance and cleanliness
Limitations, experimental design/approach

- Mainly cross-sectional studies
- Snap-shot not longitudinal
- Measurements in different non-representative buildings (bias)
- Only associations, no causal relationship
- No proper control of confounding, only through sophisticated modelling and statistical analyses
- Few interventions, stronger but also with limitations (length, repetitions)
- Few case-control, stronger but also with limitations (selection of cases and controls)
Recommendations

- Multidisciplinary studies
- Characterization of exposures in a systematic way
- Minimum protocol as regards measurements of pollutants of concern recognized as health relevant
- Improved ventilation measurements and examination which are important for health outcomes
- Prospective nested case-control studies or longitudinal experimental interventions
- Setting framework for defining ventilation requirements
Which way to go?

- Highest possible level (25-40 L/sp)
  - Energy penalty
  - Expensive
  - Difficult technically
  - Ambient air pollution

- Lowest possible level (6-7 L/sp)
  - Requires source control
  - Will not protect where sources are strong
  - Based on limited population data
  - Note generalizable
Ventilation is merely an intermediate index rather than causative factor

Outdoor air: combustion, industrial pollution, traffic, pollens, etc.
Ventilation system: ventilation, air-conditioning

Building: building materials, furnishing, equipment, consumer products, etc.
Humans: occupants & their activities
Ventilation used as a *panacea*

- Exposure limits available for few compounds only (e.g., WHO AQ Guidelines, Index project)
- Emission data are missing
- Effects of low-dose mixtures of compounds unknown
- Some pollutants are affected by ventilation (e.g. human bioeffluents) some not (e.g. SVOCs)
- Ventilation rate must be discussed in connection with ventilation system, its performance (air distribution, ventilation effectiveness) and maintenance
Framework for setting ventilation requirements

- Systematic approach/framework is missing
- Ventilation rates should reflect actual exposure levels/limits
- Ventilation rates should reflect specific health outcomes
- Outdoor air pollution, cleanliness of ventilation system, strength of pollution sources must be taken into account
- Primary prevention approach so that all source control methods entertained before ventilation used as an ultimate solution
Possible framework proposed by HealthVent

- Air supplied must always meet WHO AQ Guidelines

- When WHO AQ Guidelines met through control of sources then health-based ventilation rate equals base rate

- When WHO AQ Guidelines cannot be met through control of sources then health-based ventilation rate is a multiply of base rate
GUIDELINES FOR HEALTH-BASED VENTILATION IN EUROPE (HealthVent)
Conclusions

- Higher ventilation rates will reduce health outcomes
- There are diverse ventilation rates at which health outcomes are reduced
- There are minimum ventilation rates at which health outcomes can be avoided (reduced)
- No clear causality has been established
- No universally applicable ventilation health relationship can be established
- Epidemiological data has several limitations mainly being crude ventilation measurements, diversity of outcomes and improper characterization of exposures and weak characterization of health outcomes (mainly acute)
- Maintenance of systems plays an important role
Questions