Temperature Zoning in Highly-Insulated Buildings
Colder Bedrooms in Winter with Warm Living Rooms

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Need for Colder Bedrooms in Norway (1)

• Without considering a specific building energy performance

• Survey (Bjorvatn et al. 2017)
  – 1001 Norwegians selected randomly
  – 70% with bedroom temperature < 18°C
  – Many with bedroom temperature < 12°C
Need for Colder Bedrooms in Norway (2)

• Without considering a specific building energy performance

• Survey (Bjorvatn et al. 2017)
  – 1001 Norwegians selected randomly
  – Many keep bedroom windows always open, especially with age above 45

Temperature Zoning in nZEB (1)

• Limited temperature zoning in highly-insulated building envelopes
  – Highly-insulated external walls and high-performance windows
  – Centralized one-zone balanced mechanical ventilation with efficient heat recovery

Single temperature level for supply ventilation air

Pictures from Berge et al., Building and Environment 2016
Temperature Zoning in nZEB (2)

- Influence of building construction mode
  - Partition walls insulated in lightweight constructions
  - Positive effect on temperature zoning
  - Many lightweight wooden constructions in Norway

- \( U \approx 0.33 \text{ W/m}^2.K \)
  - \( U \approx 3.2 \text{ W/m}^2.K \)

Pictures from SINTEF Byggforskserien

Temperature Zoning in nZEB (3)

- Experience of indoor thermal environment in Norwegian passive houses
  - Based on questionnaires and field measurements
  - \( \approx 100 \) dwellings (Berge et al. 2016, Thomsen et al. 2017)

- Regarding bedrooms
  - Many occupants want colder bedrooms (\(< 16°C\))
  - \( \approx 50\% \) occupants open bedroom windows several hours every day during winter time
  - The main motivation is temperature control not IAQ
  - Occupants do not control the supply ventilation air temperature correctly to get colder bedrooms

- Regarding living areas
  - Desired indoor temperature is often between 22°C and 24°C
Temperature Zoning: example apartment (1)

- Two identical apartments from *Miljøbyen Granåsen* project in Trondheim

<table>
<thead>
<tr>
<th>Thermal property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>U external walls</td>
<td>0.17 W/m².K</td>
</tr>
<tr>
<td>U wall to atrium</td>
<td>0.16 W/m².K</td>
</tr>
<tr>
<td>U between flats</td>
<td>0.25 W/m².K</td>
</tr>
<tr>
<td>U internal walls</td>
<td>0.49 W/m².K</td>
</tr>
<tr>
<td>Thermal bridges</td>
<td>0.02 W/m².K</td>
</tr>
<tr>
<td>Infiltration (design)</td>
<td>0.6 ach at 50 Pa</td>
</tr>
<tr>
<td>Ventilation CAV</td>
<td>1.5 m³/m².h 85% rated efficiency</td>
</tr>
</tbody>
</table>

Georges et al. 2016

Temperature Zoning: example apartment (2)

- Measurement during two weeks in a passive house apartment

Georges et al. 2016
Is it due to control?

- Based on calibrated dynamic simulations
  - Multi-zone simulations in IDA ICE with embedded ventilation network

![Graph showing operative temperature over percentage of nighttime during heating season.](image1)

- Based on measurements and simulations
  - Apartment block, terraced and detached houses at Norwegian passive house level

![Graph showing space-heating needs and energy efficiency.](image2)

Conclusions for Lightweight Construction

- Based on measurements and simulations
  - Need a heat sink
  - Standard one-zone ventilation
  - Alternative ventilation strategy?
Temperature Zoning: research question

- Research showed that
  - Large temperature zoning leads to significant increase of space-heating needs ($\Delta E_{SH}$)
  - Control alone cannot decrease bedroom temperature without large $\Delta E_{SH}$
  - Something should be changed in the building concept, like the ventilation strategy

- How to reduce $\Delta E_{SH}$ with large temperature zoning?
  1. Relative importance of ventilation and heat conduction in partition walls?
  2. How alternative ventilation strategies would improve energy efficiency?

Framework of Analysis

- Steady-state heat transfer ($P$) from heated to unheated rooms

$$P = U_p (T_{set,SH} - T_{bed}) + \dot{V}_2 C_p (T_{set,SH} - T_{bed})$$

- When open bedroom window, nothing changes for heated zone except

$$T_{bed,open} < T_{bed,closed}$$

$$P_{open} > P_{closed}$$

Georges et al. 2019
Alternative ventilation strategies

- To reduce the ventilation contribution on $\Delta E$

![Diagram of ventilation strategies]

- $V_2$ switched off if bedroom with windows opened
- Balanced ventilation in bedrooms
- Decentralized ventilation in bedrooms and heated zones

Simulation Case Study

- Detached Passive House
  - 173 m² located in Oslo
  - With different construction modes (lightweight to heavy)
  - Simulated in IDA-ICE with embedded ventilation network
  - CAV with pre-accepted airflow rates from TEK17 adapted for each ventilation strategy

![Diagram of Cascade ventilation]
Steady-State Analysis

**Setup**
- Outdoor temperature selected to give typical temperature zoning
- Heavy-weight (CM1) and Lightweight (CM5) constructions
- Two different set-point temperature in living areas (21 and 24°C)
- Increase of space-heating needs analyzed $\Delta E_{SH}$ due to window opening in bedrooms

**Conclusions (1)**
- Heat conduction > ventilation effect in heavy-weight buildings (CM1)
- Heat conduction $\approx$ ventilation effect in lightweight construction (CM5)

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Steady-State Analysis

**Conclusions (2)**
- Moderate reduction of ventilation effect for strategies (B) and (C) compared to (A)
- No ventilation effect with strategy (D)
- Heat conduction part left almost unchanged between A, B, C and D
Yearly Dynamic Simulation

- Setup
  - Lightweight construction (CM5)
  - Set-point temperature in living area of 24°C
  - Compare different strategies for control

- Conclusion with closed bedroom windows
  - Higher ventilation airflow rates in (C and D) compared to A (from pre-accepted building code TEK17)
  - Slightly higher space-heating needs without cascade ventilation (C and D)

Yearly Dynamic Simulation

- Conclusions open bedroom windows
  - Always an increase of space-heating needs
  - Slightly lower increase for (B) and (C) than (A)
  - Lower increase for decentralized (D) than (A)
Conclusions (1)

• Highly-insulated building with one-zone balanced mechanical ventilation

• Need to improve energy efficiency with large temperature zoning (> 3°C)
  – Simulations show that it is not a question of control
  – Need to change the building concept

• Important remarks
  – Buffer zone with intermediate temperature level effective for zoning
  – Results can be very different with less insulated partition walls (e.g. heavy-weight buildings)

Conclusions (2)

• Regarding the increase of space-heating needs with large zoning ($\Delta E_{SH}$)

• Question 1:
  – Heat conduction dominant in heavyweight buildings (non-insulated partition walls)
  – Effect heat conduction and ventilation have the same magnitude for lightweight buildings
  – Ventilation strategy cannot solve the problem alone

• Question 2:
  – Ventilation contribution can be moderately reduced by shutting down supply air in bedrooms of mechanical ventilation when bedroom windows are opened (strategy B)
  – Ventilation contribution can be moderately reduced by balancing airflows in bedrooms (strategy C, here still with a one single supply air temperature)
  – Ventilation contribution can be significantly reduced by decentralized ventilation (D)
References

1. B. Bjorvatn et al., *Age and sex differences in bedroom habits and bedroom preferences*, Sleep Medicine, 2017 (32)
10. Selvnes, E., *Thermal zoning during winter in super-insulated residential buildings* Master thesis at Energy and Process Engineering Department, Norwegian University of Science and Technology (NTNU), 2017

Thank you for your attention!

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Case Study

- Control strategies changing set-points for
  - Heated zones, AHU heating coil, bedrooms, window and door opening

<table>
<thead>
<tr>
<th>Cases</th>
<th>Living areas</th>
<th>AHU</th>
<th>Bedrooms</th>
<th>Windows Schedule</th>
<th>Windows T_set,win</th>
<th>Door Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21 or 24°C</td>
<td>T_set,SH-3</td>
<td>T_set,SH</td>
<td>Closed</td>
<td>-</td>
<td>Closed</td>
</tr>
<tr>
<td>2</td>
<td>21 or 24°C</td>
<td>T_set,SH-3</td>
<td>None</td>
<td>Closed</td>
<td>-</td>
<td>Closed</td>
</tr>
<tr>
<td>3</td>
<td>21 or 24°C</td>
<td>16°C</td>
<td>None</td>
<td>Closed</td>
<td>-</td>
<td>Closed</td>
</tr>
<tr>
<td>4</td>
<td>21 or 24°C</td>
<td>14°C</td>
<td>None</td>
<td>Closed</td>
<td>-</td>
<td>Closed</td>
</tr>
<tr>
<td>5</td>
<td>21 or 24°C</td>
<td>T_set,SH-3</td>
<td>None</td>
<td>Open (Night)</td>
<td>16°C</td>
<td>Closed</td>
</tr>
<tr>
<td>6</td>
<td>21 or 24°C</td>
<td>16°C</td>
<td>None</td>
<td>Open (Night)</td>
<td>16°C</td>
<td>Closed</td>
</tr>
<tr>
<td>7</td>
<td>21 or 24°C</td>
<td>14°C</td>
<td>None</td>
<td>Open (Night)</td>
<td>16°C</td>
<td>Closed</td>
</tr>
<tr>
<td>8</td>
<td>21 or 24°C</td>
<td>T_set,SH-3</td>
<td>None</td>
<td>Open (Night)</td>
<td>16°C</td>
<td>Open (Day)</td>
</tr>
</tbody>
</table>

Nominal Ventilation Airflow Rates

- Pre-accepted values from building code TEK17, leading design criteria:
  - Supply airflow in bedrooms in cascade ventilation
  - Exhaust airflow in “wet” rooms without cascade ventilation

<p>| Table 2. Ventilation airflow rates for the different ventilation strategies [12]. |</p>
<table>
<thead>
<tr>
<th>Zone</th>
<th>Room</th>
<th>Supply [m³/h]</th>
<th>Return [m³/h]</th>
<th>Without cascade** Supply [m³/h]</th>
<th>Return [m³/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kitchen and Living</td>
<td>104</td>
<td>40</td>
<td>126</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>Stairs</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>Technical/Laundry</td>
<td>0</td>
<td>40</td>
<td>0</td>
<td>36</td>
</tr>
<tr>
<td>4</td>
<td>Bathroom 1st floor</td>
<td>0</td>
<td>64</td>
<td>0</td>
<td>54</td>
</tr>
<tr>
<td>5</td>
<td>Bathroom 2nd floor</td>
<td>0</td>
<td>64</td>
<td>0</td>
<td>54</td>
</tr>
<tr>
<td>6</td>
<td>Bedroom SE</td>
<td>52</td>
<td>0</td>
<td>52</td>
<td>52</td>
</tr>
<tr>
<td>7</td>
<td>Corridor 2nd floor</td>
<td>0*</td>
<td>0</td>
<td>54</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>Bedroom SW</td>
<td>26</td>
<td>0</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>9</td>
<td>Bedroom NW</td>
<td>26</td>
<td>0</td>
<td>26</td>
<td>26</td>
</tr>
</tbody>
</table>

* In strategy (b), this airflow is 104 m³/h if the supply ventilation air in bedrooms is stopped.
** This corresponds to the strategy (c) and decentralized ventilation (d).