Simplified Space-Heating Distribution using Radiators in Super-Insulated Apartment Buildings


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Background

• In Norway, concepts of energy-efficient buildings are based on a super-insulated building envelopes
  – New building regulation (TEK)
  – Norwegian Passive House (PH) standard (NS3700)
  – Zero Emission Buildings (ZEB), Nearly Zero Energy Building (NZEB)

• In super-insulated buildings, it is possible to simplify the space-heating distribution
  – High-performance glazing does not require a heat emitter to prevent draft
  – No uncomfortable mean radiant temperature (T_{mrt}) from external walls
  – Simplification using air-heating at the basis of the German PH standard definition
Research questions and methods

- There is a lack of theoretical background and experience to design simplified heat distribution in Norwegian PH
  - Previous investigations have focused on air-heating and stove-heating
  - Present contribution focuses on low-temperature radiators and apartment buildings

- Investigate the trade-off between thermal comfort and energy efficiency
  - Temperature in rooms where a single radiator is placed (typically living room)?
  - Temperature in rooms without a radiator (typically bedrooms)?
  - Do the users operate the building consistently with their desired indoor thermal environment?
  - Energy efficiency, for example with window opening?

- Methods
  1. Qualitative user interviews
  2. Field measurements (about 2 weeks)
  3. Detailed dynamic simulations (IDA-ICE)
Test case

- 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 (Villavent 200)</td>
<td>1.5 m³/m².h 85% rated efficiency</td>
</tr>
</tbody>
</table>
Test case

- **Space-heating distribution**
  - One radiator in the corridor
  - Electric air pre-heating battery
  - Floor heating in bathroom

- **Temperature measurements (red dots)**
  - iButton DS1922L-F5 (± 0.5°C)
  - Stratification in living room, kitchen and corridor
  - At least, one sensor in each room
  - Sensors in AHU and air terminal devices (ATDs)
  - Outdoor air temperature

- **Set-point temperatures registered in a diary**

- **Opening measurements**
  - Binary signal (open/closed)
  - Windows and internal doors
User satisfaction

• **User questionnaire in MiljøGranåsen (from Berge et al. 2016)**
  – 62 houses (but row and detached houses), same heat distribution strategy
  – Most people **satisfied with thermal comfort in the living room**
  – 50% people dissatisfied with **too high temperatures** in bedrooms
  – Many occupants nonetheless do not operate supply air pre-heating consistently
  – 50% **open bedroom windows** during a few hours during winter (essentially for temperature control)

• **User 1 interview (single person)**
  – Requires 24°C in living room, 16-18°C in bedrooms
  – Too cold in living room (22°C) (due to potential leakage in windows)
  – **Too warm bedrooms** (cannot open windows during night due to noise)

• **User 2 interview (single person)**
  – Requires 22°C in living room, 12-15°C in bedrooms
  – Too cold in living room (due to potential leakage in windows)
  – Satisfied with the temperature in bedrooms but **windows always open**
Measurement: heat distribution within room (1)

- Temperature stratification and distribution in corridor, living room, kitchen
- Flat 2
  - Uniform temperature between corridor, living room and kitchen
  - Acceptable stratification (< 3°C)
Measurement: heat distribution within room (b)

- Temperature stratification and distribution in corridor, living room, kitchen
- Flat 1
  - Uniform temperature between living room and kitchen
  - BUT significant $\Delta T$ between corridor and living room (leakage?)

![Temperature distribution living/corridor chart]

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**ZEB** The Research Centre on Zero Emission Buildings
**NTNU – Trondheim** Norwegian University of Science and Technology
Measurement: bedroom (1)

- **Flat 1**
  - Bedroom at about **20°C while 16°C desired**, windows almost never open, door closed
  - Typical ~2°C **temperature difference** with the heated corridor
  - **Inconsistent** pre-heating of air after heat recovery unit (Tset,AH ~20°C)
Measurement: bedroom (2)

- **Flat 2**
  - Bedroom at about 16°C as desired, windows always open, door mostly closed
  - **Window opening creates ~4°C temperature difference** with the heated corridor
  - Consistent no pre-heating of air after heat recovery unit (Tset,AH = Tset,HR)

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![Graph showing temperature and window/door usage over time in a large bedroom.](image-url)
Building simulation using IDA-ICE

- **Objective: what can we expect using BPS?**
  - Cannot address the question of temperature distribution between corridor and living room (requires a CFD)
  - Investigate the optimal control to get low temperature in bedrooms with a minimal increase of the space-heating needs

- **Model calibrated with measurements**
  - Opening of door and windows from measurement, set-points from diary
  - Internal gains defined as a function of the data collected during interviews
  - Total solar irradiation on horizontal plane from weather station (3 km away)
**Alternative control strategies**

- **Play with different set-points**
  1. For the temperature in corridor (Tset,SH)
  2. For the heat recovery efficiency (Tset,HR)
  3. For the air-heating battery after AHU (Tset,AH)
  4. For the window and internal door opening

<table>
<thead>
<tr>
<th>Control</th>
<th>Tset,HR</th>
<th>Tset,AH</th>
<th>Tset,SH</th>
<th>Window</th>
<th>Door</th>
</tr>
</thead>
<tbody>
<tr>
<td>0, baseline</td>
<td>No</td>
<td>20°C</td>
<td>Exp. Data (24°C)</td>
<td>Closed</td>
<td>Closed</td>
</tr>
<tr>
<td>1</td>
<td>No</td>
<td>16°C</td>
<td>Exp. Data (24°C)</td>
<td>Closed</td>
<td>Closed</td>
</tr>
<tr>
<td>2</td>
<td>16°C</td>
<td>16°C</td>
<td>Exp. Data (24°C)</td>
<td>Closed</td>
<td>Closed</td>
</tr>
<tr>
<td>2b</td>
<td>16°C</td>
<td>16°C</td>
<td>+Night-setback (16°C)</td>
<td>Closed</td>
<td>Closed</td>
</tr>
<tr>
<td>2c</td>
<td>16°C</td>
<td>16°C</td>
<td>Constant 20°C</td>
<td>Closed</td>
<td>Closed</td>
</tr>
<tr>
<td>3</td>
<td>14°C</td>
<td>14°C</td>
<td>Exp. Data (24°C)</td>
<td>Closed</td>
<td>Closed</td>
</tr>
<tr>
<td>4</td>
<td>16°C</td>
<td>16°C</td>
<td>Exp. Data (24°C)</td>
<td>Open if T&gt;16°C and nighttime</td>
<td>Closed</td>
</tr>
<tr>
<td>4b</td>
<td>16°C</td>
<td>16°C</td>
<td>Exp. Data (24°C)</td>
<td>Open if T&gt;16°C and nighttime</td>
<td>Open in daytime (window closed)</td>
</tr>
<tr>
<td>5</td>
<td>16°C</td>
<td>16°C</td>
<td>Exp. Data (24°C)</td>
<td>Open</td>
<td>Closed</td>
</tr>
</tbody>
</table>
Results: real boundary conditions

- Reduced Tset,AH does not really helps (case 1)
- Reduced HR efficiency with Tset,HR 16°C reduces of ~2°C (case 2)
  - Night setback in living room does not help (case 2b)
  - Reduced constant living room temperature reduces to ~3°C (case 2c)
- Reduced HR efficiency with Tset,HR 14°C reduces of ~3°C (case 3, but draft)
- Opening of window manages to control temperature at ~16°C (case 4)
- If bedroom reheated during daytime, not enough time to reach 16°C (case 4b)
Results: standard boundary conditions (NS3700)

- Baseline and case 1 have the typical 15 kWh/m².year with $T_{set,SH} = 21^\circ C$
- Increasing to $T_{set,SH} = 24^\circ C$ gives 22 kWh/m².year
- Each control alternative leads to an increase of the space-heating needs
  - Reducing the HR efficiency with $T_{set,HR} = 16^\circ C$ gives +25% (case 2)
  - Reducing the HR efficiency with $T_{set,HR} = 14^\circ C$ gives +40% (case 3)
  - Opening the window if the bedroom temperature $> 16^\circ C$ gives +40% (case 4)
  - Opening during the night and re-heating during day gives +80% (case 4b)
A world where buildings do not contribute with greenhouse gas emissions

Results: standard boundary conditions (NS3700)

• Temperature duration curve (during occupancy)

\[ T_{set,SH} = 21^\circ C \]

\[ T_{set,SH} = 24^\circ C \]
Conclusions

• **The control cannot solve the problem of “too warm” bedrooms**

  1. Cannot decrease the bedroom temperature to 16°C without introducing a significant increase of the space-heating needs and draft

  2. The set-point temperature for the air-heating battery (Tset,AH) is not always consistent but has a small impact compared to consistent operation (in terms of thermal comfort and energy needs)

  3. A cyclic heating of the bedroom during daytime and cooling during nighttime critical for both thermal comfort (slow dynamics) and energy needs (significant increase)

  4. The next step should investigate on a change on the building and the ventilation system
     - Increase the thermal insulation of internal walls
     - Move the radiator in the living room and create a buffer zone with the corridor
     - Introduce a two-zones ventilation system (publication of Berge et al. 2016)

• **The distribution in the room were the heat emitter is placed**

  – Moving radiator to the living room would be beneficial (does not need central position)

  – Investigations cannot be supported by standard BPS tools (needs CFD)