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

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Husbanken

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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

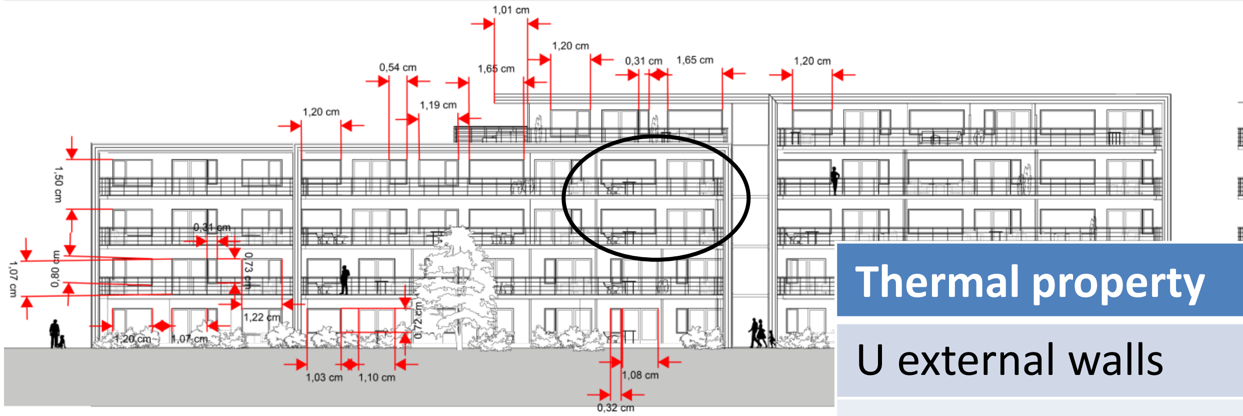
Research questions and methods

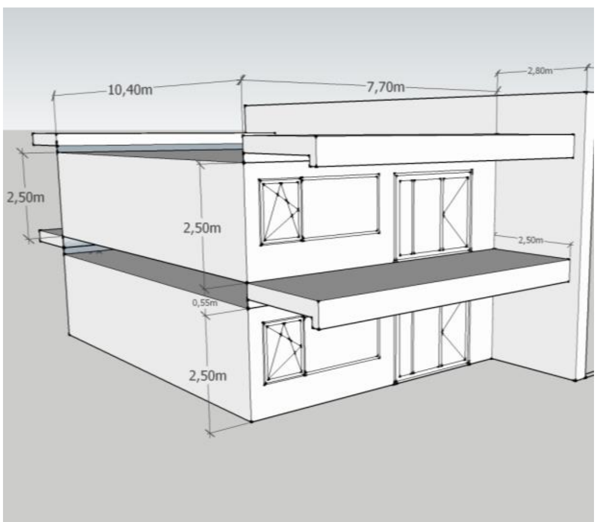
- There is a lack of theoretical background and experience to design simplified heat distribution in Norwegian PH
  - Previous investigations have focused on **air-heating** and **stove heating**
  - Present contribution focuses on **low-temperature radiators** and **apartment buildings**

- Investigate the trade-off between thermal comfort and energy efficiency
  - Temperature in rooms where the a **single radiator** is placed (typically living room)?
  - Temperature in rooms **without** 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



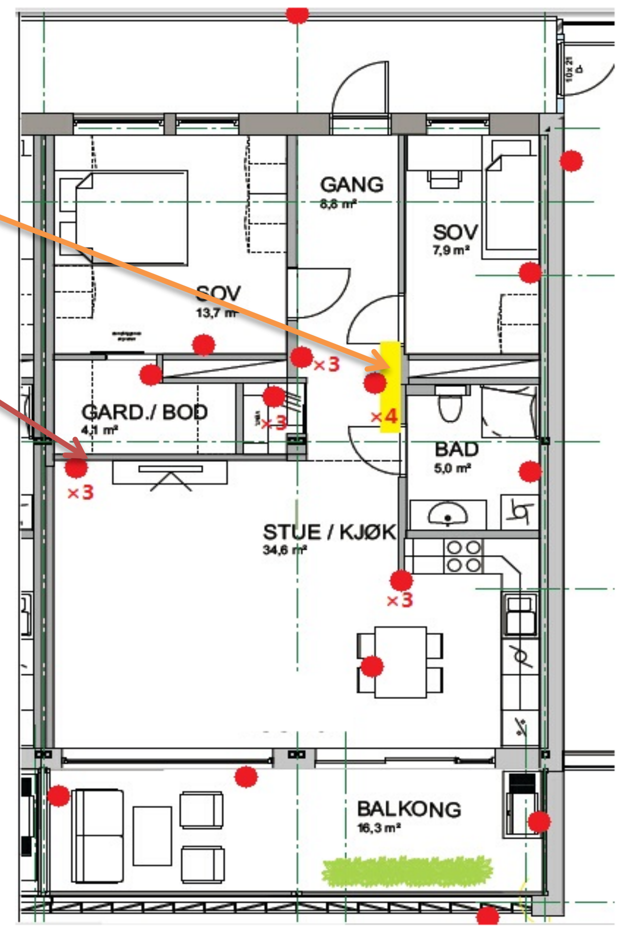


Thermal property	Value
U external walls	0.17 W/m².K
U wall to atrium	0.16 W/m².K
U between flats	0.25 W/m².K
U internal walls	0.49 W/m².K
Thermal bridges	0.02 W/m².K
Infiltration (design)	0.6 ach at 50 Pa
Ventilation (Villavent 200)	1.5 m³/m².h 85% rated efficiency

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

North

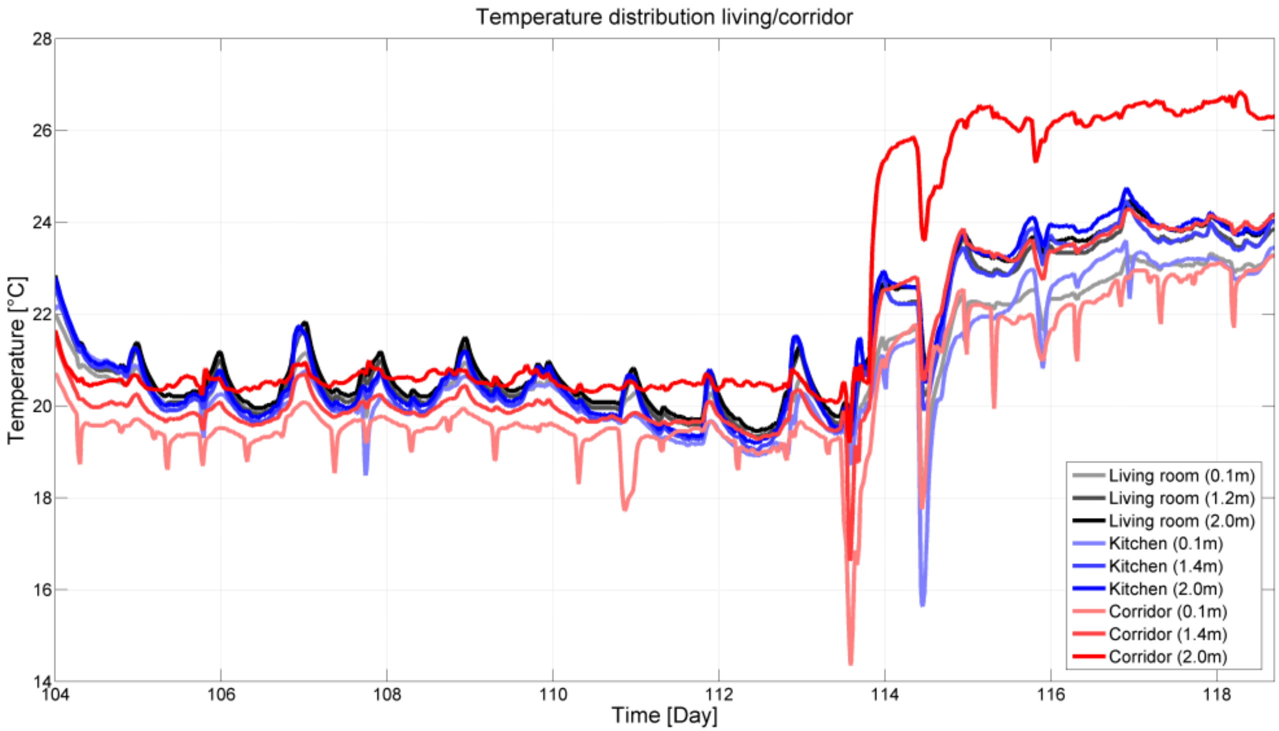


User satisfaction

- 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 due to potential leakage in windows)
  - Satisfied with the temperature in bedrooms but **windows always open**

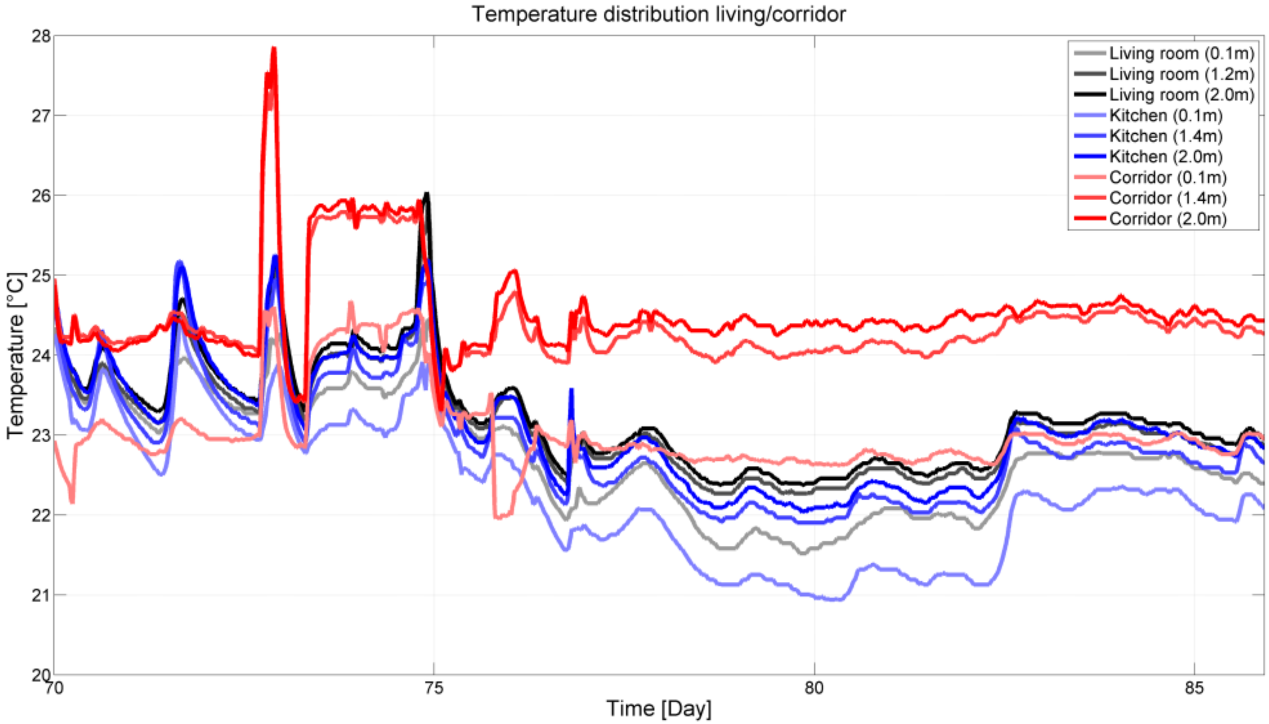
Measurement: heat distribution within room (1)

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



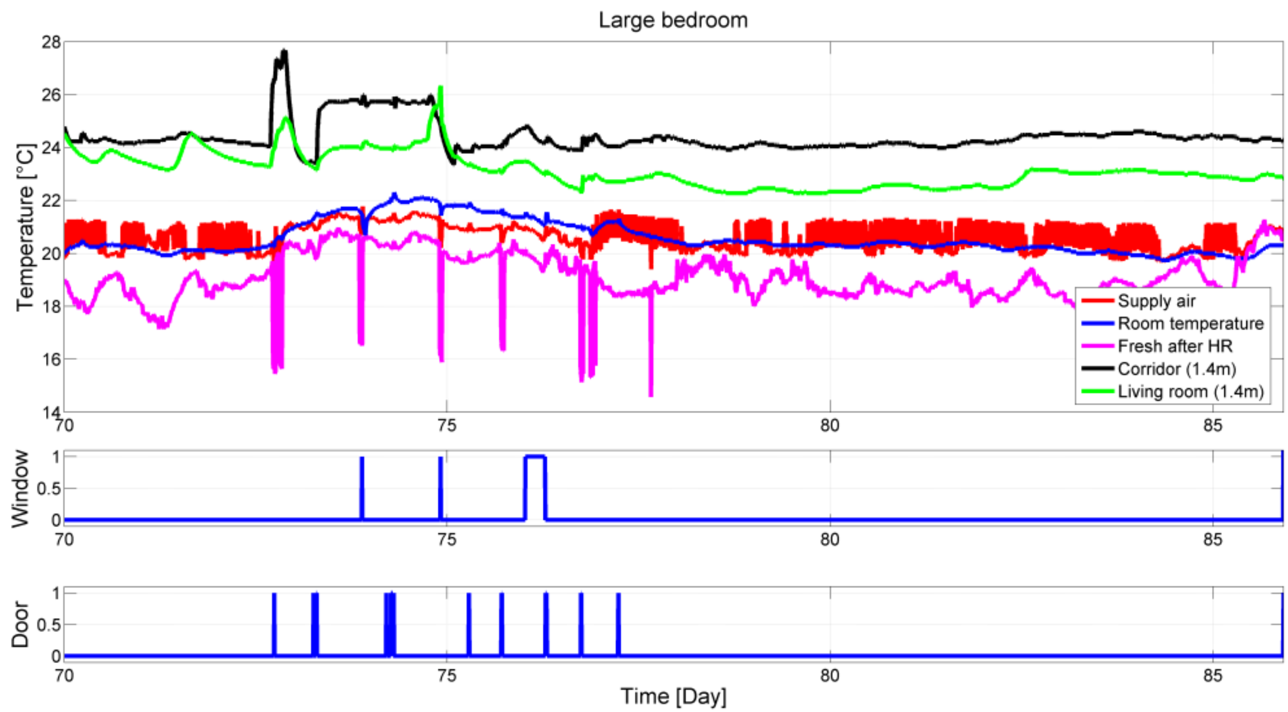
Measurement: heat distribution within room (b)

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



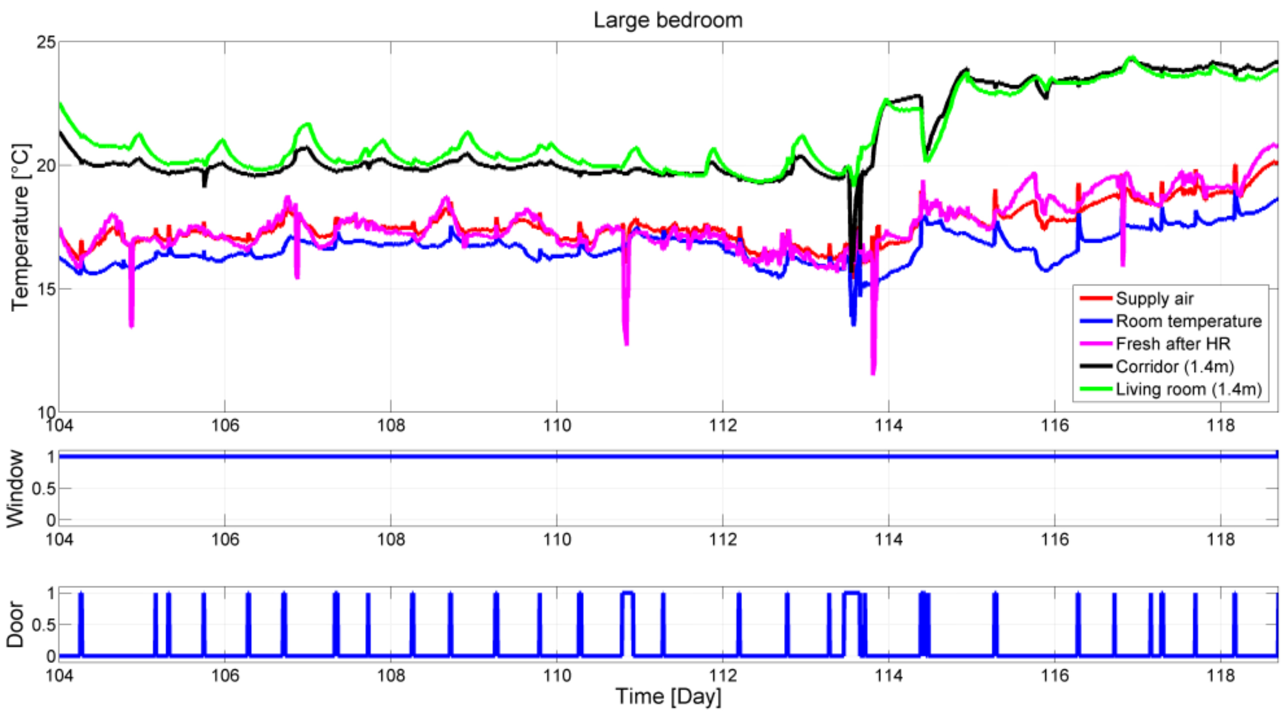
Measurement: bedroom (1)

- 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 ~20C°)



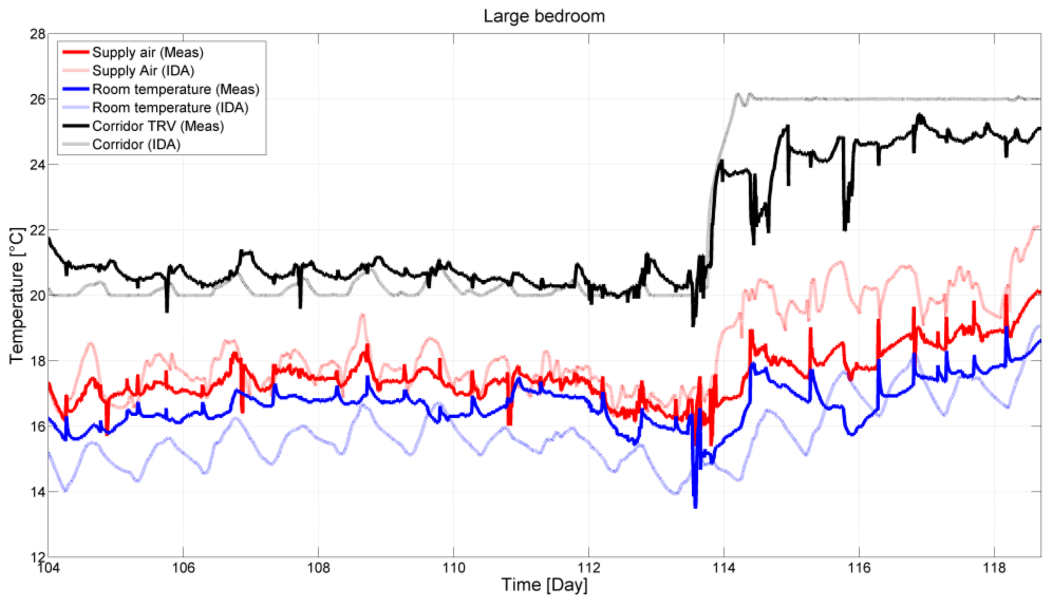
Measurement: bedroom (2)

- 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)



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)



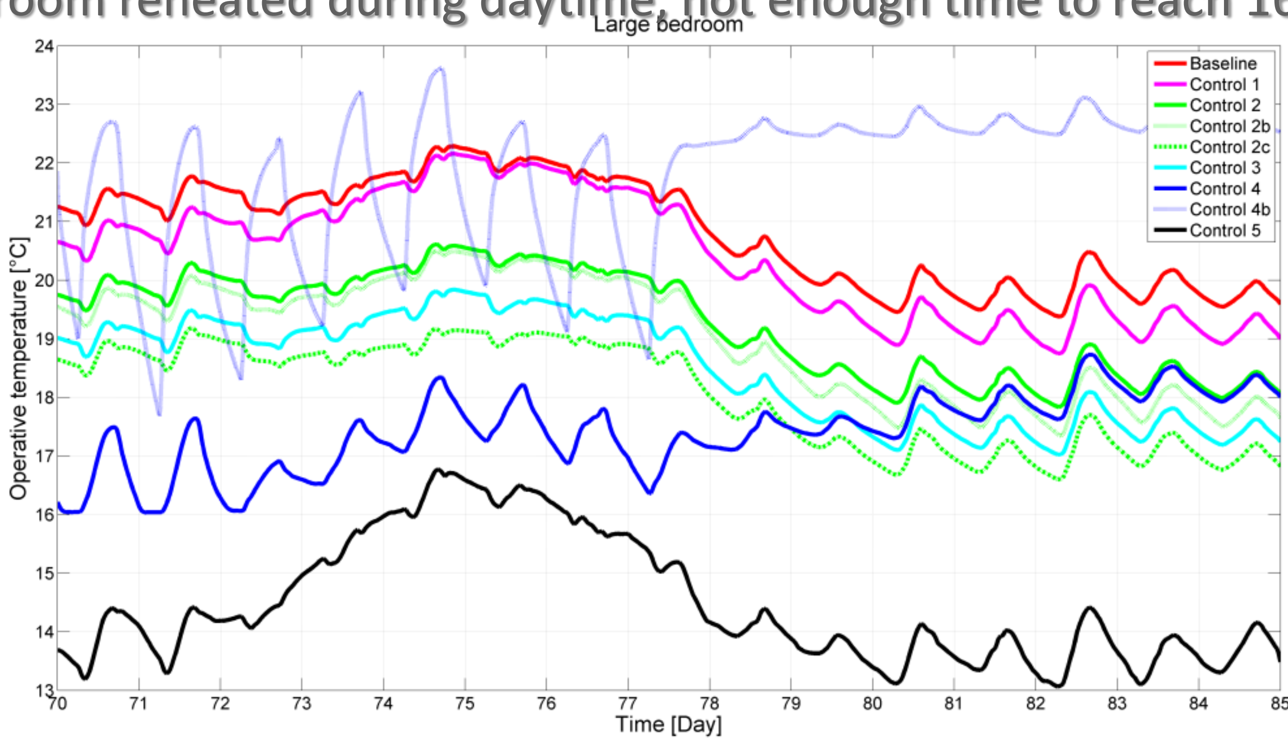
Alternative control strategies

- 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

Control	Tset,HR	Tset,AH	Tset,SH	Window	Door
0, baseline	No	20°C	Exp. Data (24°C)	Closed	Closed
1	No	16°C	Exp. Data (24°C)	Closed	Closed
2	16°C	16°C	Exp. Data (24°C)	Closed	Closed
2b	16°C	16°C	+Night-setback (16°C)	Closed	Closed
2c	16°C	16°C	Constant 20°C	Closed	Closed
3	14°C	14°C	Exp. Data (24°C)	Closed	Closed
4	16°C	16°C	Exp. Data (24°C)	Open if T>16°C and nighttime	Closed
4b	16°C	16°C	Exp. Data (24°C)	Open if T>16°C and nighttime	Open in daytime (window closed)
5	16°C	16°C	Exp. Data (24°C)	Open	Closed

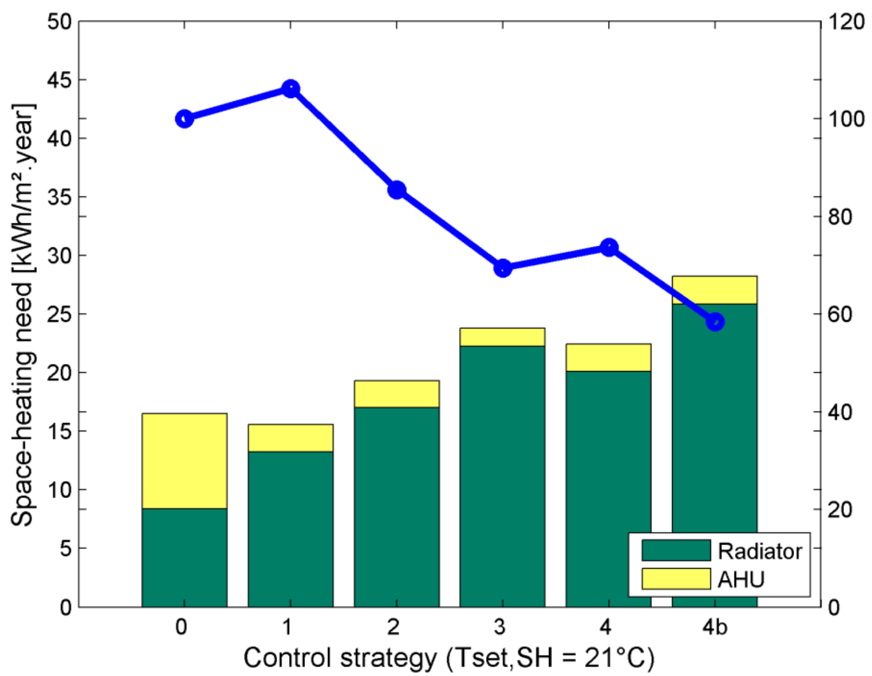
Results: real boundary conditions

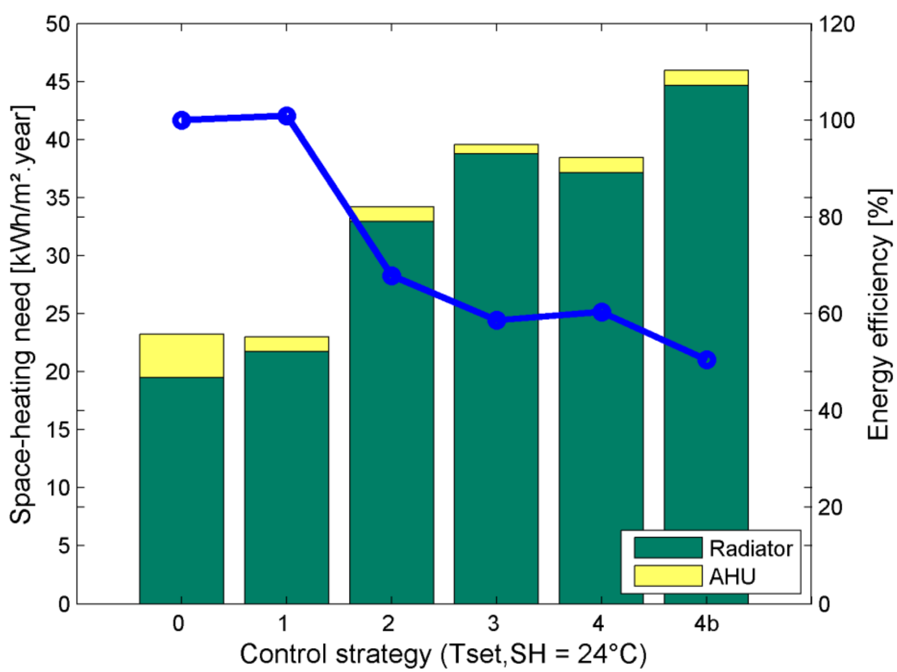
- Reduced Tset,AH does not really helps (case 1)
- Reduced HR efficiency with Tset,HR 16°C reduces of ~2°C (case 2)
  - Night setback in living room does not help (case 2b)
  - Reduced constant living room temperature reduces to ~3°C (case 2c)
- Reduced HR efficiency with Tset,HR 14°C reduces of ~3°C (case3, 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)

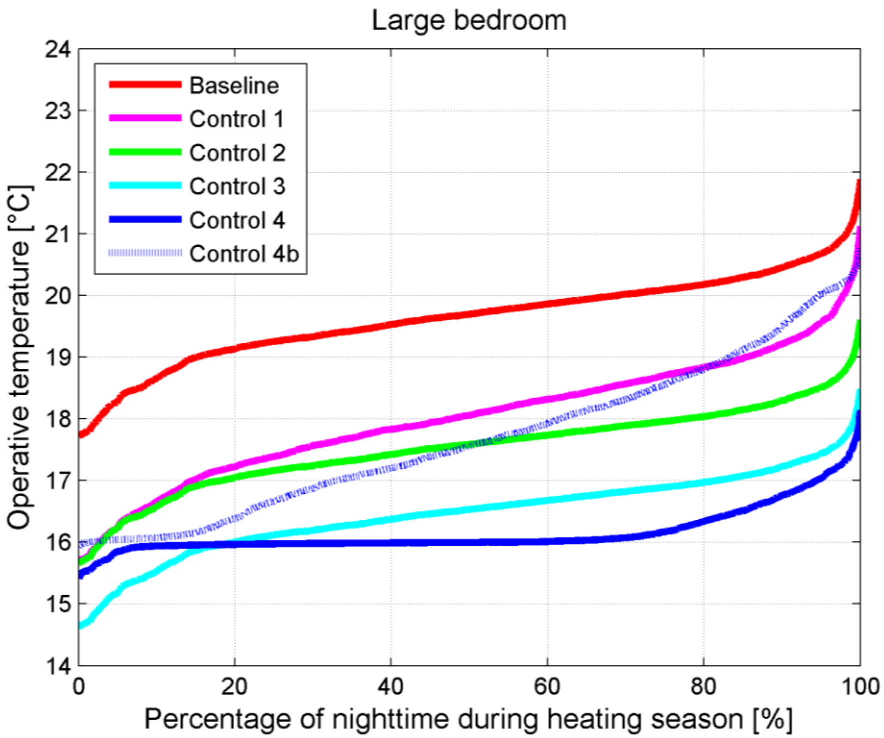
- Baseline and case 1 have the typical 15 kWh/m².year with Tset,SH = 21°C
- Increasing to Tset,SH = 24°C gives 22 kWh/m².year
- Each control alternative leads to an increase of the space-heating needs
  - Reducing the HR efficiency with Tset,HR = 16°C gives +25% (case 2)
  - Reducing the HR efficiency with Tset,HR = 14°C gives +40% (case 3)
  - Opening the window if the bedroom temperature > 16°C gives +40% (case 4)
  - Opening during the night and re-heating during day gives +80% (case 4b)



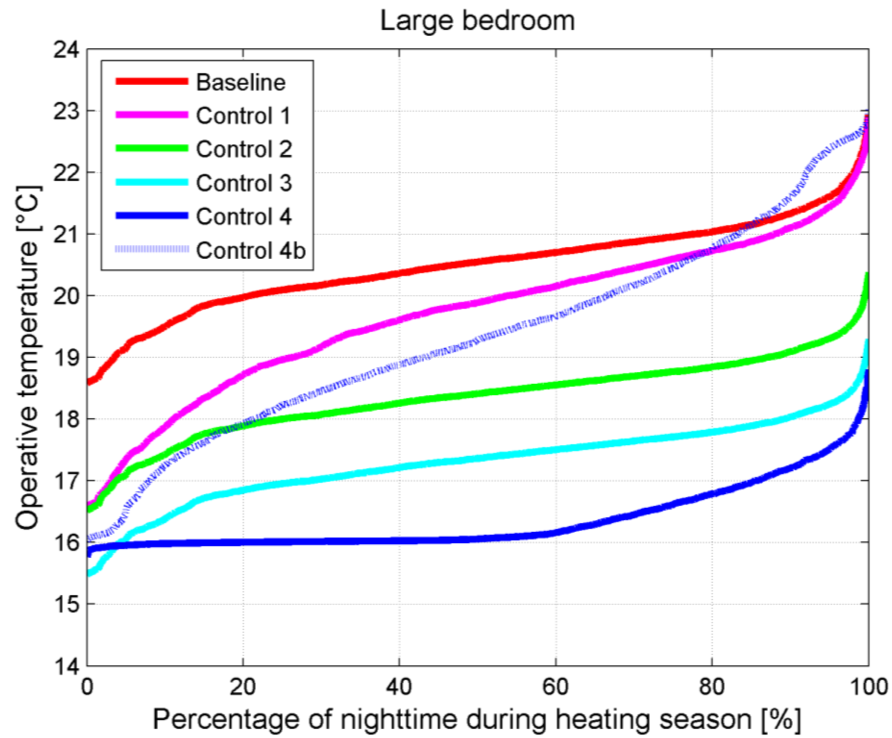


Results: standard boundary conditions (NS3700)

- Temperature duration curve (during occupancy)



Tset,SH = 21°C



Tset,SH = 24°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)