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the innovation and valorization formula

Investigating the potential of adaptable thermal energy storage in lightweight buildings

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seminar duurzaam bouwen met staal 2012

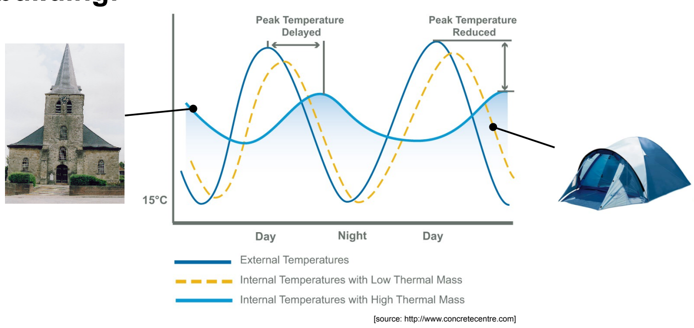
TU/e Technische Universiteit **Eindhoven** University of Technology

TATA STEEL

Contents

Thermal mass

- Thermal mass describes the thermal storage capacity of a building:



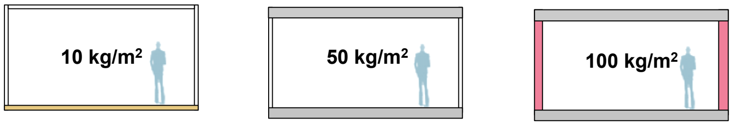
- Lightweight: fast response → Less energy for pre-heating, risk of overheating
- Heavyweight: slow response → Higher energy demand during intermittent use

Thermal mass

- Thermal mass can be quantified using a simplified calculation of the active thermal mass (*that part of the total mass that absorbs and releases energy*)

Temperature of a daily cycle will only reach to a depth of ca. 60mm in a 200mm concrete floor: this 60mm is regarded as the active thermal mass

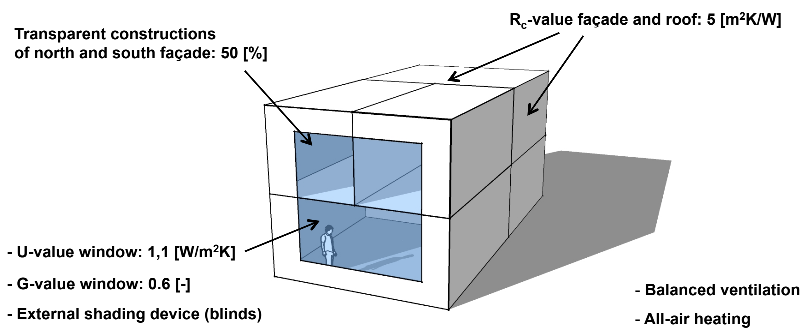
- Examples:



wooden floors, gypsum walls — concrete floors, gypsum walls — concrete floors, mansonry walls

Building case study

- Case study of a building with five zones, modeled in building performance simulation program ESP-r
- Based on Zonne-entree Apeldoorn (The Netherlands)

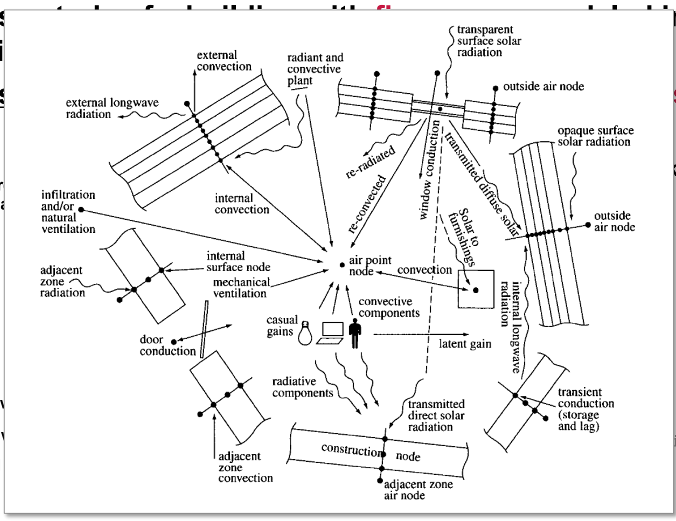


Building case study

- Ca[…] […] bui[…]
- Bas[…] […]s)

Transpar[…] of north […] […]/W]

- U-value […]
- G-value […]
- External […] […]ilation



[Clarke, 2001]

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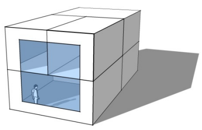
Building case study

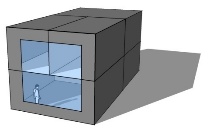
- Simulations of a lightweight and heavyweight building variant are performed to illustrate the influence of thermal mass on building performance

Low thermal mass



15 kg/m²

High thermal mass



100 kg/m²

- Same thermal resistance of the constructions (R_c)
- Ideal control strategy
- Heating setpoint when room is occupied: 22°C
- Heating setpoint when room is unoccupied: 14°C

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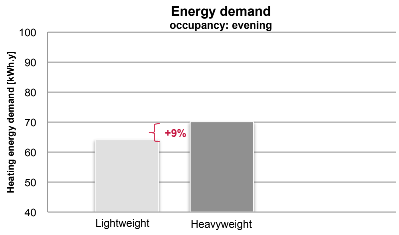
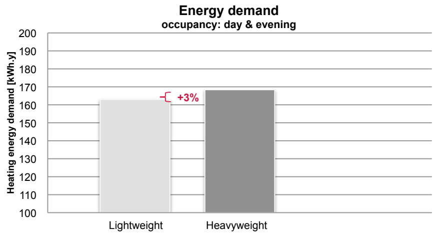
Lightweight and heavyweight

- Influence of thermal mass on the building's heating energy demand for a whole year
- Two occupancy patterns: evenings (18:00h – 24:00h) and day & evening (8:00h – 24:00h)

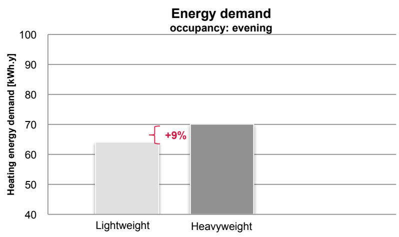


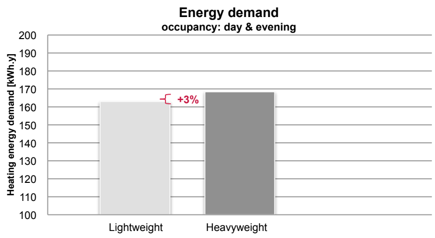


- When the building is used intermittently, choosing for the lightweight variant will reduce the heating energy demand compared to the heavyweight variant

Lightweight and heavyweight

- Influence of thermal mass on the building's heating energy demand for a whole year
- Two occupancy patterns: evenings (18:00h – 24:00h) and day & evening (8:00h – 24:00h)

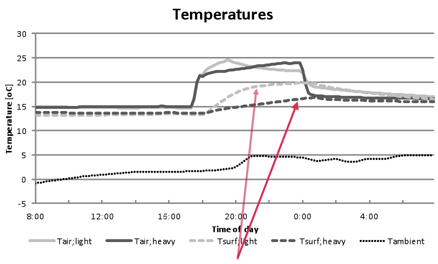


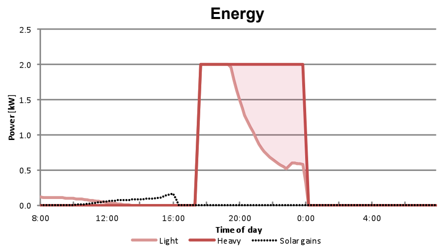


- The unoccupied period causes a temperature drop which increases the benefit of low thermal mass!

Lightweight and heavyweight

- **Simulation results** of a **winter day** show the energy benefit
- Room (ground floor, south facing) was unoccupied for the last two days, **heating starts at 17:30h**





Lightweight shows faster increase of the **walls surface temperatures**, resulting in a **higher** level of **thermal comfort**…

…while demanding **less heating energy**

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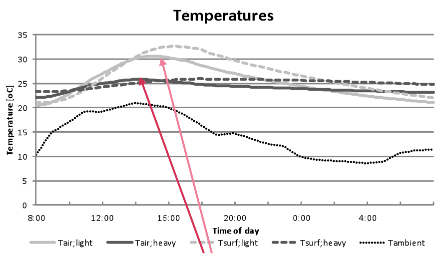
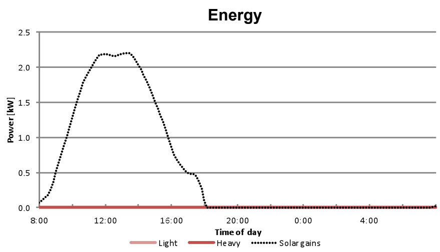
Lightweight and heavyweight

- **Simulation results** of a **summer day** for the same room
- **High solar gains** around noon, <u>no blinds</u>





Heavyweight reduces peak temperatures compared to lightweight, resulting in a **higher** level of **thermal comfort**

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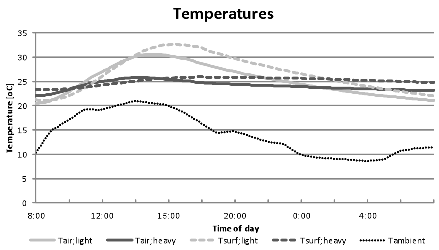
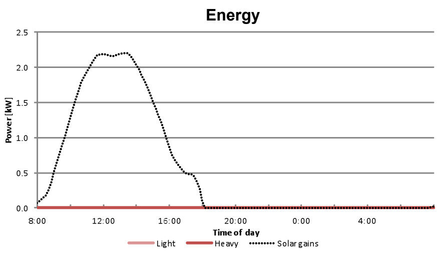
Lightweight and heavyweight

- Simulation results of a summer day for the same room
- High solar gains around noon, no blinds





→ Overheating in the lightweight variant can be reduced significantly with (external) blinds

Optimal thermal mass

- These results show that the preferred thermal mass of a building depends on building use and seasons

- What is the optimal thermal mass per season?

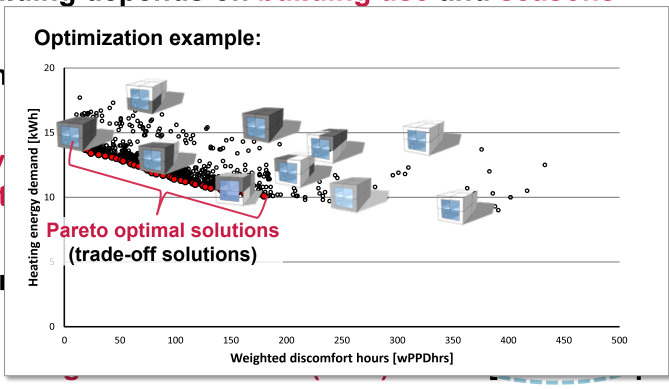
→ Investigate optimal thermal mass using multi-objective optimization

- Performance-indicators (objectives):
  - Heating energy demand [kWh/m^2 per year]
  - Weighted discomfort (PPD) hours [wPPDhrs per year]

In Dutch: GTO-uren

Optimal thermal mass

- These results show that the preferred thermal mass of a building depends on building use and seasons



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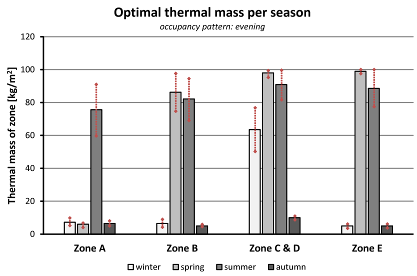
In Dutch: GTO-uren

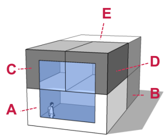
Optimal thermal mass

- Optimal thermal mass per zone per season for evening occupancy:



→Optimal thermal mass changes during the year

→Optimal thermal mass is sensitive to orientation, floor level and change of seasons



Optimal thermal mass

- Each room as an unique optimal thermal mass depending on orientation, floor level and building use

→In general choosing the optimal thermal mass for a building depends on many design and location specific factors

→It is possible to adjust the thermal mass of lightweight buildings to a desired (optimal) level

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   - Direct thermal coupled
   - Indirect thermal coupled
   - Adaptation mechanisms
   - Scoping study
3. Case study

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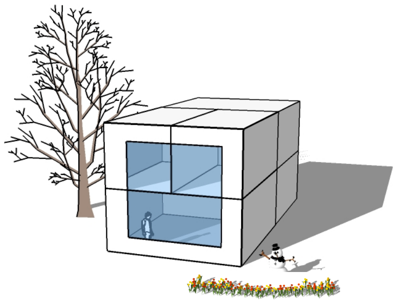
Adaptable thermal mass

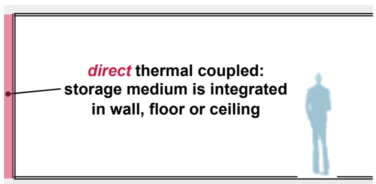
→Optimal thermal mass changes during the year

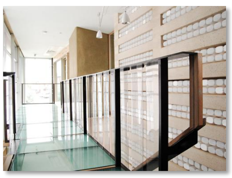
- Is it possible to use an adaptable thermal mass to reduce the energy demand and increase thermal comfort in residential houses (in the Netherlands)?



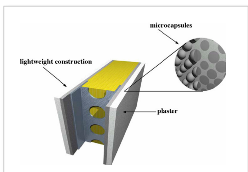
Thermal energy storage

- Use thermal energy storage (TES) to 'add thermal mass' to lightweight buildings:





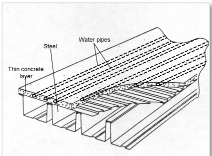
water containers
[Marsh, 2010]



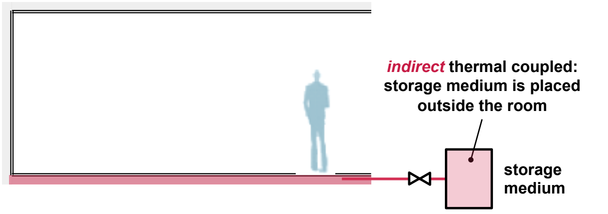
plaster with PCM
[Schossig et al., 2005]

Thermal energy storage

- Use thermal energy storage (TES) to **'add thermal mass'** to **lightweight** buildings:

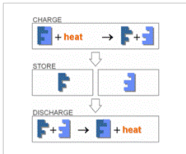


thermally activated building system (TABS)

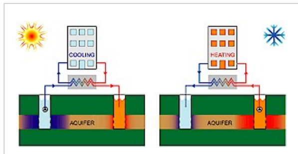


water storage tank

phase change slurries
[Mehling and Cabeza, 2005]



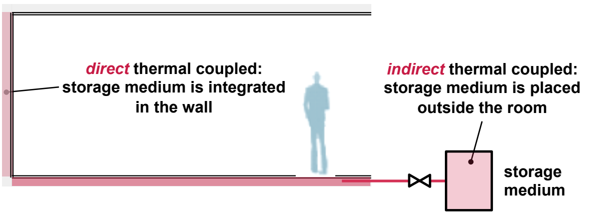
thermo-chemical storage
[www.ecn.nl]



aquifer thermal energy storage (WKO)
[www.iea-eces.org]

Thermal energy storage

- Use thermal energy storage (TES) to **'add thermal mass'** to **lightweight** buildings:

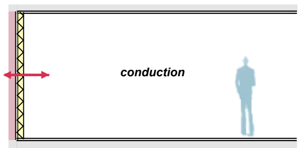


- Make thermal storage **adaptable** in time:
  - **Indirect thermal coupled**: use **conventional techniques**, i.e. distribution system with valves etc.
  - **Direct thermal coupled**: needs **adaptation mechanism**

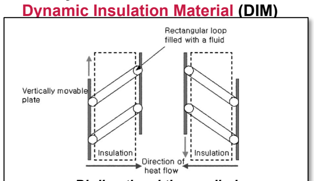
Adaptable thermal energy storage

- Examples direct thermal coupled with adaptation mechanism:

High thermal storage wall with thermodiode

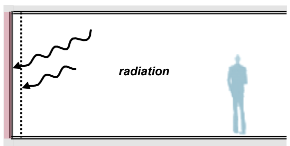


Beyond the state-of-the-art: Dynamic Insulation Material (DIM)



Bi-directional thermodiode
[Chun et al., 2002]

High thermal storage wall with switchable glazing



High thermal storage floor with forced ventilation

Switchable glazing

Adaptable thermal energy storage

- *Adaptable thermal energy storage increases building performance and robustness to changing user behavior, seasonal variations and future climate changes*

→ What is the potential of these concepts?

→ Scoping study to identify promising concepts using building performance simulation

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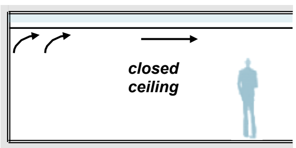
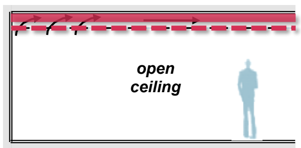
Case study

- Phase change materials (PCM) above suspended ceiling:





Horizontal shutter/screen:

[Source: Chung Tai Roller Shutters, http://www.chungtai-rs.com.hk]

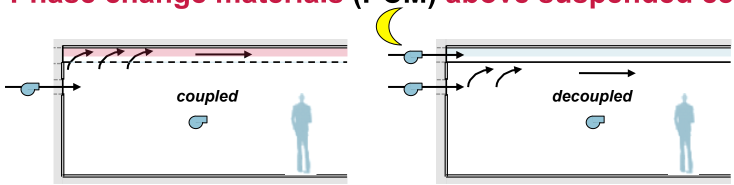
Horizontal louvre:

[Source: Carbolite,http://www.carbolite.com.au]

Fans in ceiling:

Case study

- Phase change materials (PCM) above suspended ceiling:

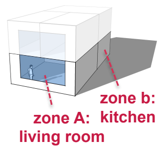


- Possible control options:
  1. Thermal storage capacity: coupled / decoupled
  2. Cavity ventilation: natural / mechanical
  3. Night ventilation: natural / mechanical
  4. Ventilation rate: low / medium / high

→ Model predictive controller defines the optimal control strategy

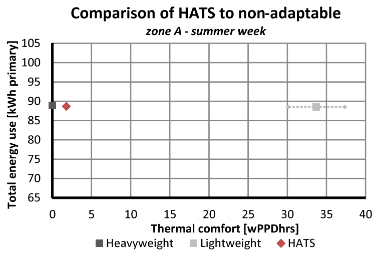
Case study - simulations

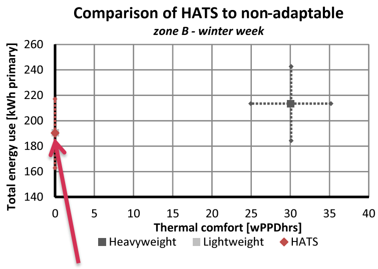
- Model of two rooms with the suspended ceiling
- What is the optimal PCM melting temperature (T_{melt})?
- Two references cases: heavyweight and lightweight
- All building cases have the same ventilation and heating capacity!
- Performance indicators:
  - Total primary energy use (heating + fans)
  - Weighted discomfort hours
- Three weeks are simulated:
  1. Spring week
  2. Hot summer week (max. 30°C)
  3. Cold winter week (min. -8°C)



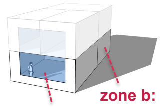
Case study - results

- Results summer and winter week for T_{melt} = 22°C:





Adaptable (HATS) control sequence: lightweight, except for one heavyweight day



Case study - results

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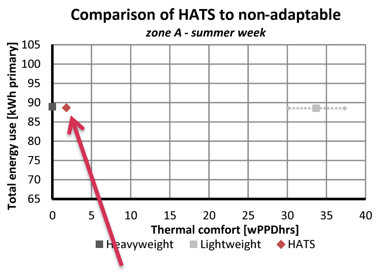
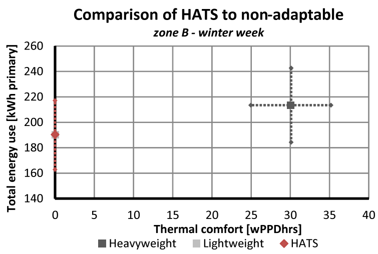
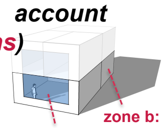




Adaptable (HATS) control sequence: heavyweight
(no optimal comfort due to disturbances in the controller: controller chose for the most robust control sequence taking into account disturbances due to occupant behavior and weather predictions)



Case study - results

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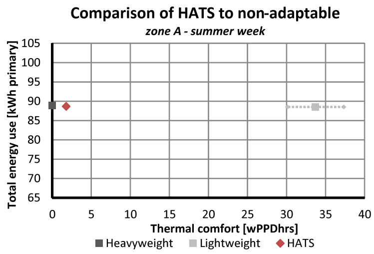
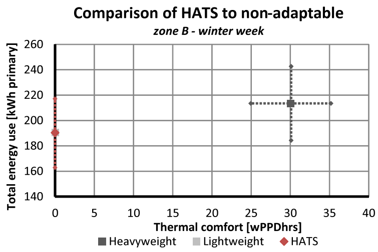
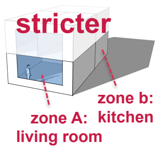


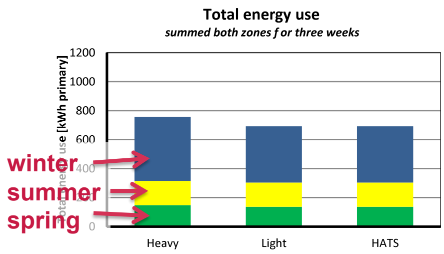


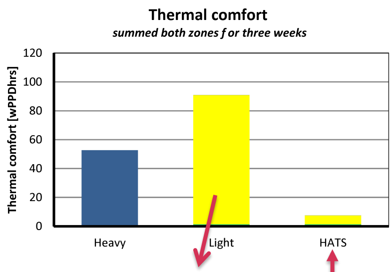
- Thermal comfort of the reference cases can be improved by altering the design (which will increase energy use):
  - Lightweight: higher ventilation capacity and stricter closing of blinds
  - Heavyweight: higher heating capacity



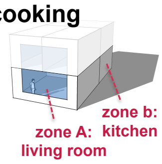
Case study - results

- Summed results for both zones and all three weeks:





Main cause is combination of high outdoor temperatures with high internal loads for cooking in zone B



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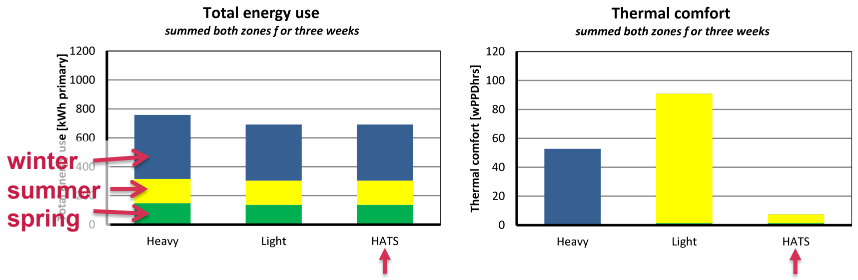
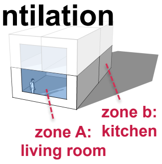


- HATS shows lowest energy demand and highest thermal comfort, while requiring the smallest ventilation and heating capacity!



→ Potential!

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Thank you!

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