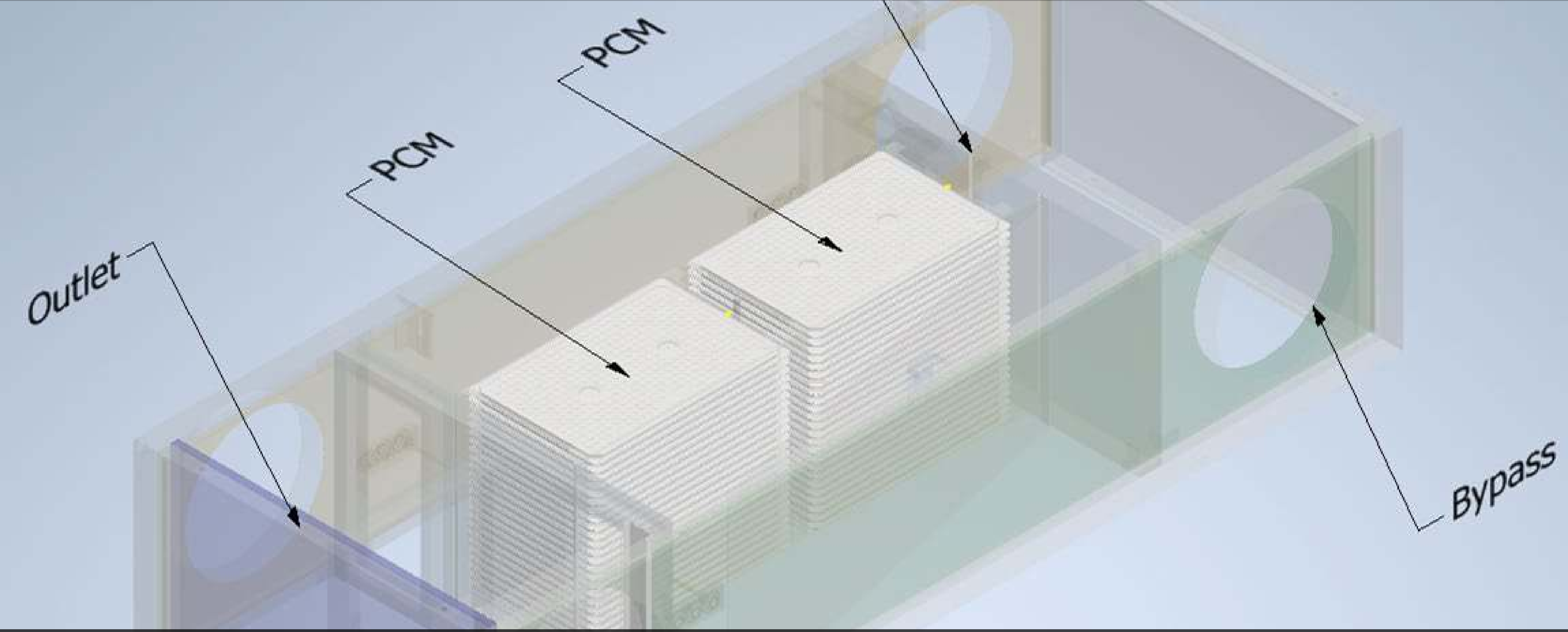


Performance evaluering af PCM baseret køleløsning i HVAC

Danvak Dagen 2022

d. 6 April

Viktor Bue Ljungdahl

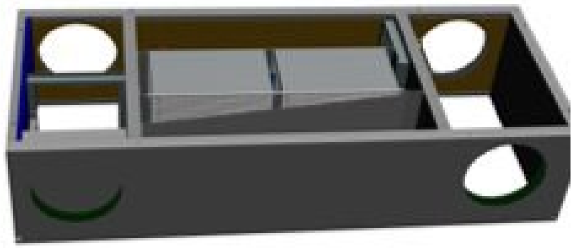
- Cevilingeniør i energiteknologi (2014-2020)
  - SDU
- Ph.d. studerende (2018-2022)
  - Syddansk Universitet (SDU)
  - Center for Energy Informatics (CEI)
- Titel på projekt:
  - “Modelling, design and assessment of innovative phase change material-based HVAC systems”

SDU
ENERGY INFORMATICS

NeGeV

Next Generation Ventilation

- Sponsoreret af EUDP
- 5 projekt partnere
- 2018-2021
- PCM-baseret køleløsning



SDU ENERGY INFORMATICS

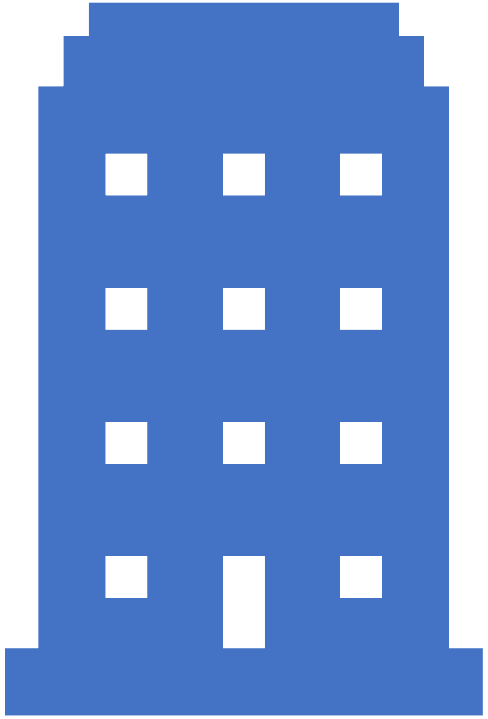
RUBITHERM PHASE CHANGE MATERIAL

EUDP Energiteknologisk udvikling og demonstration

DANISH TECHNOLOGICAL INSTITUTE

EXHAUSTO

Bitzer



Motivation

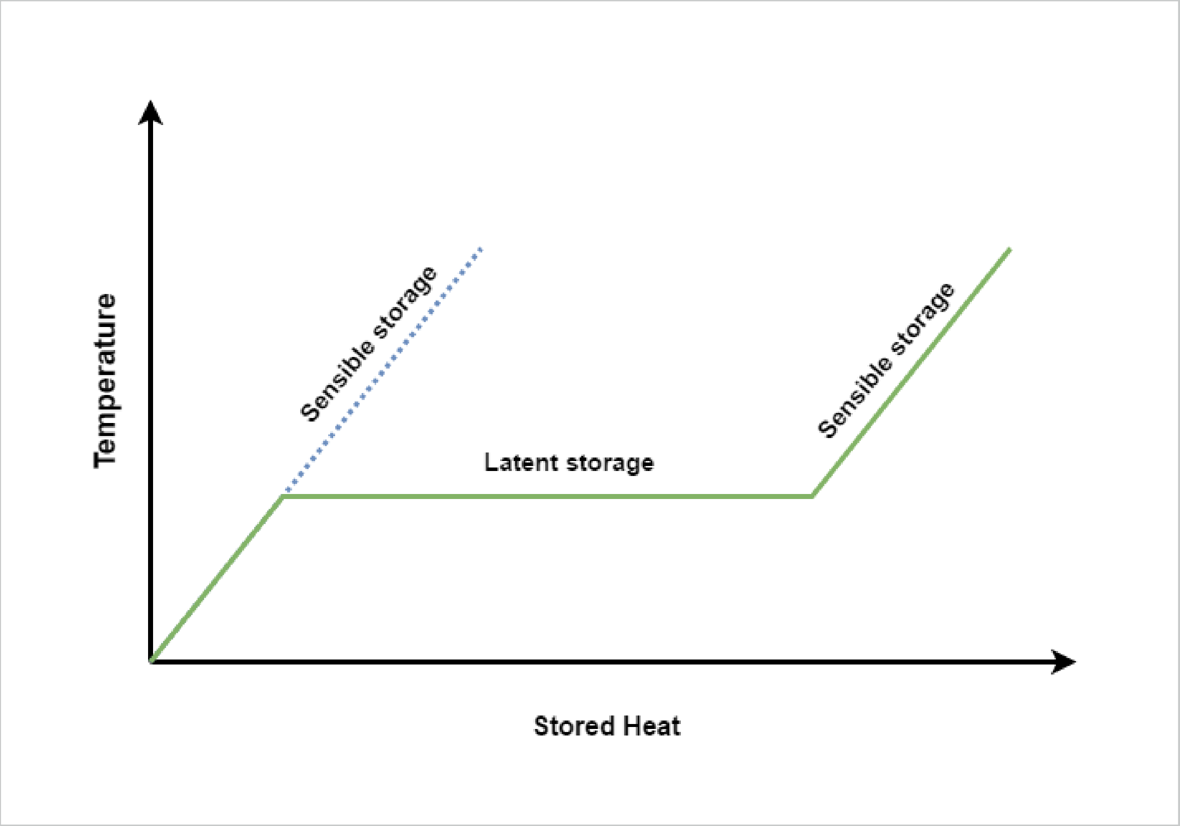
- Bygnings sektoren→ ca 30 % globale energiforbrug
  - 40-50 % af dette kommer fra Heating Ventilation and Air Conditioning (HVAC)
- Kølebehov er stigende
  - Konventionel køling har højt energiforbrug og bruger miljøbelastende kølemidler
- PCM har vist stort potentiale i mange typer af termiske løsninger
  - Aktive/passive løsnigner
  - For at opnå benyttelse er aktive løsninger nødt til at vise at de kan være kompetitive

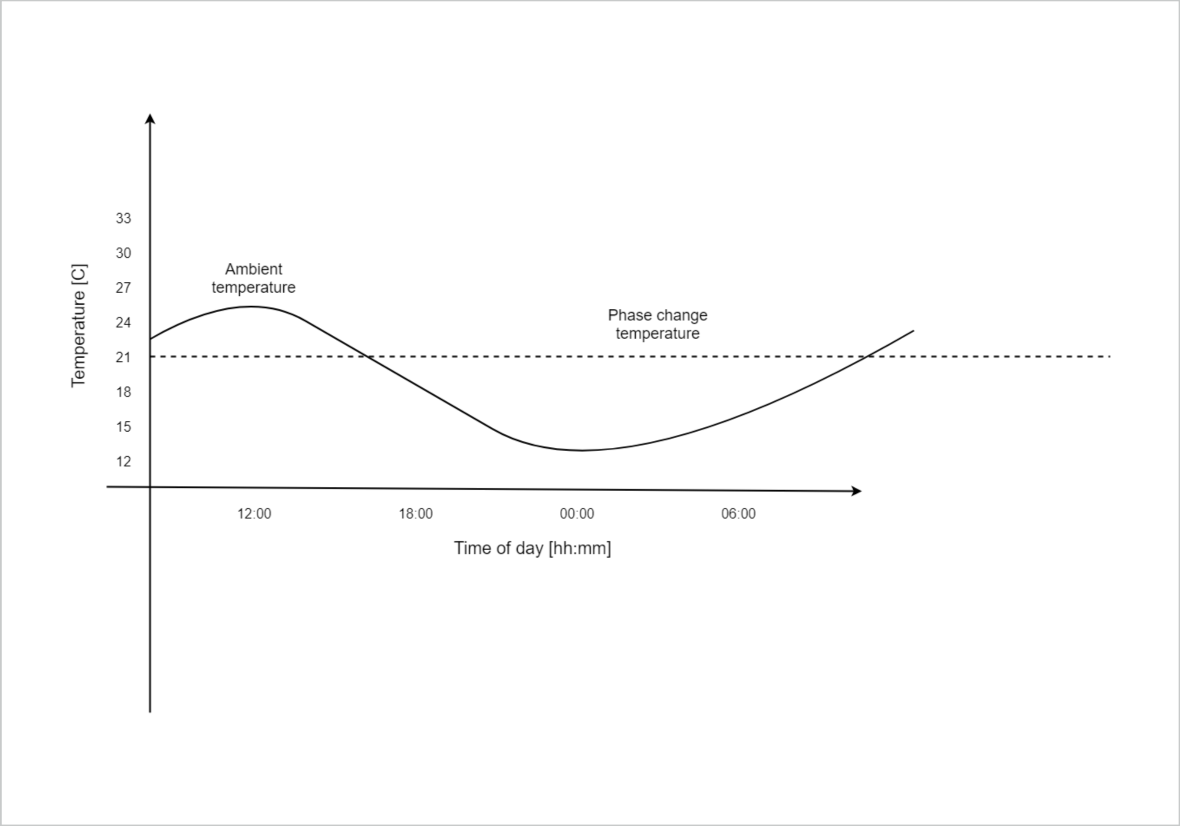
Faseændringsmaterialer (PCM)

- 3 faser
  - Fast
  - Flydende
  - Gas
- Alting
- Salthydrater
  - (salt hydrates)
  - uorganiske
- Parafiner
  - Organiske

Hvorfor faseændring?

- Højt energiindhold
- Oplagring
- Konstant temperatur
- Udnytte kilder med lav temperatur

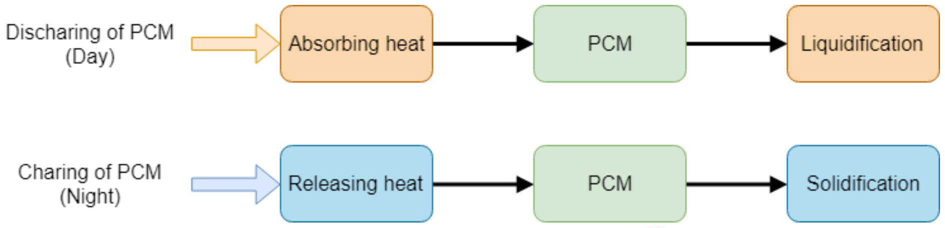


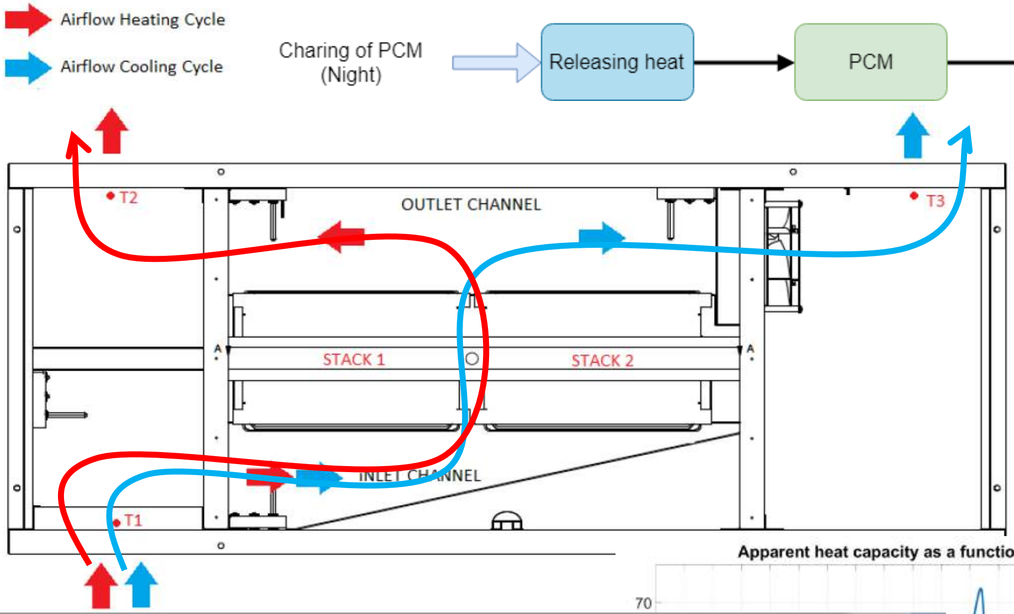


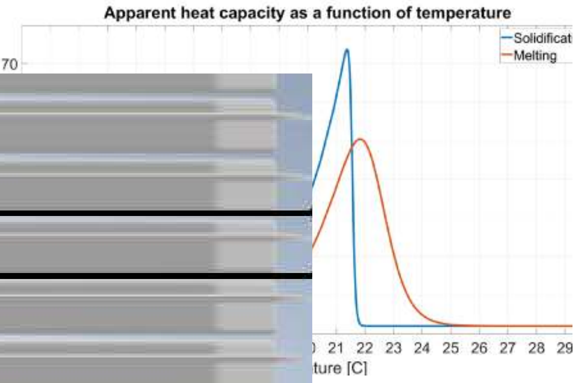
PCM baseret køling

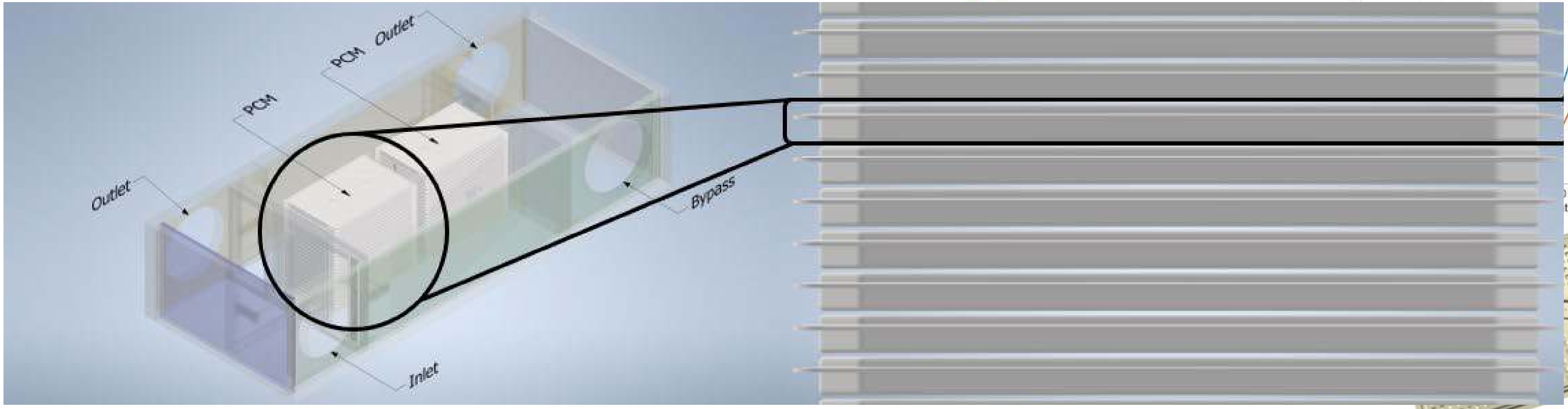
- Add-on til et ventilation system
- 96 kg PCM
- SP21EK
- 1-zone køle-levering

- Køler PCM'et ned om natten (Solidificering)
- Køler forsyningsluften ned om dagen (Smeltning)



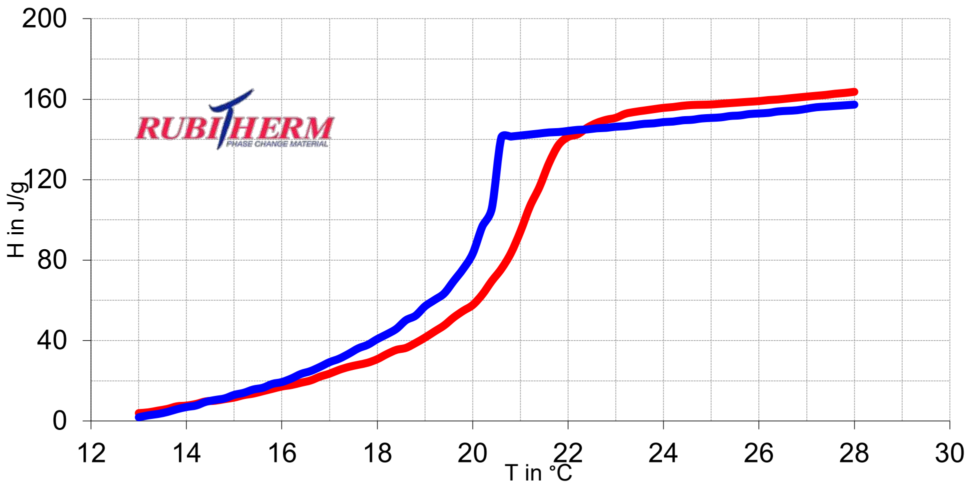


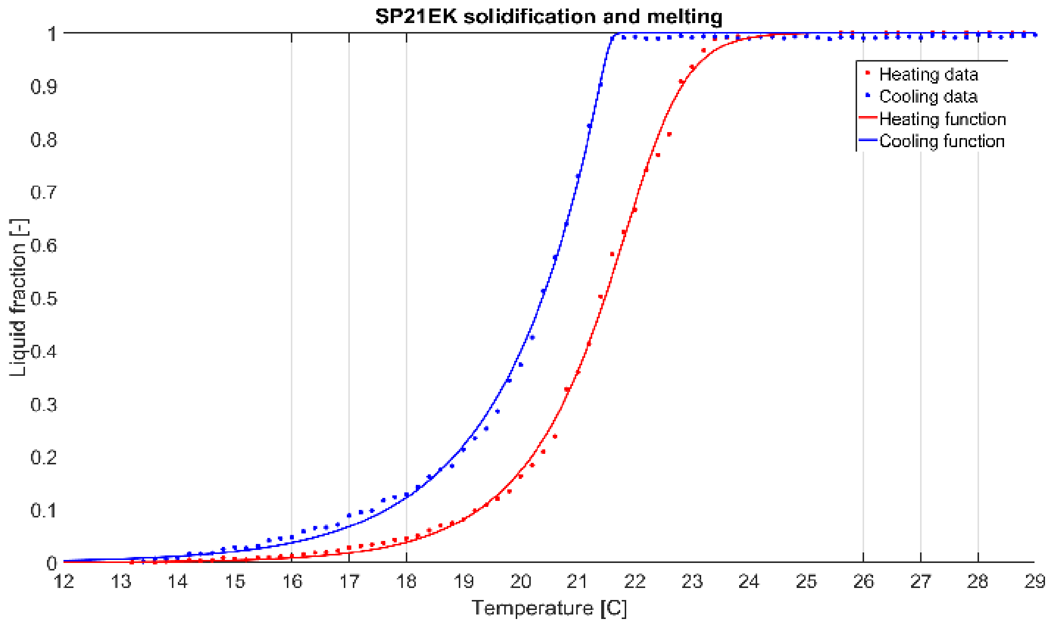




Hysterese – opførsel under faseskift

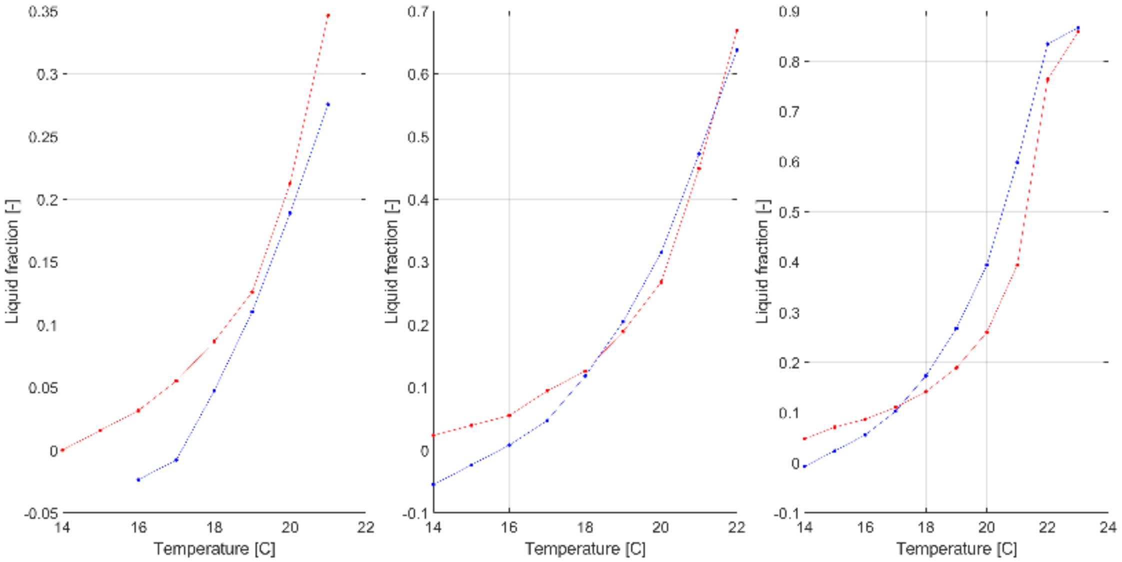
- Ikke ideel opførsel
- Isotermisk faseskifte
- Forskellig smelte og solidificeringstemperaturer
- Superkøling

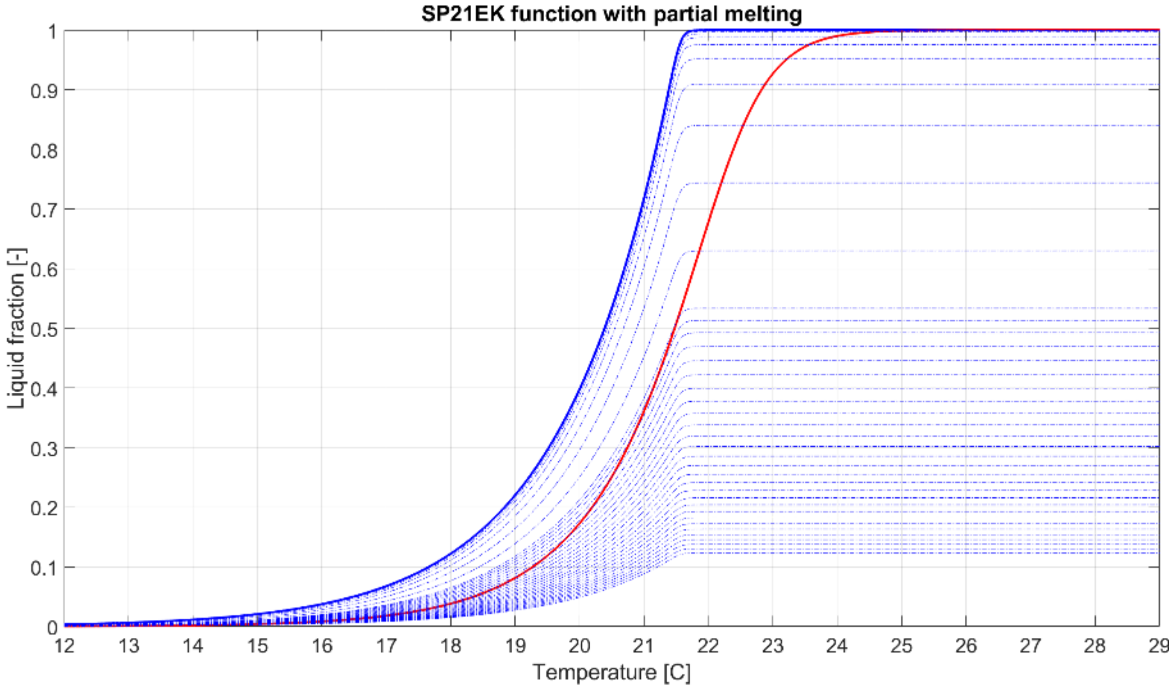


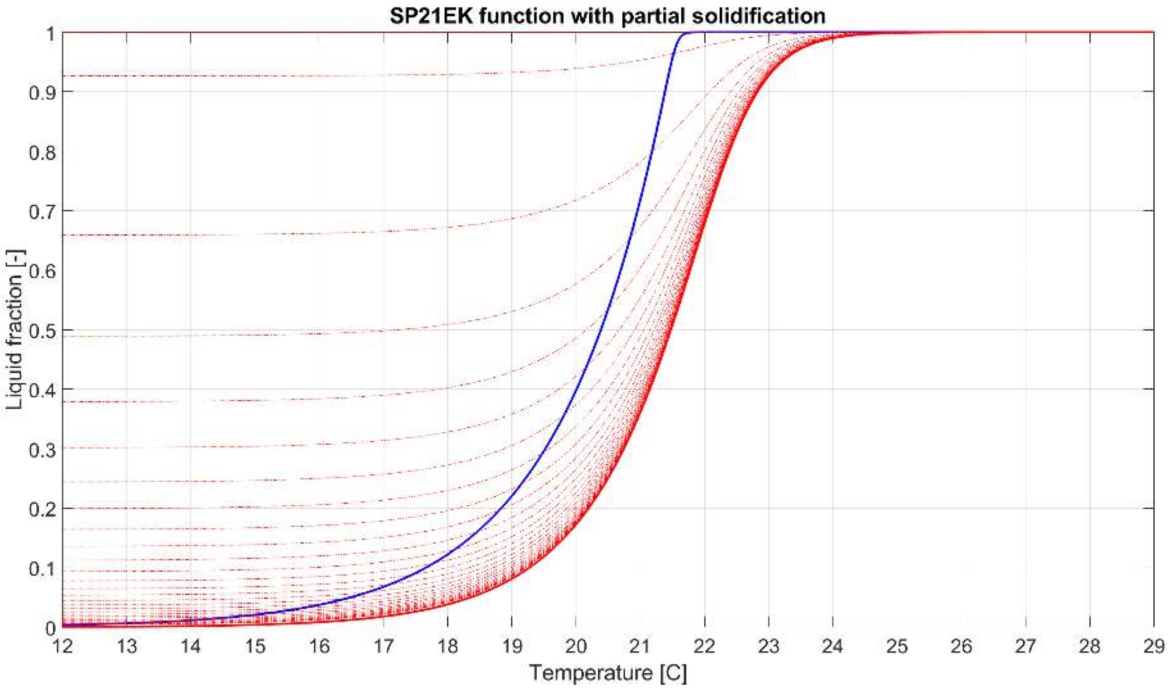


Partiel faseskift

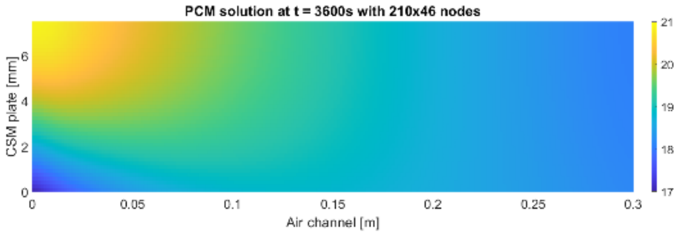
Ikke garanteret fuldt faseskift

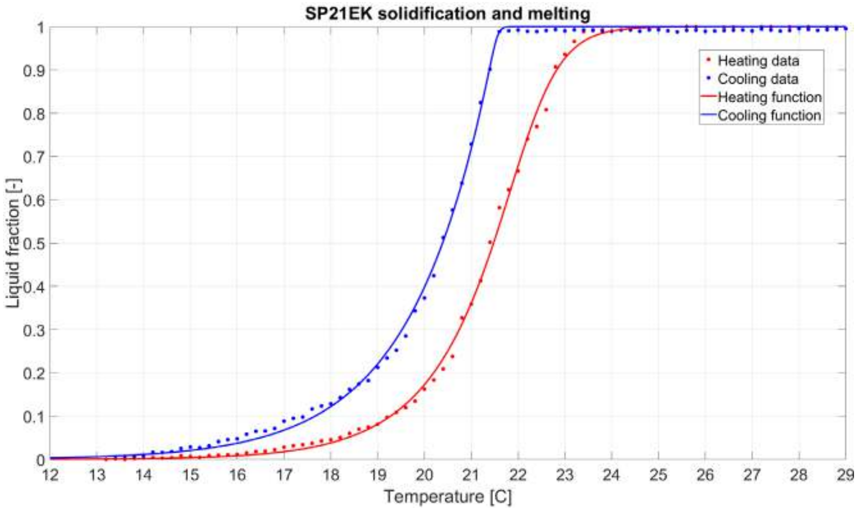




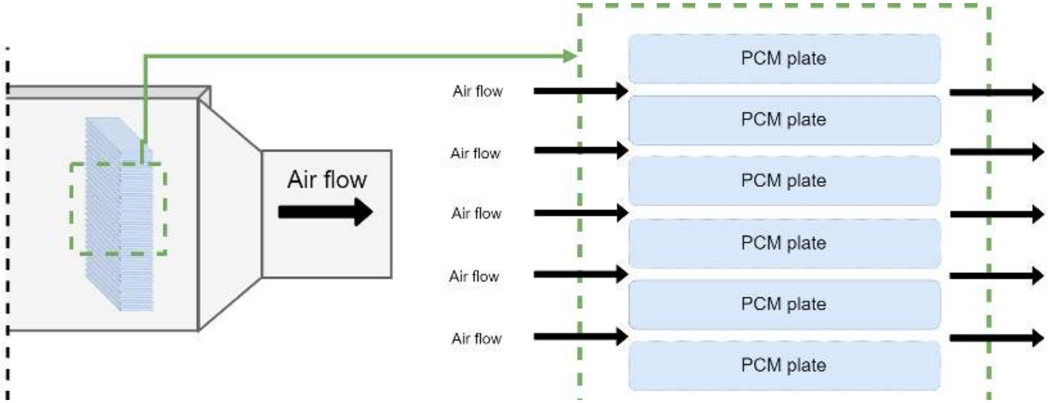


PCM model



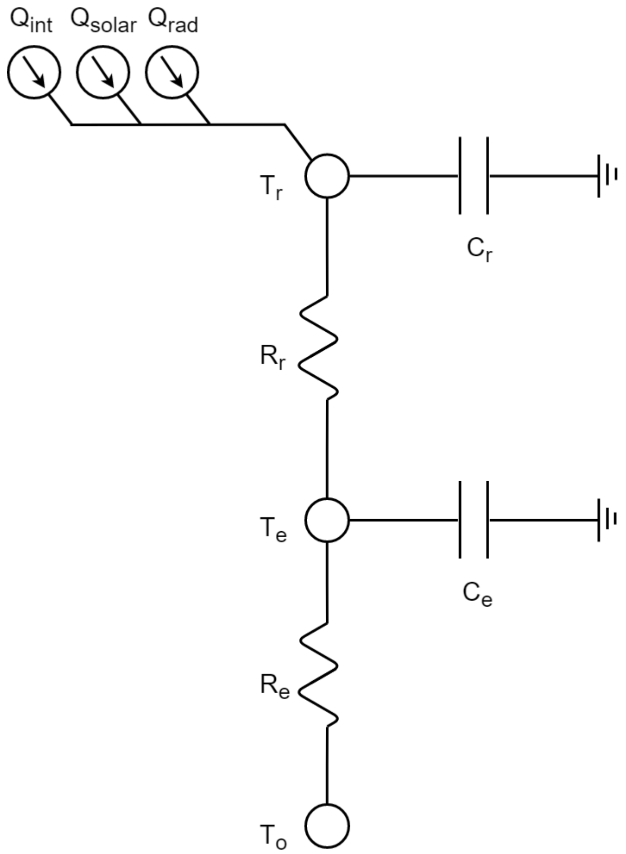


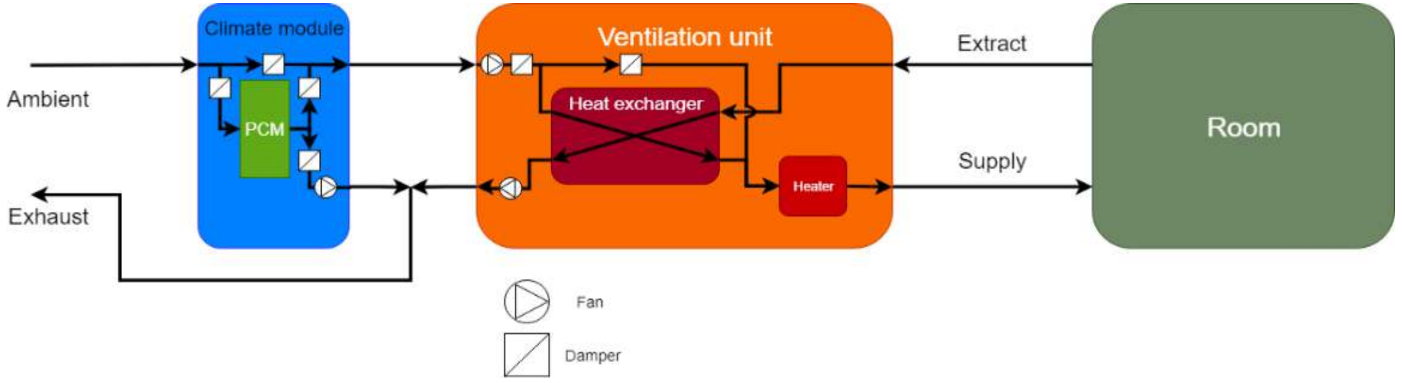
- 2D numerisk model
  - 1/2 PCM panel & luft kanal
  - Varme konduktion inde i PCM
  - Konvektion varme overførsel mellem luft og PCM
  - Hysterese i PCM materialet

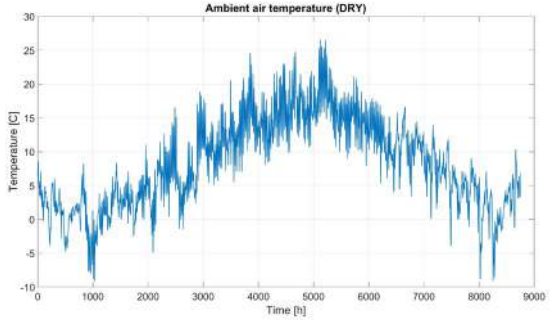


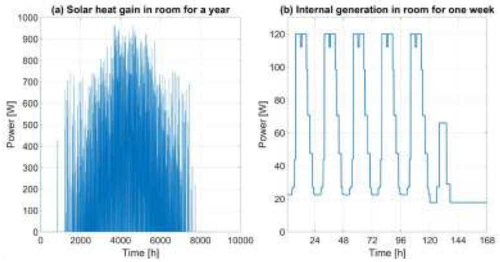
Rum model & ventilation system integration

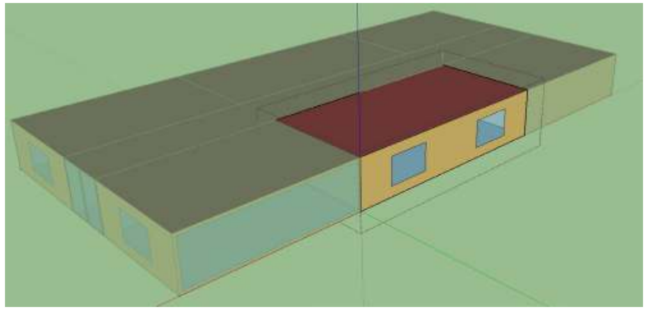
- Resistor-capacitor termisk model af zonen
- Energibalancer og varme koefficient korrelation baserede ventilation model
- System modeling
  - Klima modul model
  - Ventilation system model
  - Rum model
- Simulering med klima data

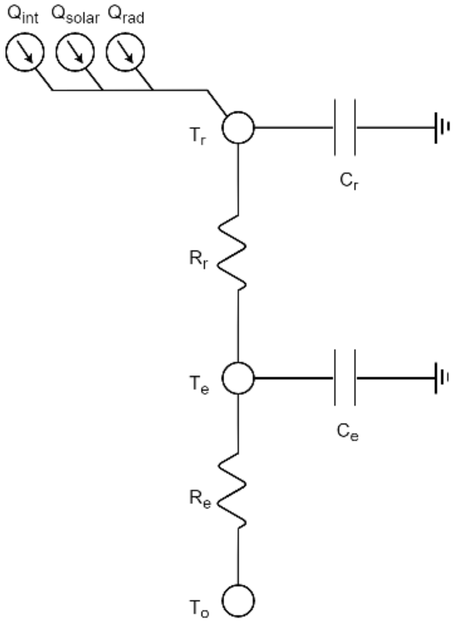










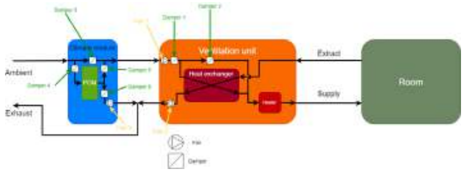


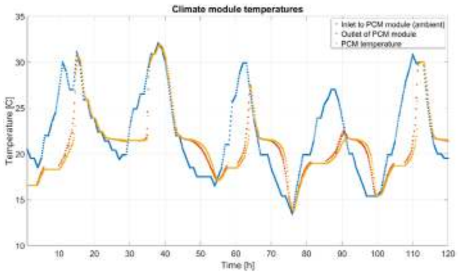
Case study

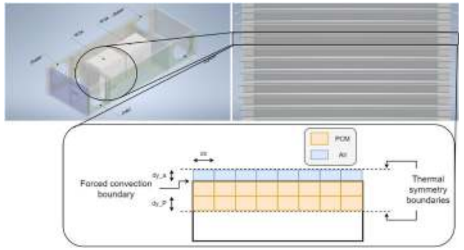
- Dansk klima
  - Design Reference Year (DRY)
- Internal varme generation fra skole
- Skemalagt CO_2-generation
- 25 mennesker
  - 08:00-16:00
- Varmeindstrålingsprofil fra sol
- Bygning
  - 6 x 10 x 3.5 m
- Temperatur set point: 21°C ± 2°C
- CO_2 set point: 800-1200ppm

Mål

- Modeling af systemet
  - Numeriske PCM model
  - Resistor-capacitor rum model
  - Energi balance, ventilation system model
- Klima modulets performance
  - Energi performance
  - Termisk komfort performance
  - Indendørs miljø performance

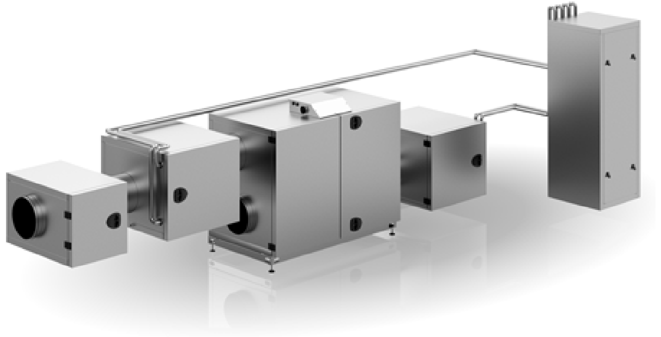




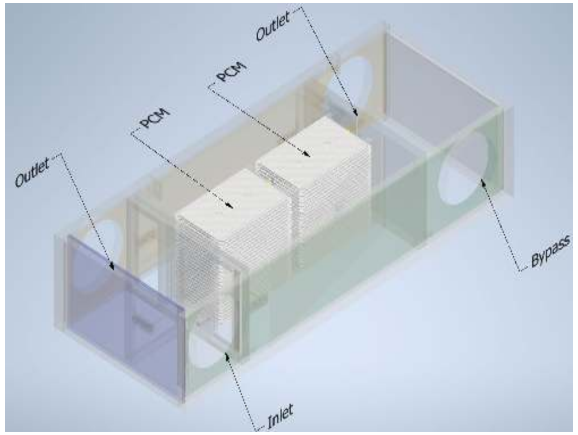


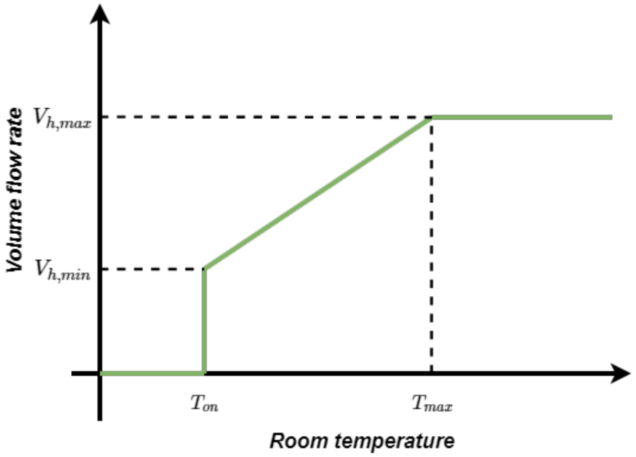
	Ventilation system (Reference)	Konventionel køling (Kompressor baseret)	PCM
Årligt elektricitets forbrug [kWh]	-	-	-
Yearly termisk comfort brud [°Ch]	-	-	-
Gennemsnitlig CO2 niveau [ppm]	-	-	-
Højeste rum temperatur [°C]	-	-	-

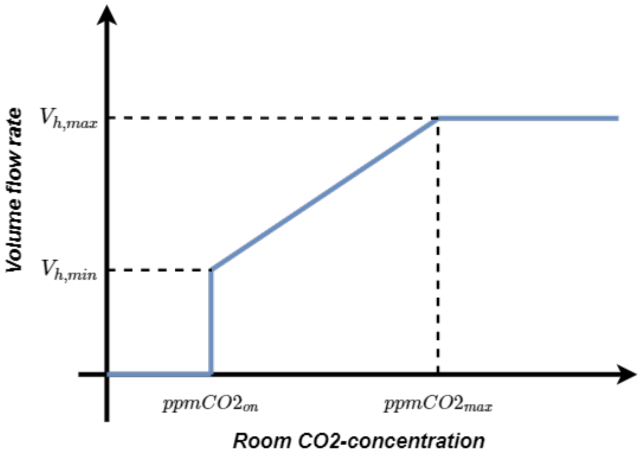
Scenarier



- Referencer
  - Ventilation baseret operation
- Kompressor baseret teknologi
- PCM baseret køling
- Forskellige kontrol strategier

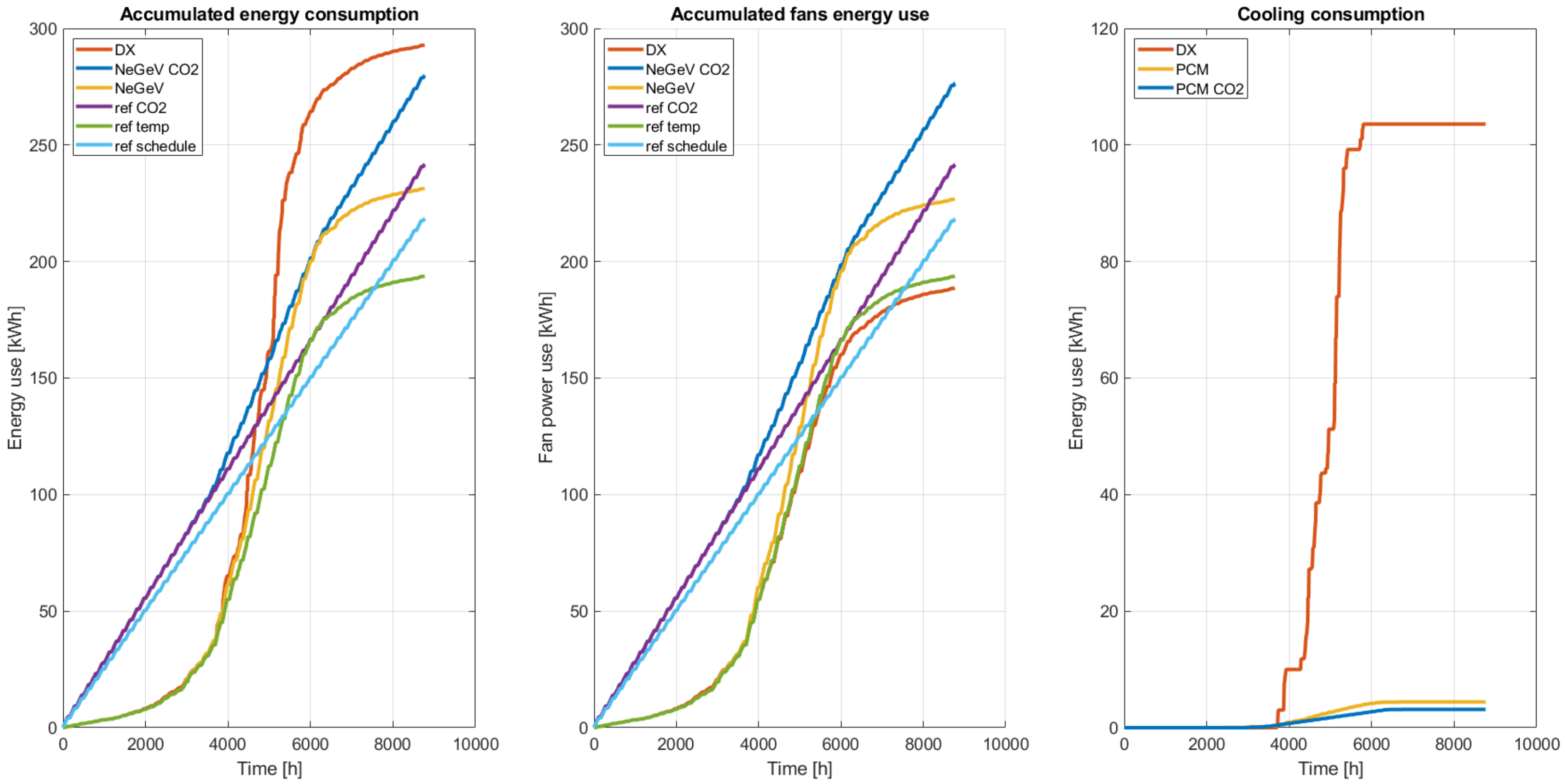






Key performance indicators

- Energi forbrug
  - Akkumuleret energiforbrug fra:
    - Blæsere
    - Spjæd motorer (All)
    - Kompressor (Konventionel køling)
    - Tryk tab i PCM modulet
- Termisk komfort
  - Højeste temperatur i rummet
  - Brud af øvre termisk grænse.
- Indendørs miljø
  - Gennemsnittelig CO_2-koncentration
  - Brud af øvre CO_2-koncentration



Energi forbrug - sammenligning

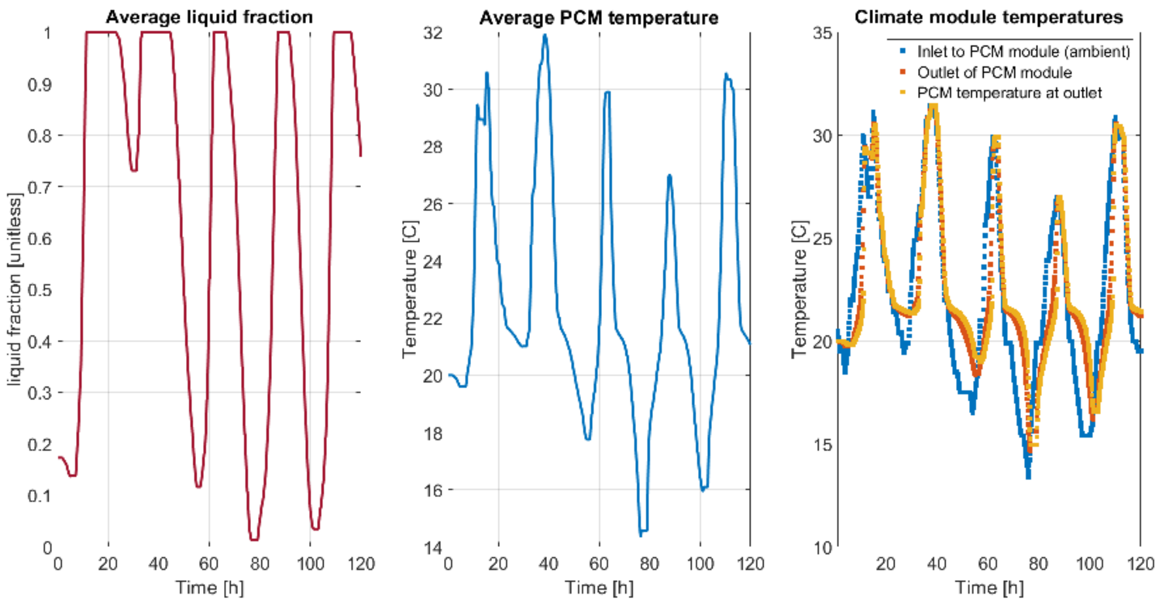
- Reference - 16-19 % forøget elforbrug
  - Oftere benyttelse
  - Benyttelse om natten til regenerering
- Konventionel køling - 27 % reduktion i elforbrug
  - Højere elforbrug associeret med køling.

Termisk komfort

$$Thermal\,Violation_{acc} = \sum_{i=1}^{t}(T_{room,i} - 23°C) \times \Delta t \qquad , \qquad T_{room,i} > 23°C$$

DRY

	Ref temp	Ref CO2	DX	PCM temp	PCM CO2	Schedule
Accumulated violation [°Ch]	307.8	1611	0.00385	127.4	1123	1802
Highest room temperature [°C]	31.9	35.7	27.7	30.5	34.1	35.9



- Reference - Reduceret max temperatur med 1.4-1.6 °C
- Reference – 30-59 % reduktion I termisk komfort brud

Indendørsmiljø

- Gennemsnitlig CO2-koncentration
- Højeste CO2-koncentration

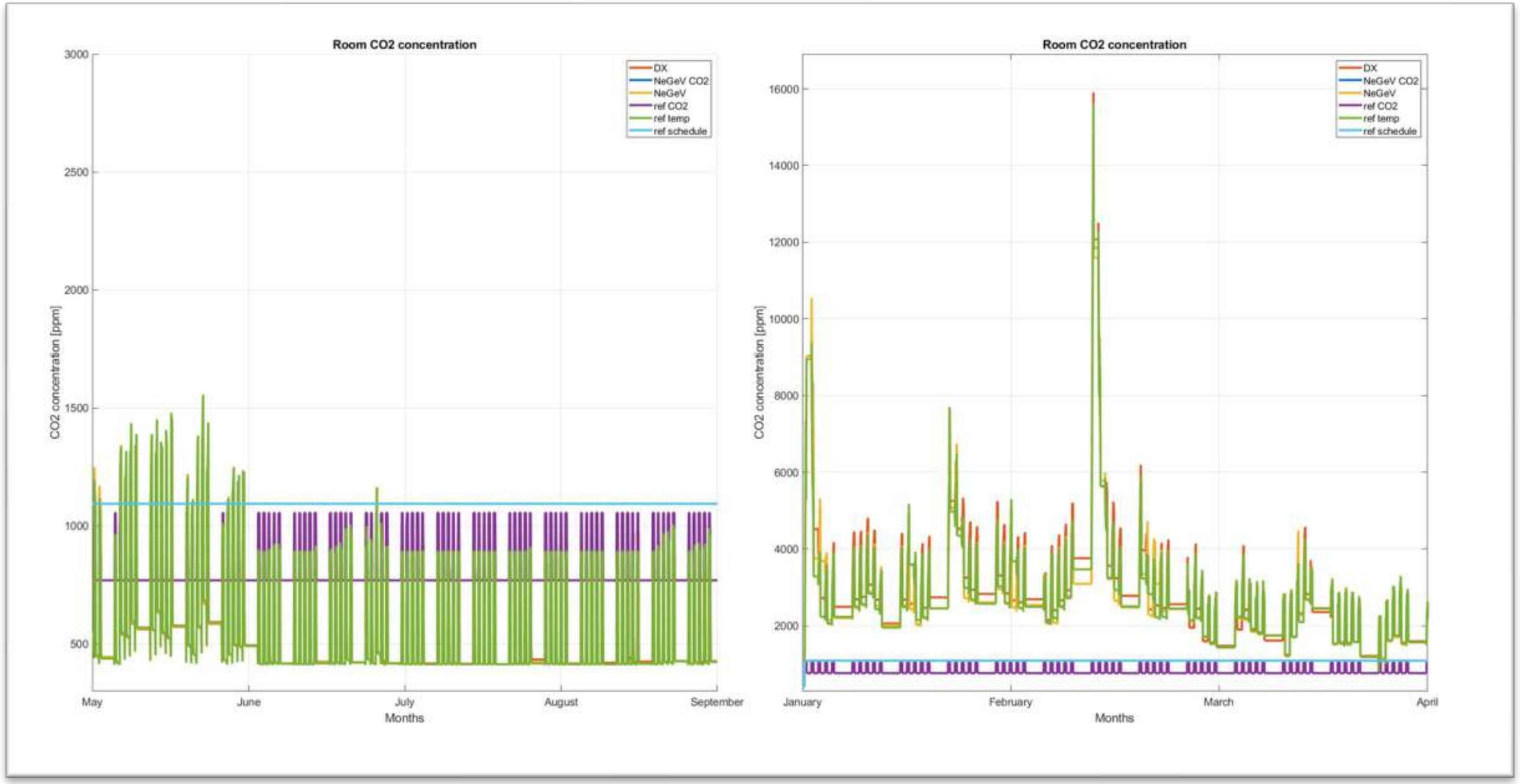


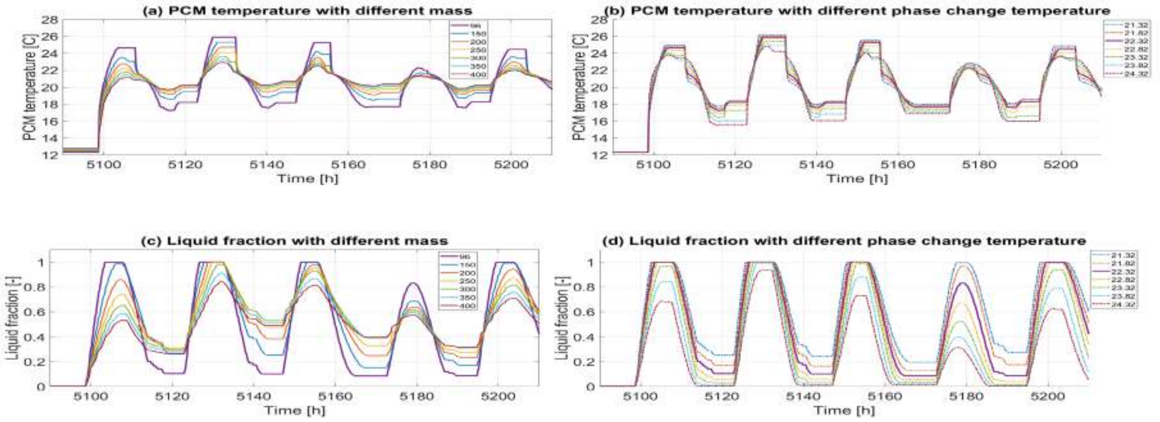
Table 3: *Indoor environment violations for each of the scenarios*

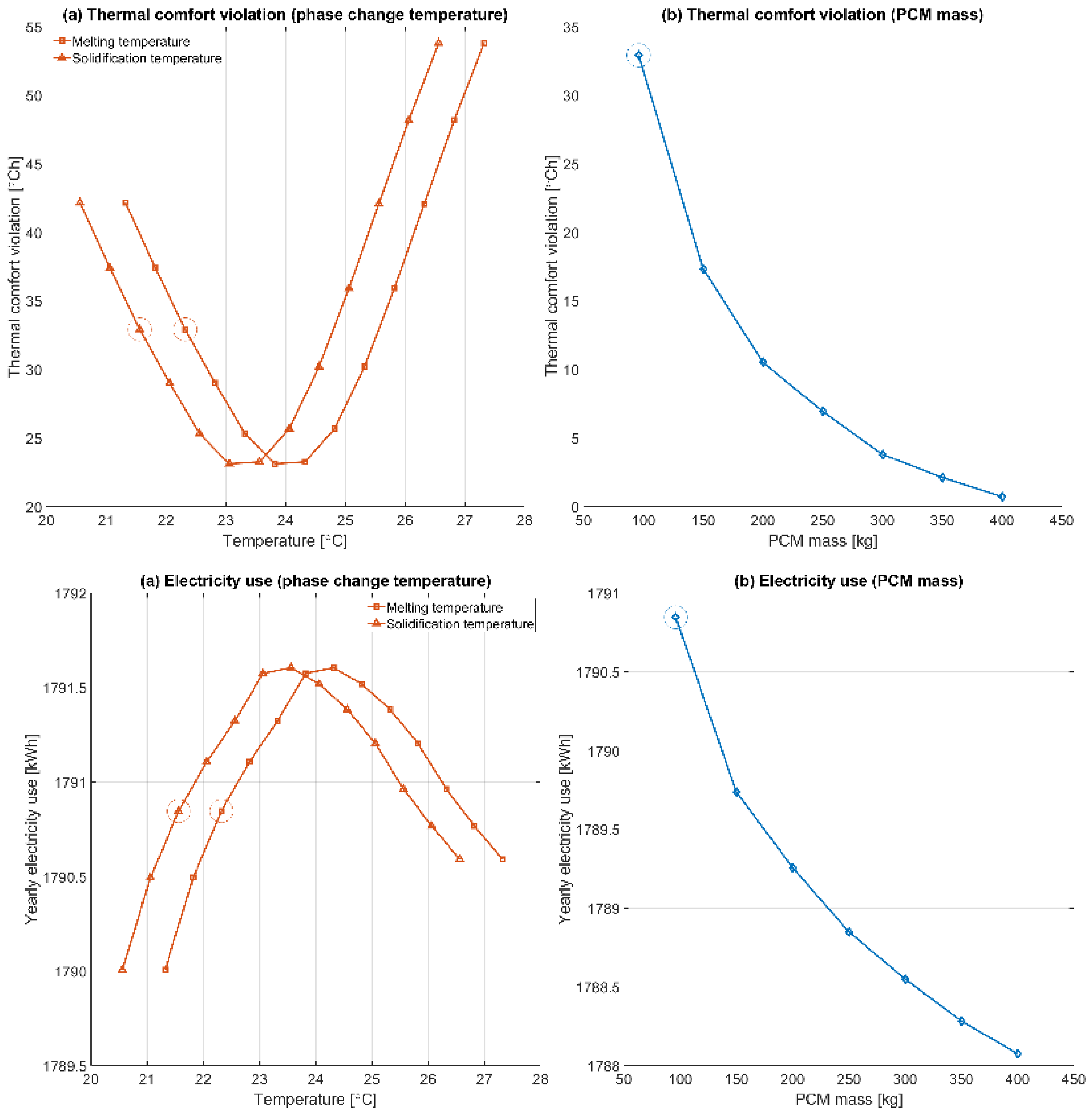
DRY	Ref temp	Ref CO2	DX	PCM temp	PCM CO2	Schedule
Average CO2 concentration [ppm]	2097	1050	2156	2110	1050	1093
Highest CO2 concentration [ppm]	15,617	1056.2	15,906	14,805	1056.2	1093.1

Extreme Conditions	Ref temp	Ref CO2	DX	PCM temp	PCM CO2	Schedule
Average CO2 concentration [ppm]	875.1	1047	899.6	886.5	1047	1086
Highest CO2 concentration [ppm]	892	1056	1368	1760	1056	1093

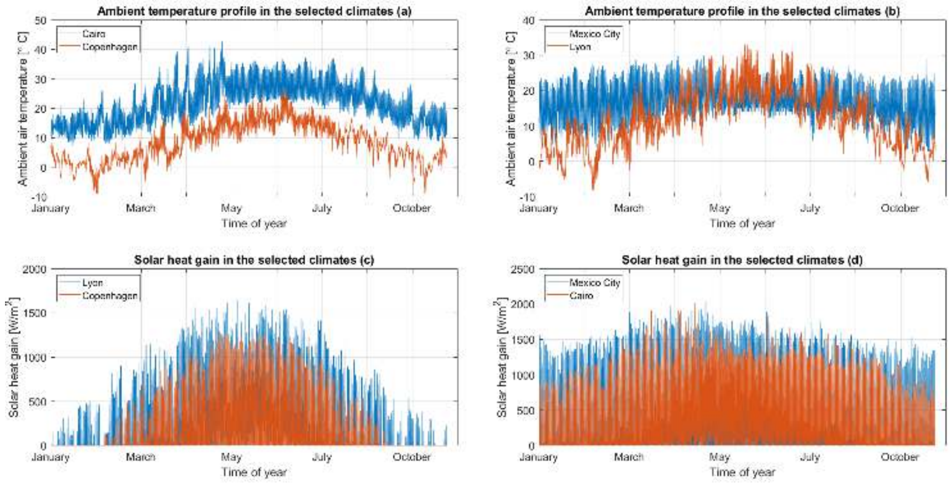
Parameter studie

- Termisk komfort
  - Smelte temperatur: 23.82C
  - Solidificerings temperatur: 23.06C
  - 1.5C stigning
    - 30 % fald i komfort brud
- Elektricitetsforbrug
  - Lille forskel
  - Højeste forskel ved optimal temperatur.





Fremtidige undersøgelser



- Klimaundersøgelser
  - Klimaer med større kølebehov
  - Temperaturdistribution
- Optimal design
  - PCM masse
  - Faseskifttemperatur
  - Luftkanalstørrelse

Konklusion

- Køling med energibesparrelse
- Bedre køling end med ventilation, men et gab i forhold til konventionel køling
- Middelvej
- Parameter studie viser at der er højere potentiale
- Muligvis bedre business case i varmere klimaer

Spørgsmål?