Lab of Applied MultiPhase Thermal Engineering

INTERNAT ENERGY SOLUTIONS

COMSOL CONFERENCE
2014 BOSTON

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Thermal Modeling in a Historical Building - Improving Thermal Comfort Through the Siting of a Passive Mass of Phase Change Material

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Introduction

- Thermal discomfort in retrofitted historical buildings
  - occupation incompatibility with the building's original intent
  - poor building envelope performance
- The Toronto Carpet Factory is a retrofitted historical building with poor building performance falling outside of ASHRAE* comfort guidelines (23°C < T < 26°C)

Toronto Carpet Factory historical building

http://www.mytorontorealty.com/images/10911/liberty-village-2.jpg

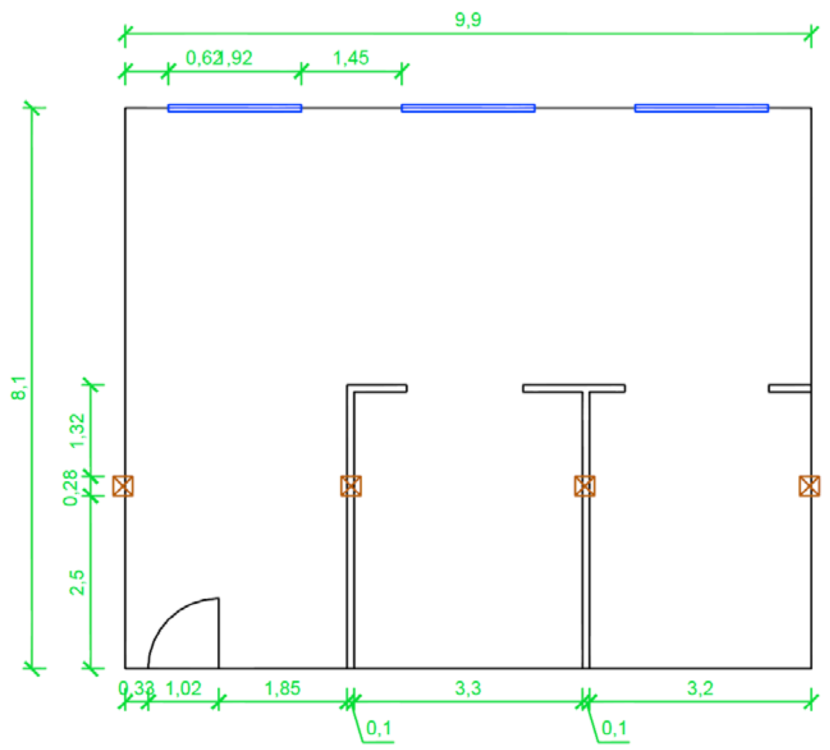
Objectives

- Use COMSOL Multiphysics 4.4 to simulate heat transfer in an office room in the Toronto Carpet Factory
- Study how siting a Phase Change Material (PCM) as a layer on the floor and ceiling impacts the temperature distribution and history in the room

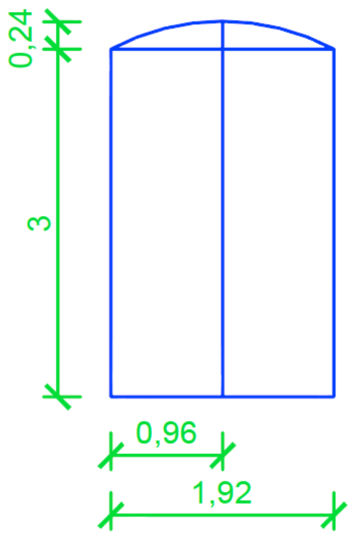
Office room

Office Room Features

- The office is located on the third floor of a five floor building
- It faces West and measures 9.9 m (depth) X 8.1 m (width) X 4.21 m (height)



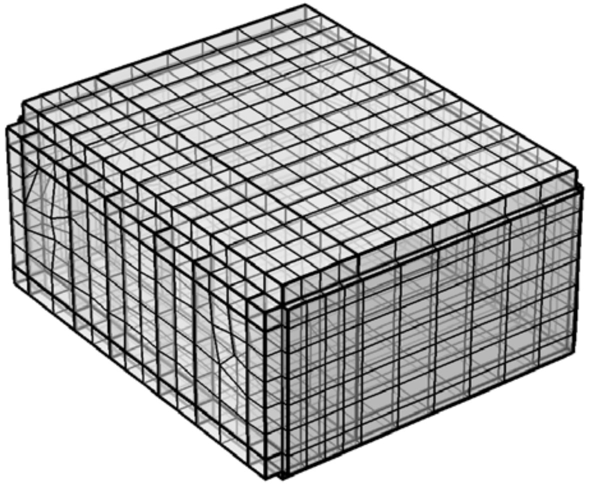
Room dimensions



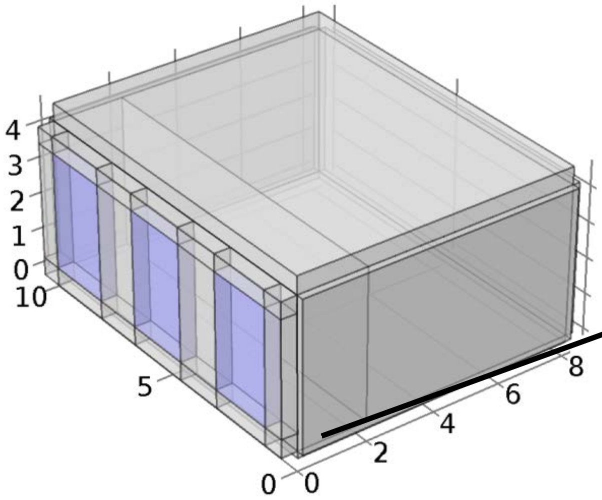
Window dimensions

COMSOL® – Geometry and Mesh

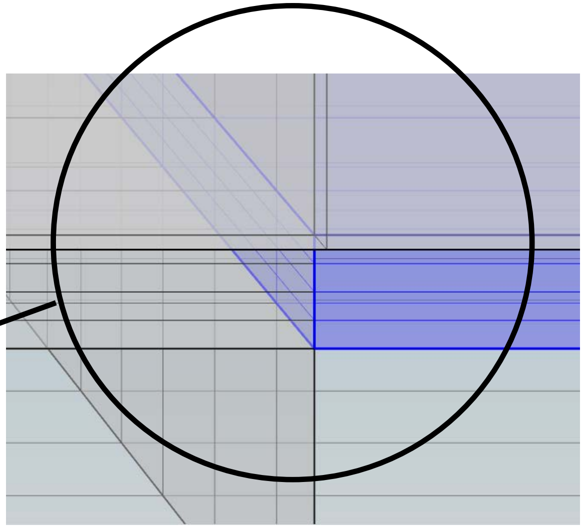
- The three shaded rectangles represent the window sills where the sun rays enter the room
- The mesh used was based on quadrilateral elements
- There were 2064 elements used (resulted in simulations taking an excess of 2 days for 1 hour of simulated time)



Swept quadrilateral mesh



Room geometry used in simulations



Mesh distribution in the PCM (blue)

COMSOL® – Building Materials

- The selected physics in the model required both thermophsyical and solar radiative properties of the materials in the model

Material	ρ (kg/m³)	k (W/mK)	C_p (J/kgK)
Brick	1670	0.66	838
Wood (Oak)	820	0.3	2390
Gypsum Wallboard	800	0.17	1000
Air	COMSOL Materials Database		

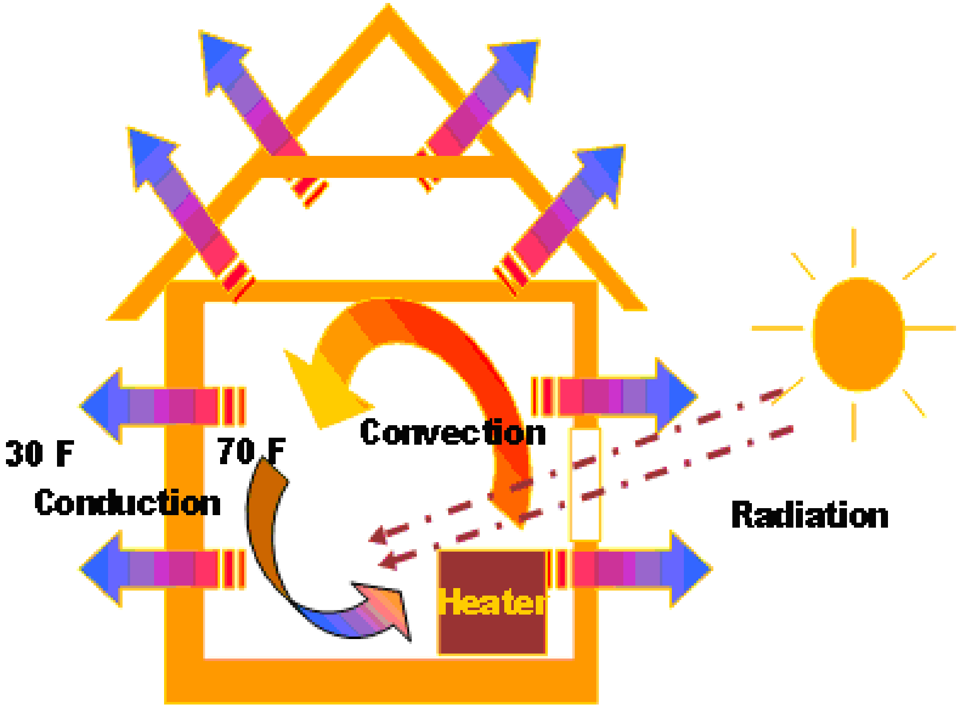
Thermophysical properties for the domains

Material	Solar Absorptivity	Surface emissivity
Brick	0.63	0.93
Wood (Oak) & PCM	0.35	0.89
White paint	0.25	0.89

Solar radiative properties for the boundaries

COMSOL® – Simulated Physics

- The two parent physics nodes used were
  - heat transfer with radiation in participating media:
    - heat transfer from surface-to-surface radiation
    - phase change
    - natural convection
  - laminar flow



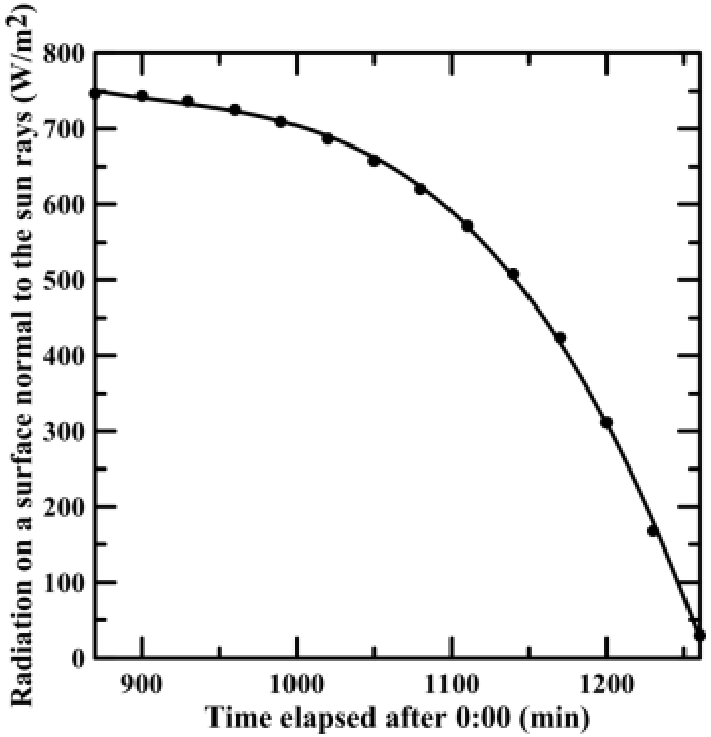
The model couples heat transfer from all three mechanisms

https://www.e-education.psu.edu/egee102/files/egee102/images/Lesson_07/L7_HeatTransfer.gif

COMSOL® – Radiation

- The heat flux from the sun rays are the forcing condition
- The built-in solar model in COMSOL was used with the following parameters
  - The simulations depended on a mid-August day in 2013
  - The heat flux was not kept at the constant 1000 W/m^2 default; a time dependent equation was used

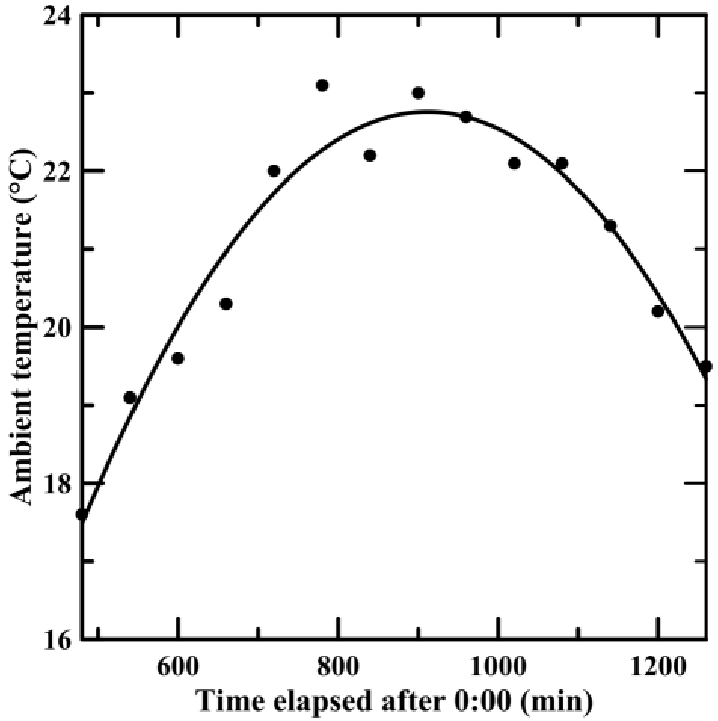
Data from Department of Ecology of the State of Washington
http://www.ecy.wa.gov/programs/eap/models.html



Latitude (+ to N)	Longitude (+ to E)	Time zone (+ UTC)
43.639	-79.425	-4
Day	**Month**	**Year**
15	08	2013
Hour	**Minute**	**Second**
0	0	t

COMSOL® – Convective Heat Transfer

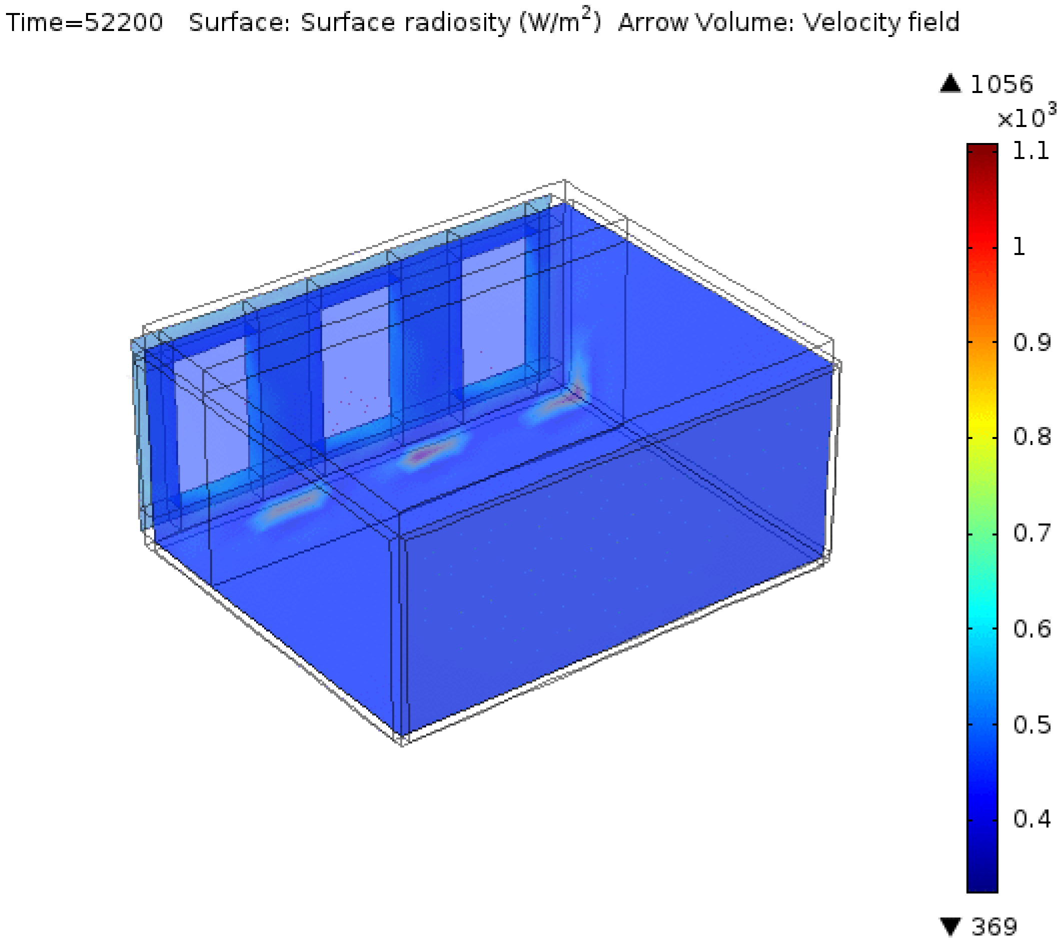
- The main cooling mechanism for the room was convection on the brick wall with the outside air
- The ambient temperature varied based on data collected by Environment Canada



Data from
http://climate.weather.gc.ca/climateData/hourlydata_e.html?timeframe=1&Prov=ONT&StationID=31688&hlyRange=2002-06-04|2014-07-02&Year=2013&Month=8&Day=10

COMSOL® – Visualization

- Radiosity on the floor of the room
- Convection cell



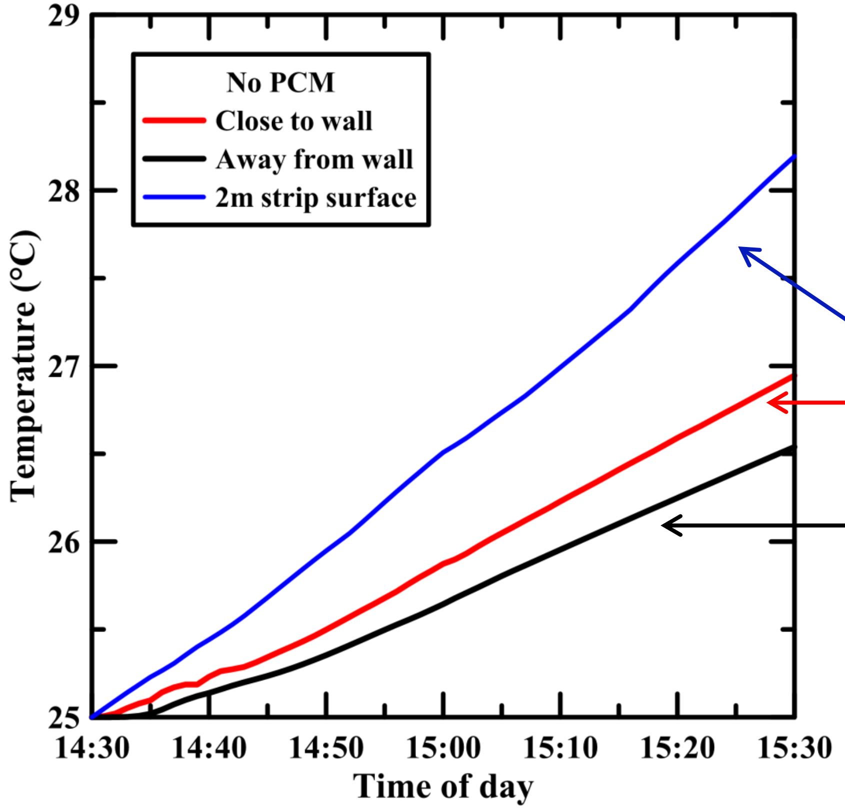
COMSOL® – PCM Properties

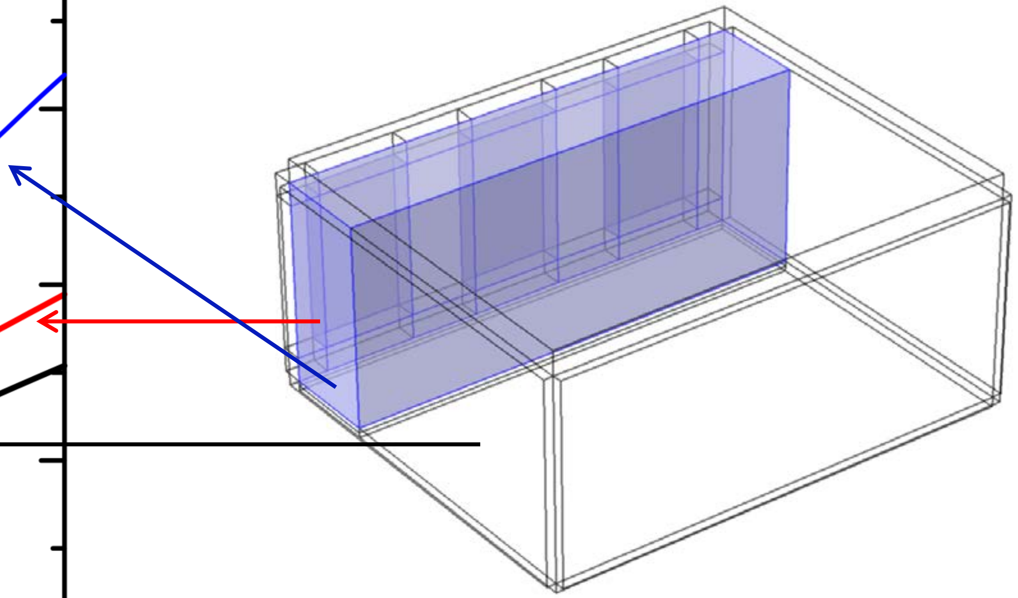
- Butyl Stearate ($C_{22}H_{44}O_2$) was chosen as the PCM with the most appropriate properties

T_m (°C)	26.3
ΔH_m (kJ/kg)	167
k_s (W/mK)	~ 0.16
k_l (W/mK)	0.16
C_{ps} (kJ/kgK)	1.6
C_{pl} (kJ/kgK)	1.9
ρ (kg/m³)	850

Results – No PCM

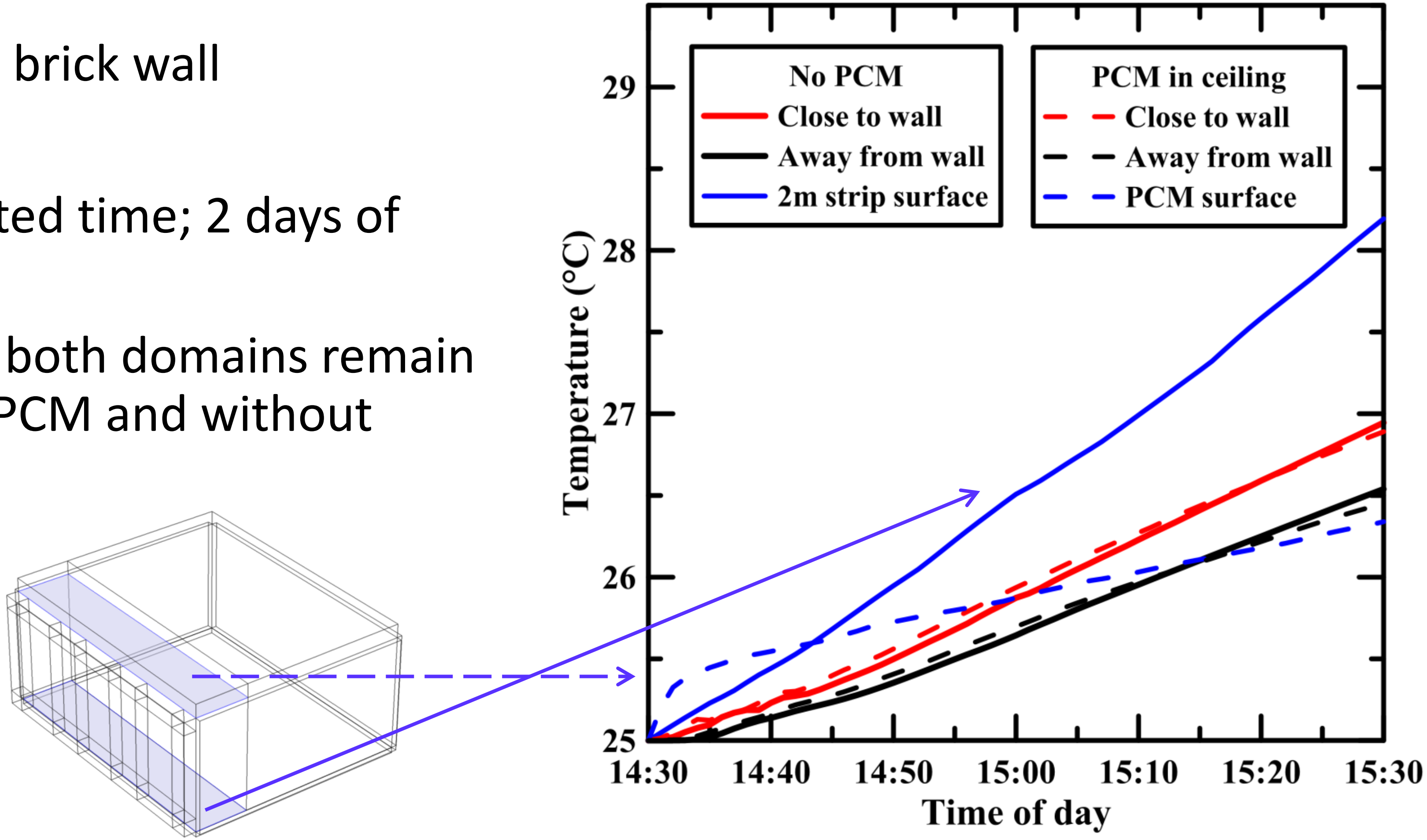
- The first simulation modeled coupled conduction, convection, and radiation in the room with no PCM
- The simulation had an initial condition of 25 °C and started at 14:30





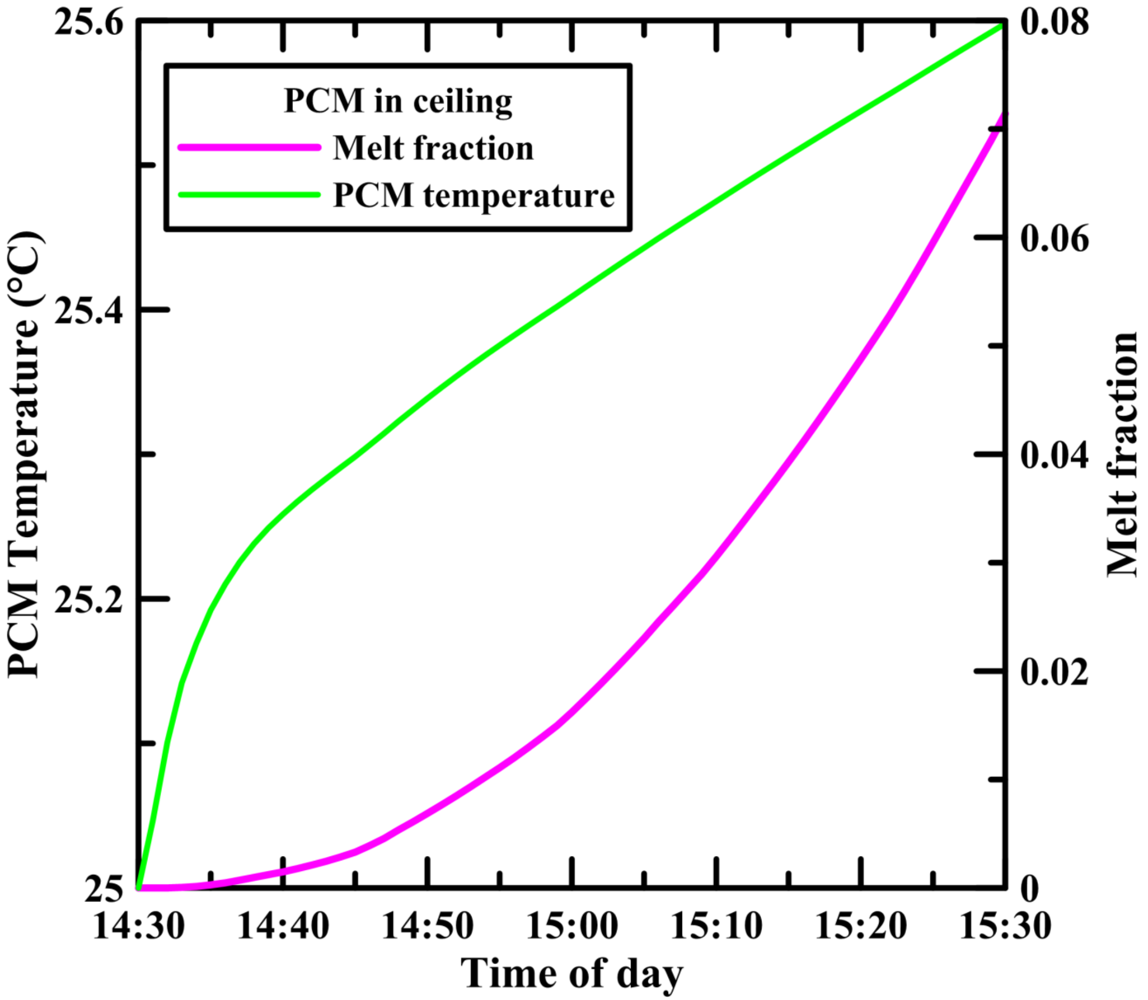
Results – With PCM (Ceiling)

- PCM implementation:
  - 1 cm layer
  - 2 m from the brick wall
  - In the ceiling
- 1 hour of simulated time; 2 days of run time
- Temperatures in both domains remain similar with the PCM and without



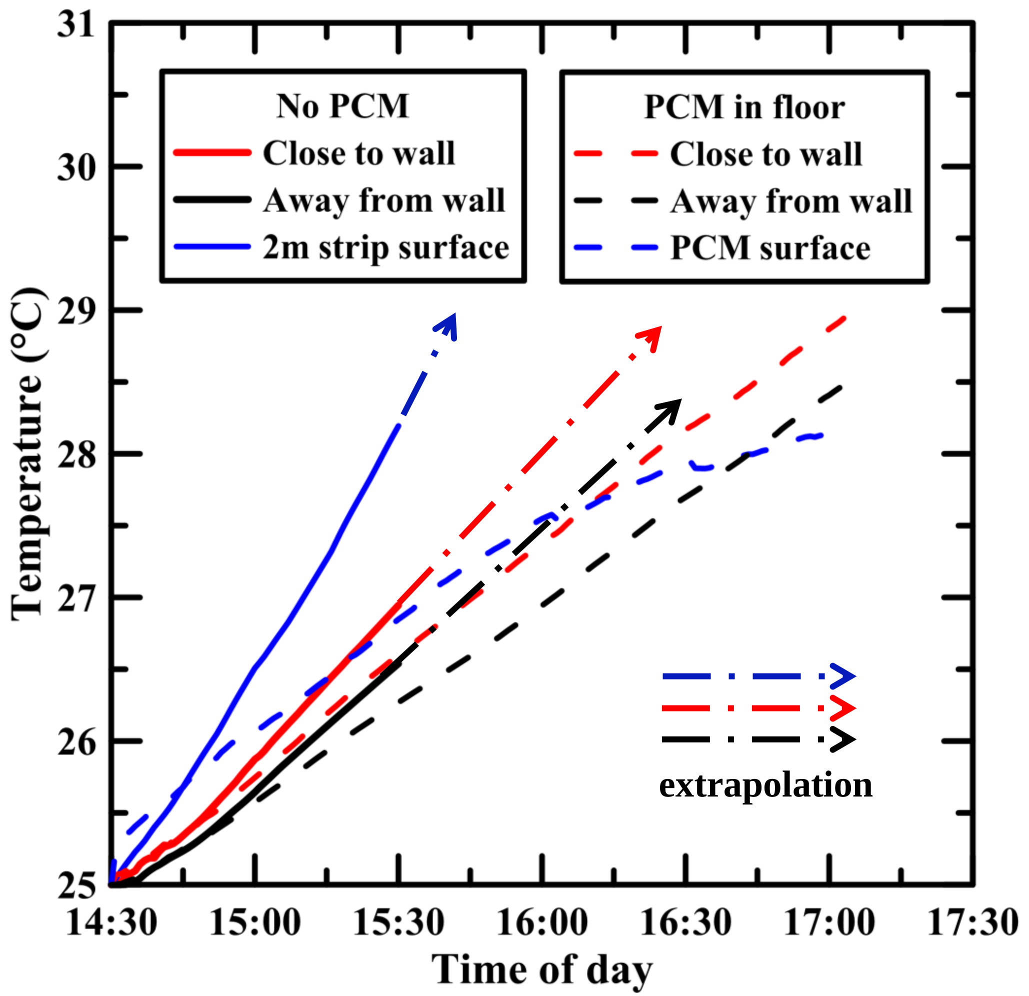
Results – With PCM (Ceiling)

- PCM only melts 7%



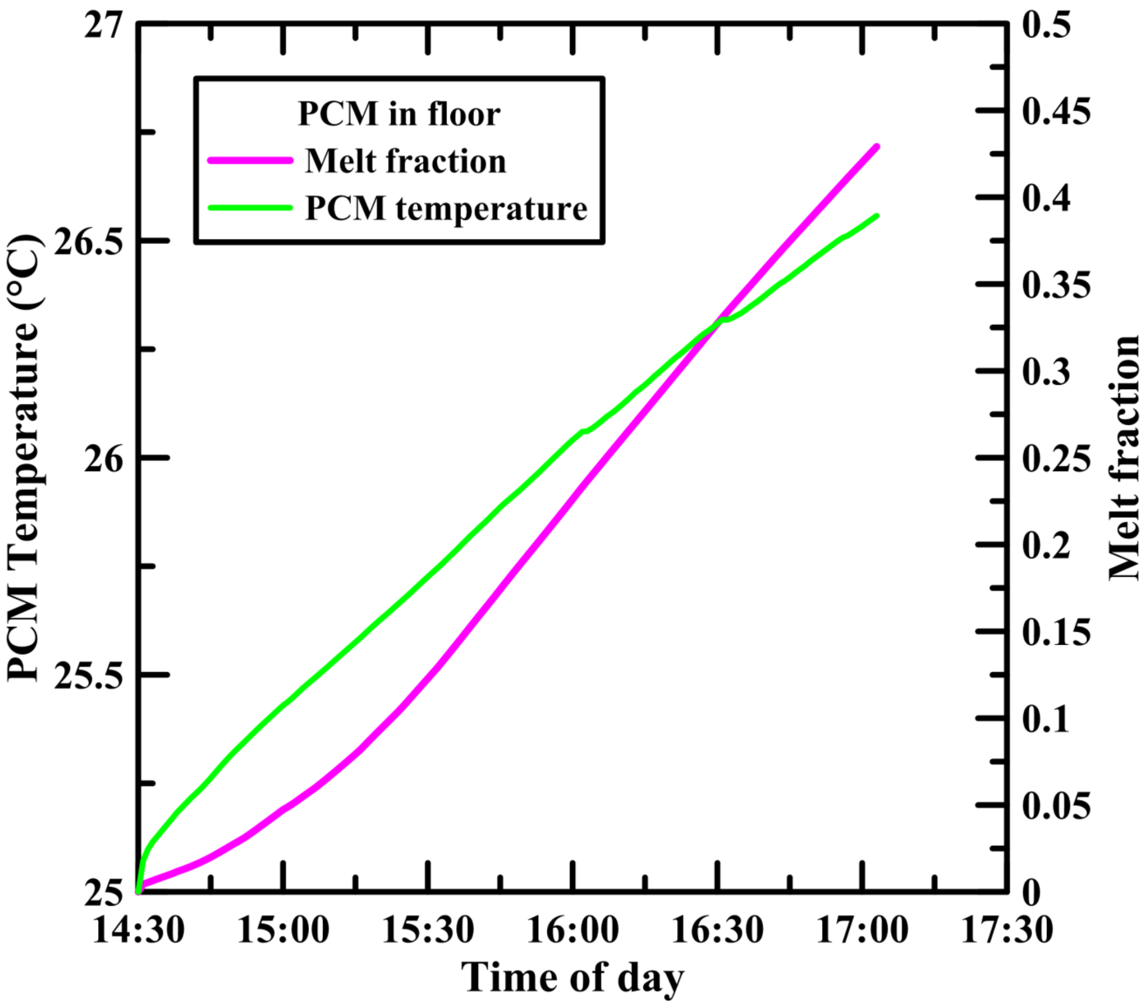
Results – With PCM (Floor)

- PCM implementation:
  - 1 cm layer
  - 2 m from the brick wall
  - In the floor
- 2.5 hours of simulated time; 8 days of run time
- Temperatures in both domains were reduced about 1.5 °C



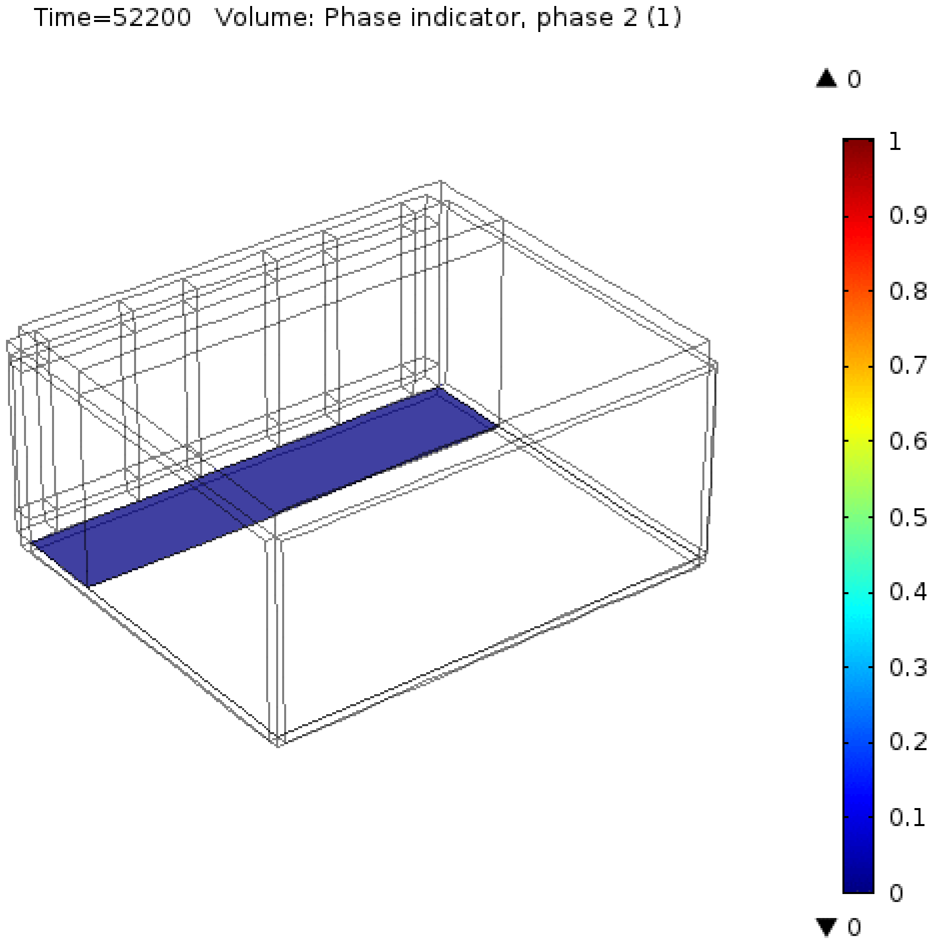
Results – With PCM (Floor)

- PCM melts 45%



Results – Visualization

- PCM melting
- red = fully melted



Conclusions

- Phase change materials can be used effectively to reduce temperature spikes in buildings
- Finding the ideal characteristics of the PCM storage body, such as its type, mass, shape, and location, is more challenging and requires further investigation
- COMSOL is a versatile and powerful software capable of simultaneously simulating heat transfer through conduction, convection, radiation, and phase change
- However, the simulations take a long time and use a lot of resources
- Optimization of the model is the next step

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Thanks to

- Natural Science and Engineering Research Council of Canada (NSERC)
- Canadian Foundation for Innovation (CFI)
- Institute for Research in Materials (IRM)

NSERC CRSNG

Canada Foundation for Innovation
Fondation canadienne pour l'innovation

IRM
INSTITUTE FOR RESEARCH IN MATERIALS

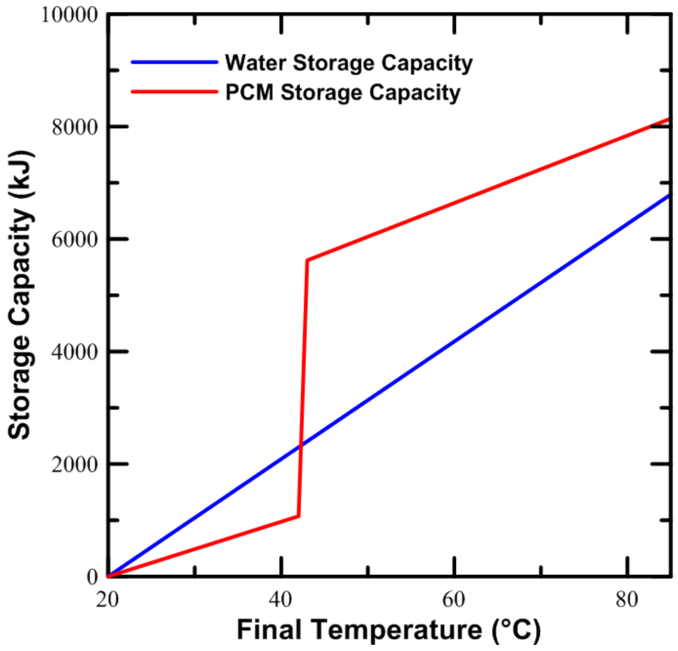
Questions?

Background on PCMs

- A phase change material is a substance with a high heat of fusion, which if melted, is capable of storing large amounts of energy that is released upon solidification
- PCMs have two main advantages
  - Increased heat storage density (2-14 times more than water) and
  - Mainly-isothermal heat storage behaviour

Heat pack (uses a PCM to store heat)

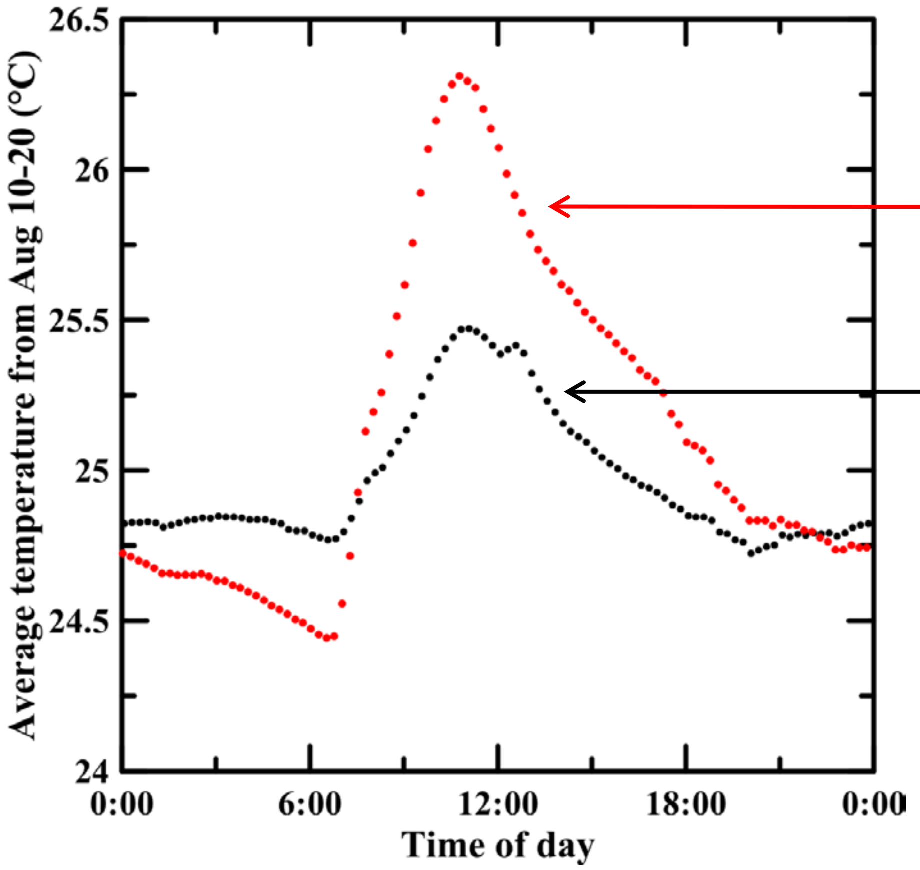
http://www.electrichandwarmers.com/images/medium.jpg

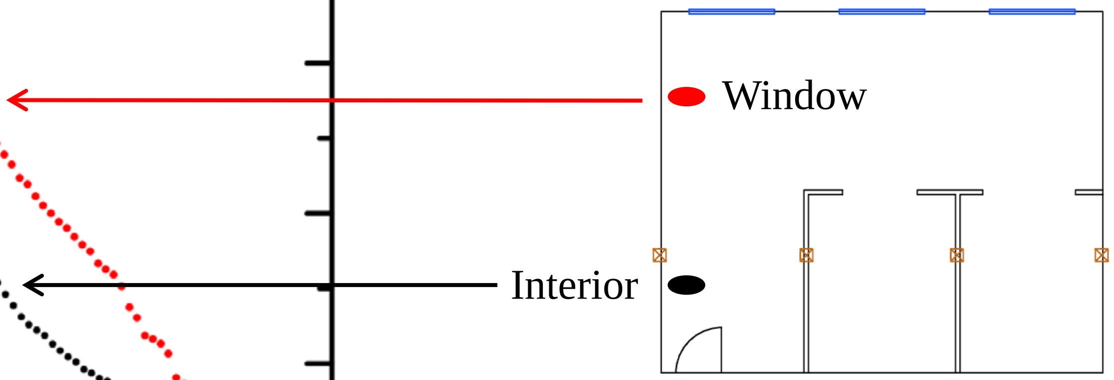


Sensible vs latent heat storage materials

The problem

- Large ambient temperature spike
- In addition, air conditioning was used heavily to maintain the temperature at an acceptable level





Approximate Location of data loggers in the room

COMSOL® – Phase Change

- COMSOL has a built-in node that deals with phase change
- The heat capacity of the material changes with temperature following a Gaussian distribution