



Engineering Energy Efficiency: a Green Building Project for High School

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The topic

Engineering task: design, test and improve a model of an energy-efficient house

Science content: heat transfer

Model: Engineering the Future (Boston Museum of Science)

Project goals

Develop a month-long high school engineering project for research and general use.

Compare hands-on with simulation-enhanced experiments.

Collect data on the efficacy of simulations for learning science and engineering.

Larger goals

Focus on an urgent real-world problem: Energy

Science content integrated with engineering practice

Simulations that support science understanding (seeing the invisible)

Simulations that support engineering design

Closely parallel hands-on and simulation experiments

Research questions

Do students using simulation-enhanced curriculum:

- do better in meeting the design challenges, acquiring the content knowledge, and transferring it to a new context?
- explore a greater variety of designs in order to optimize the design?
- show an increased ability to integrate the science with the engineering design?



The products you can use

**Workbook for a month-long engineering
project**

**Numerous stand-alone experiments in heat
transfer**

Energy2D and Energy3D simulation software

Why hands-on? Why simulations?

Hands-on:

- Engaging
- Connect to the natural world
- Learn about real measurement
- Explore the unexpected

Simulations:

- Engaging
- Save time
- Many experiments
- Test many variables
- Do “impossible” experiments
- See the invisible

Seeming conflicts

Science vs engineering	?
Hands-on vs simulations	?
Isolated vs whole-system experiments	?
Trial & error vs Reasoned choices	?

Our choices (1)

Science vs engineering

Integrate science &
engineering

Hands-on vs simulations

Research: compare hands-
on with simulations

Product: hands-on and
simulations enhance each
other

Our choices (2)

Isolated vs
whole-system experiments

Isolated science
experiments that are
relevant to the whole
system

Engineering focus on
whole-system experiments

Trial & error
vs
Reasoned choices

Ask for reasoning and
evidence

Criteria for measurements

- Quick
- Interesting
- Large effects
- Relevant to real buildings

Workbook outline

Hands-on	Simulation-enhanced
Build and test a standard house	Build and test a standard house
Heat transfer basics (Hands-on)	Heat transfer basics (Energy2D)
Design and build your own house	Design and build your own house
Modify your house	Modify your house
Summer cooling	Summer cooling
Final report	Final report

Build and test a standard house

Build a standard house



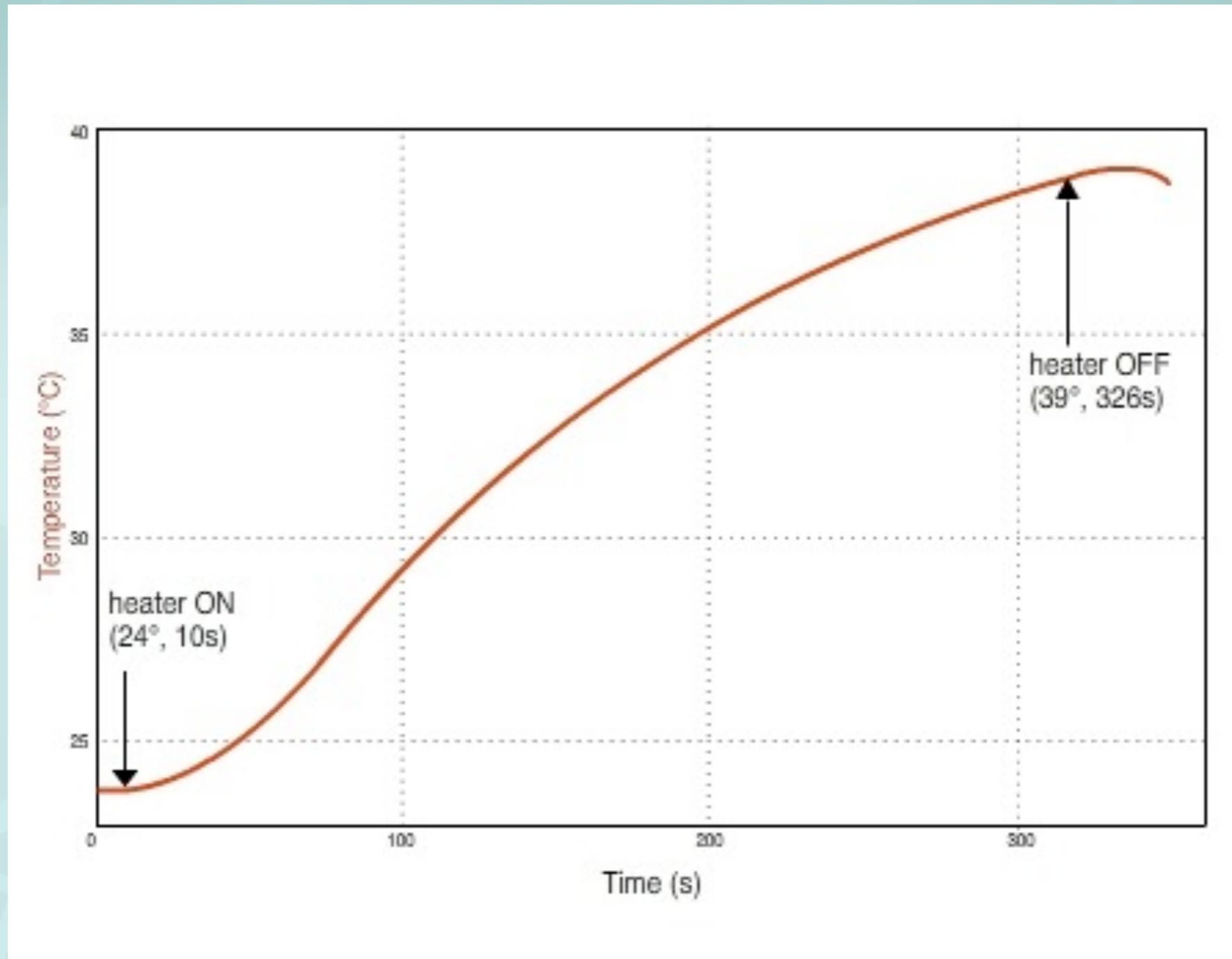
Build and test a standard house

Test the standard house



Build and test a standard house

Warm up the house, calculate energy





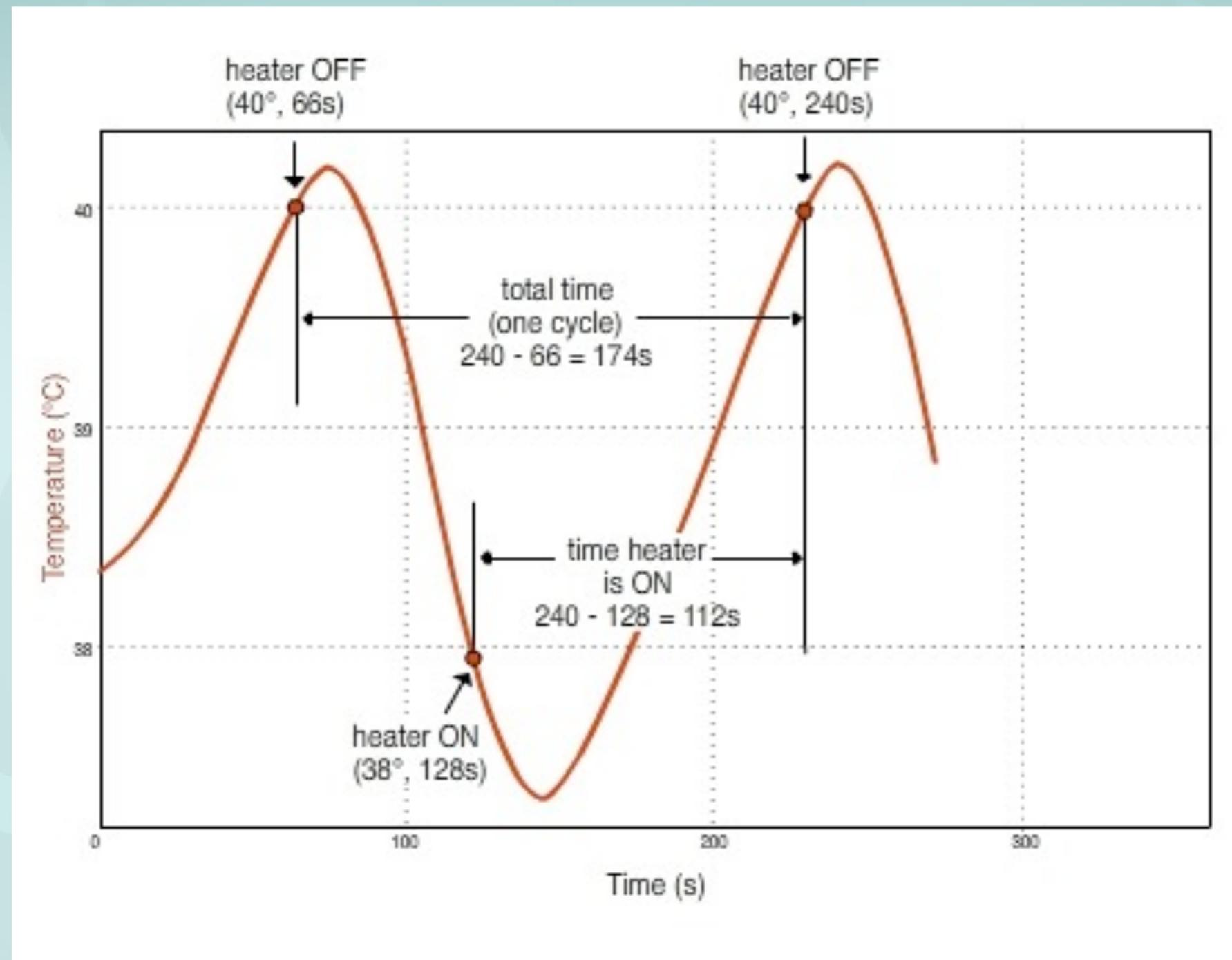
Build and test a standard house

Keep the house warm: Human thermostat



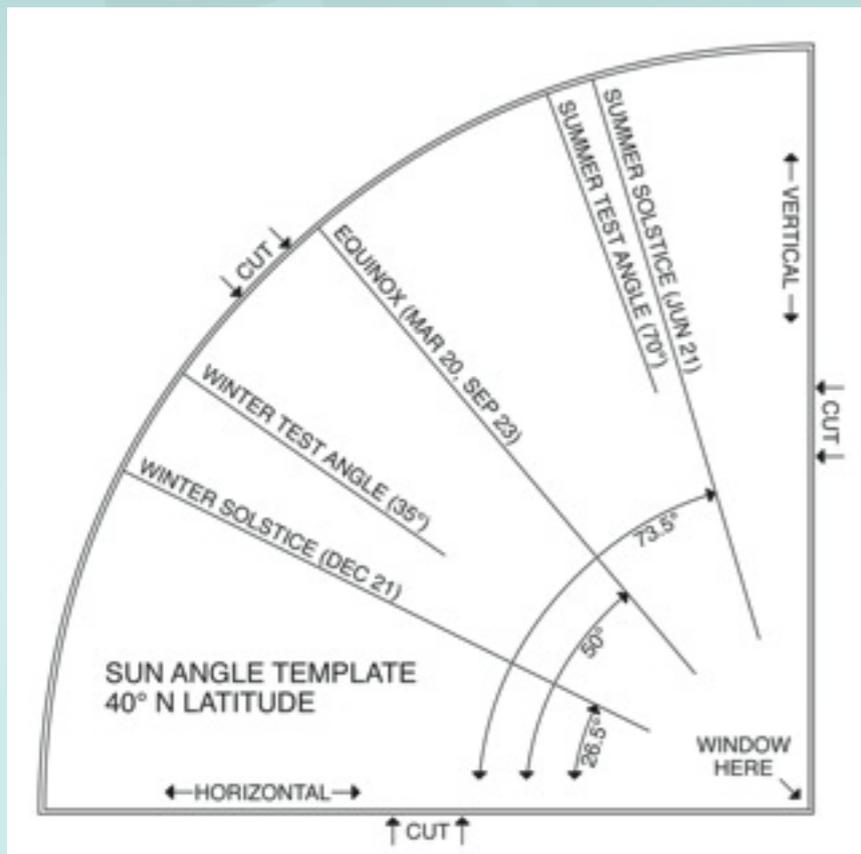
Build and test a standard house

Calculate power consumption



Build and test a standard house

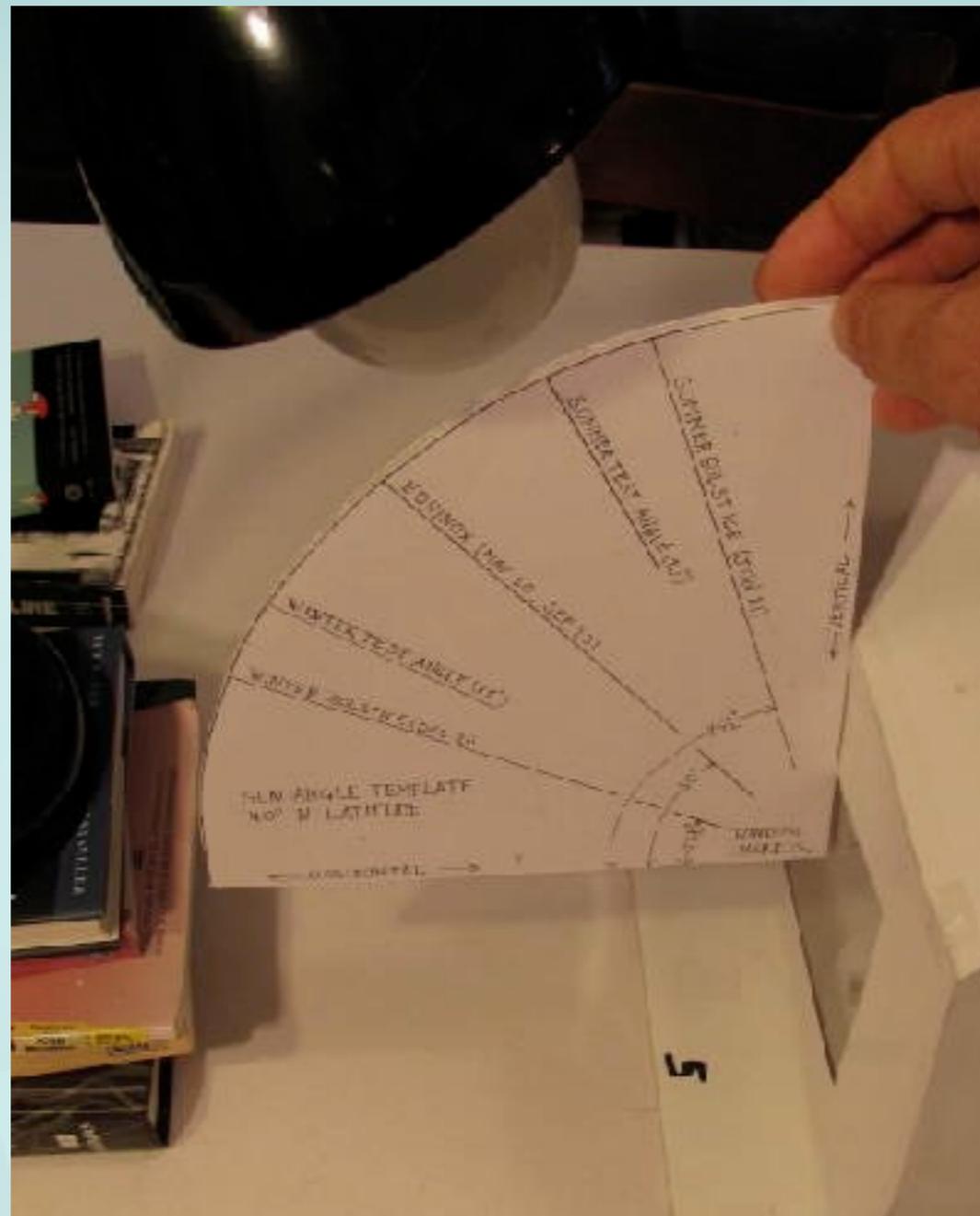
Winter solar heating Calculate saved energy



Build and test a standard house

Summer cooling

Measure temperature rise in 5 minutes



Heat Transfer Basics

- Heat capacity
- Energy and power
- Conduction
- Convection
- Radiation
- Energy from the sun

Heat capacity and thermal equilibrium

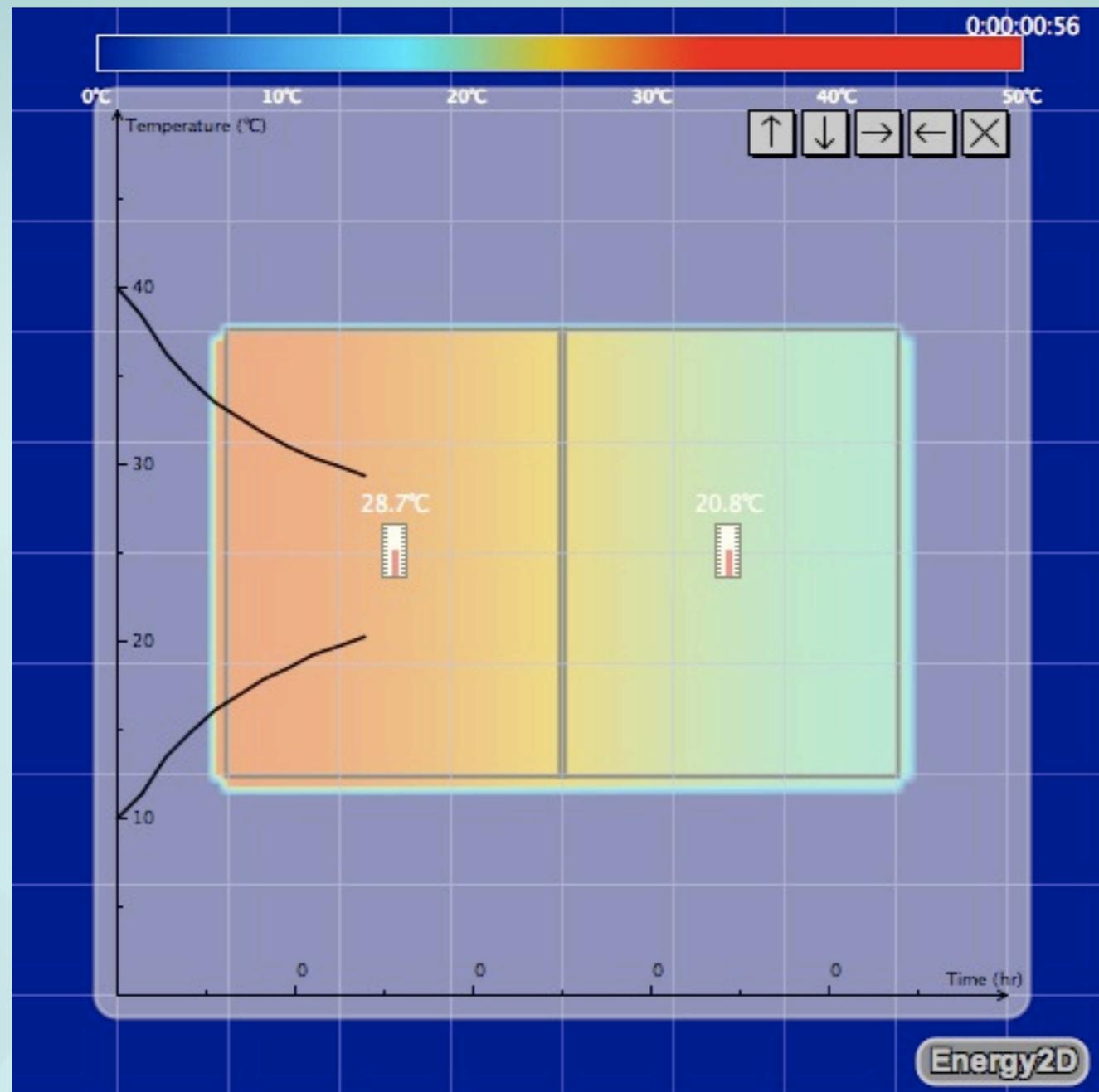
Thermal equilibrium with different heat capacities - hands-on

- water plus water
- water plus oil
- water plus rocks
- easier in Energy2D!

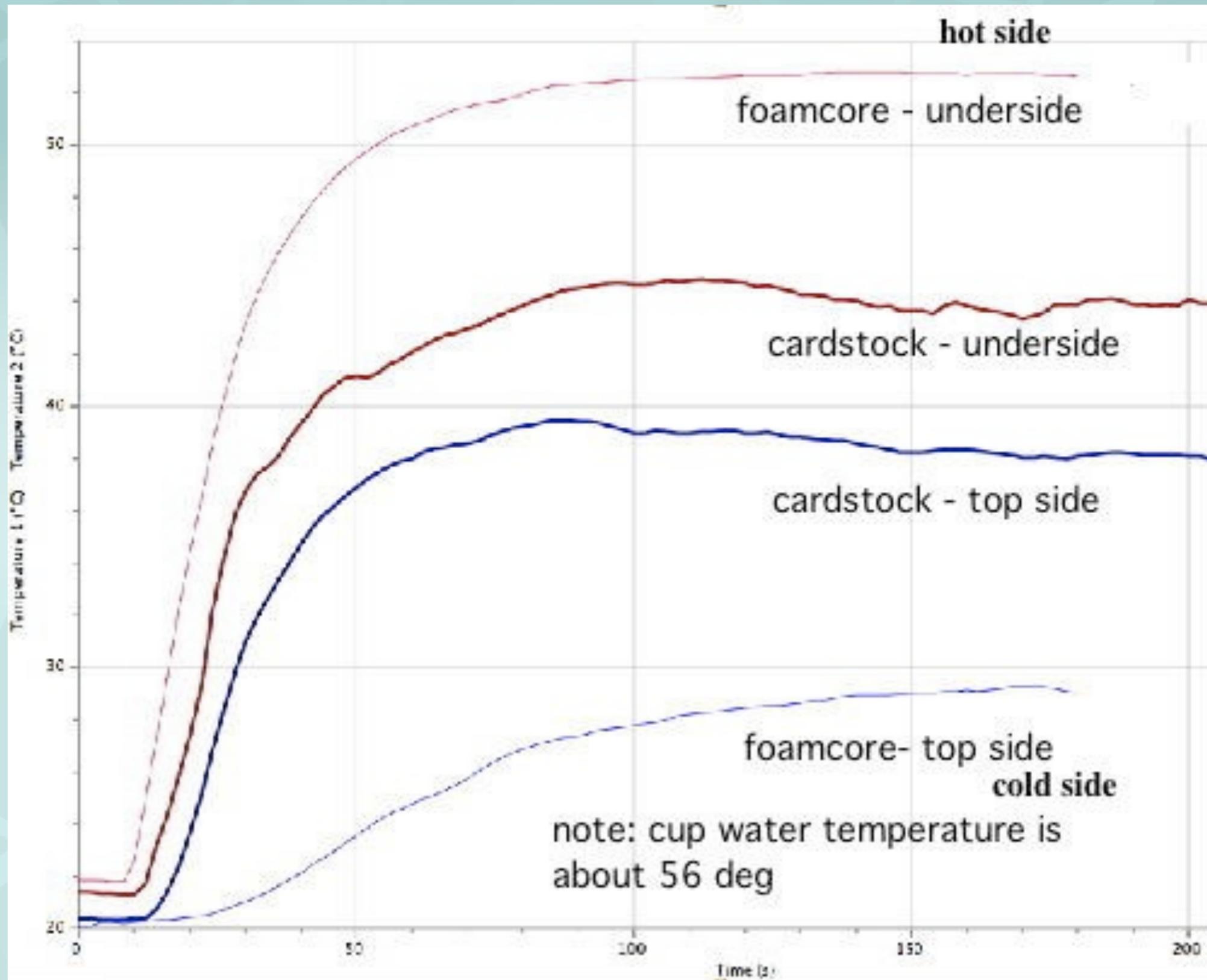


Heat capacity and thermal equilibrium

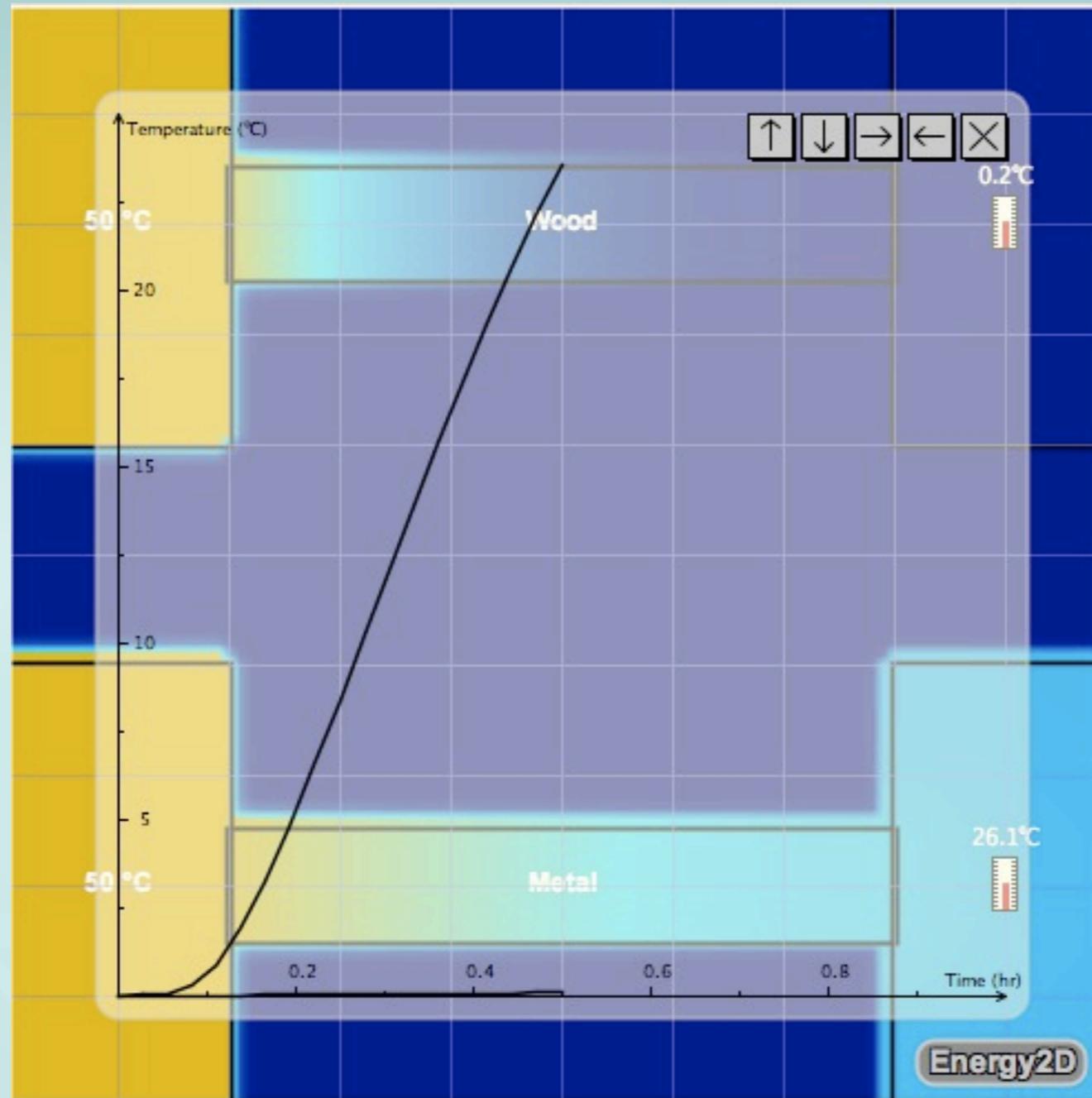
Thermal equilibrium between two objects - Energy2D



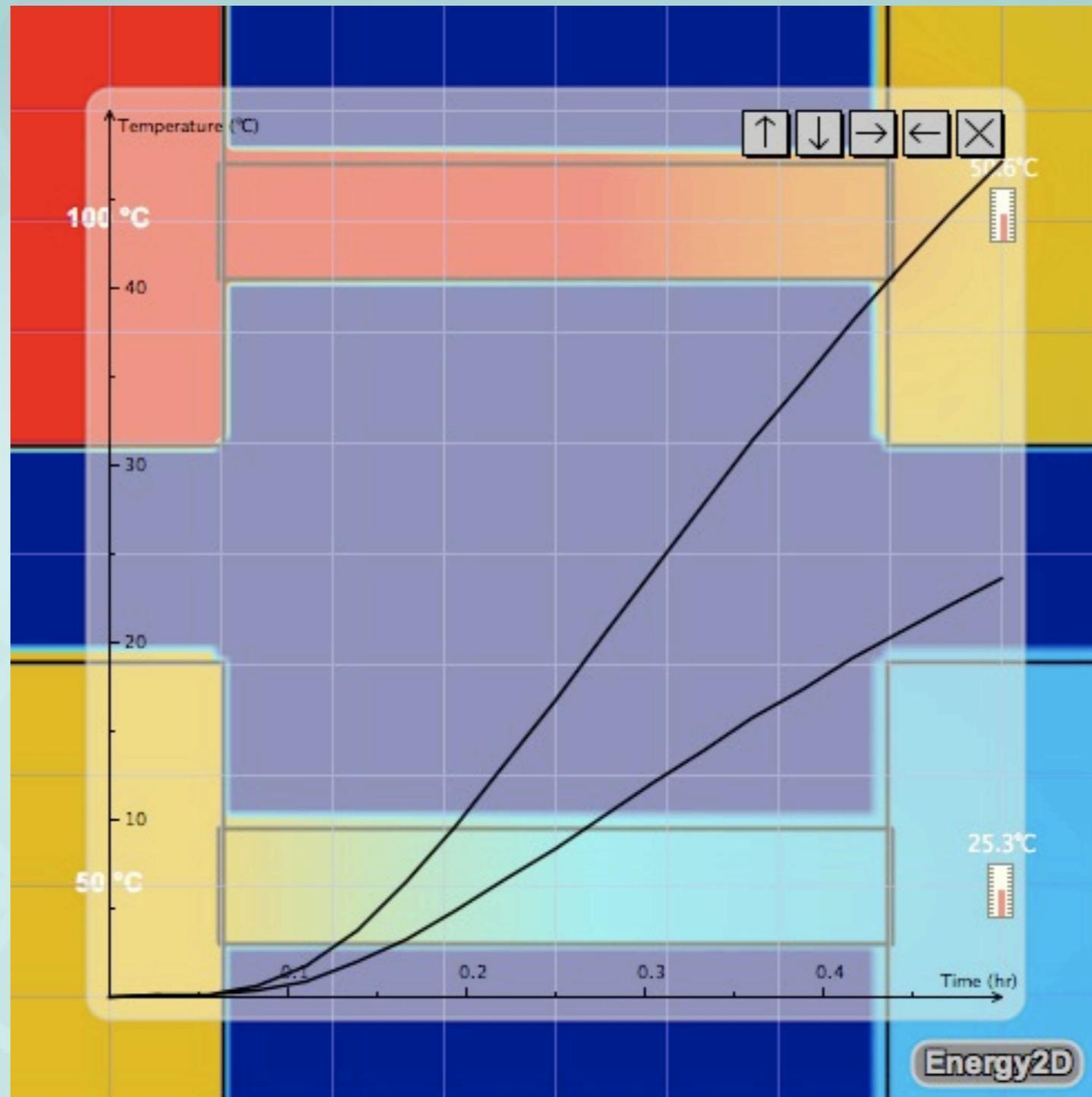
Conduction - Hands-on



Thermal conductivity of wood and metal

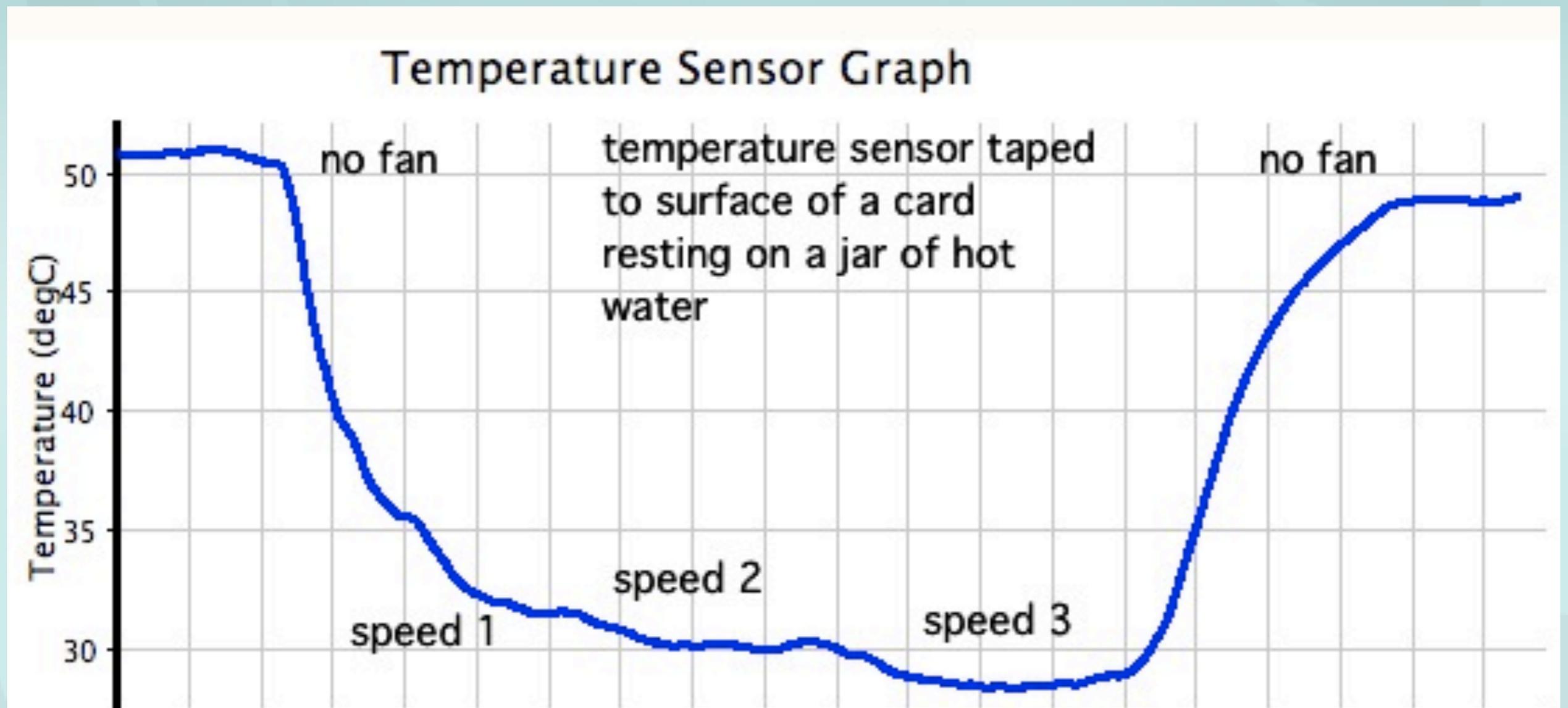


The effect of temperature difference



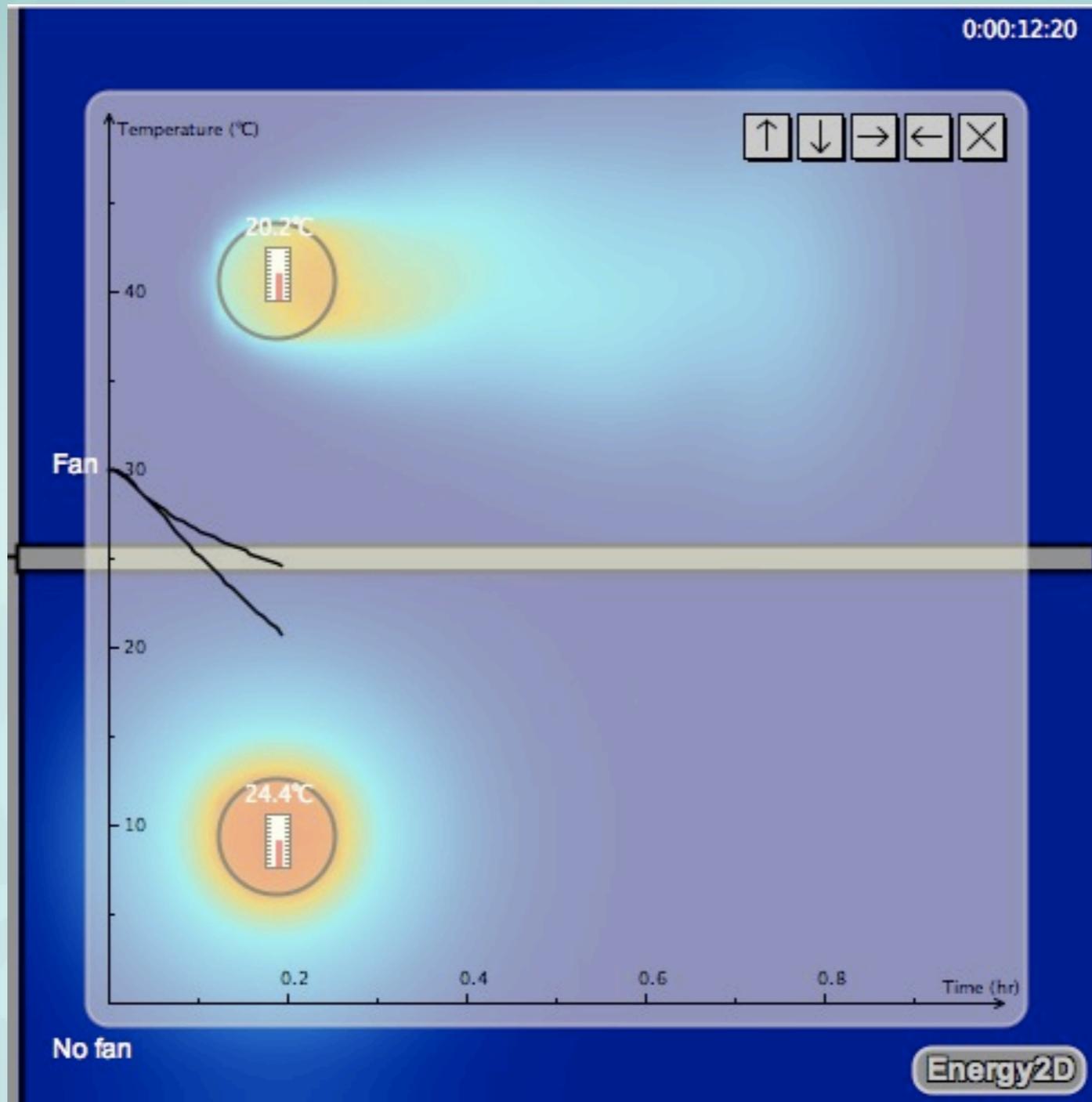
Forced convection - Hands-on

Wind chill



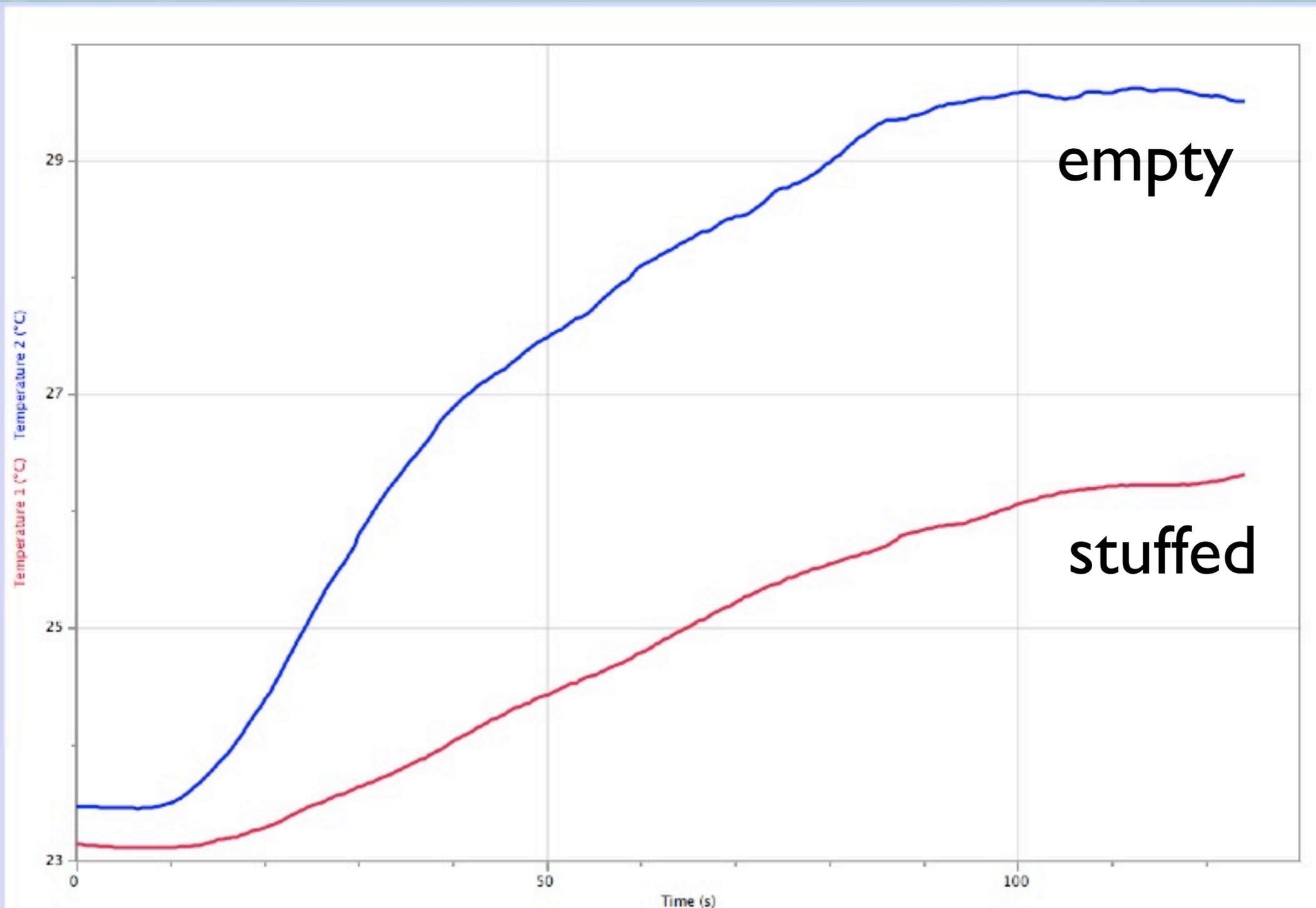
Forced convection - Energy2D

Effect of a fan



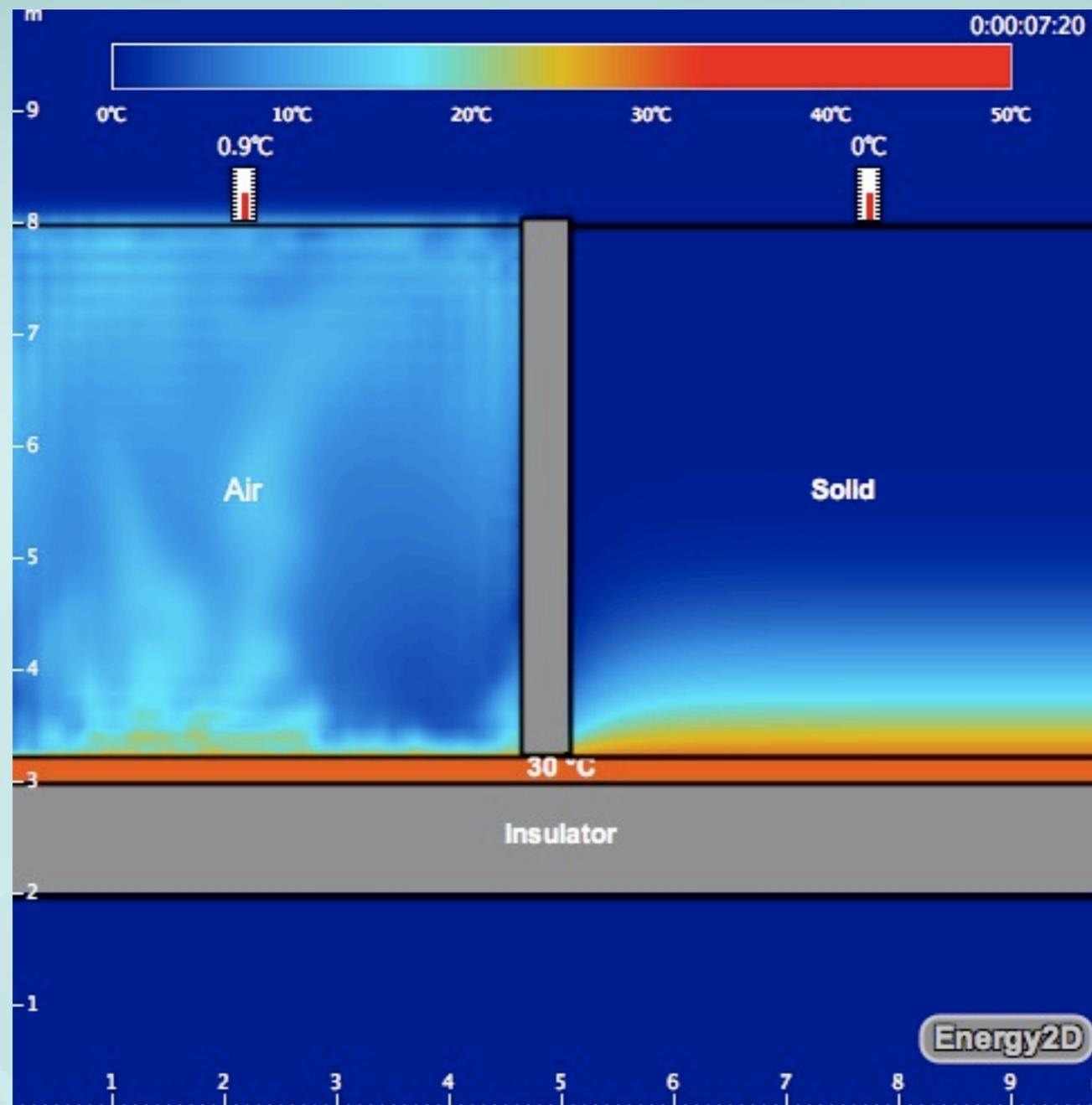
Natural convection - Hands-on

natural convection in a cup

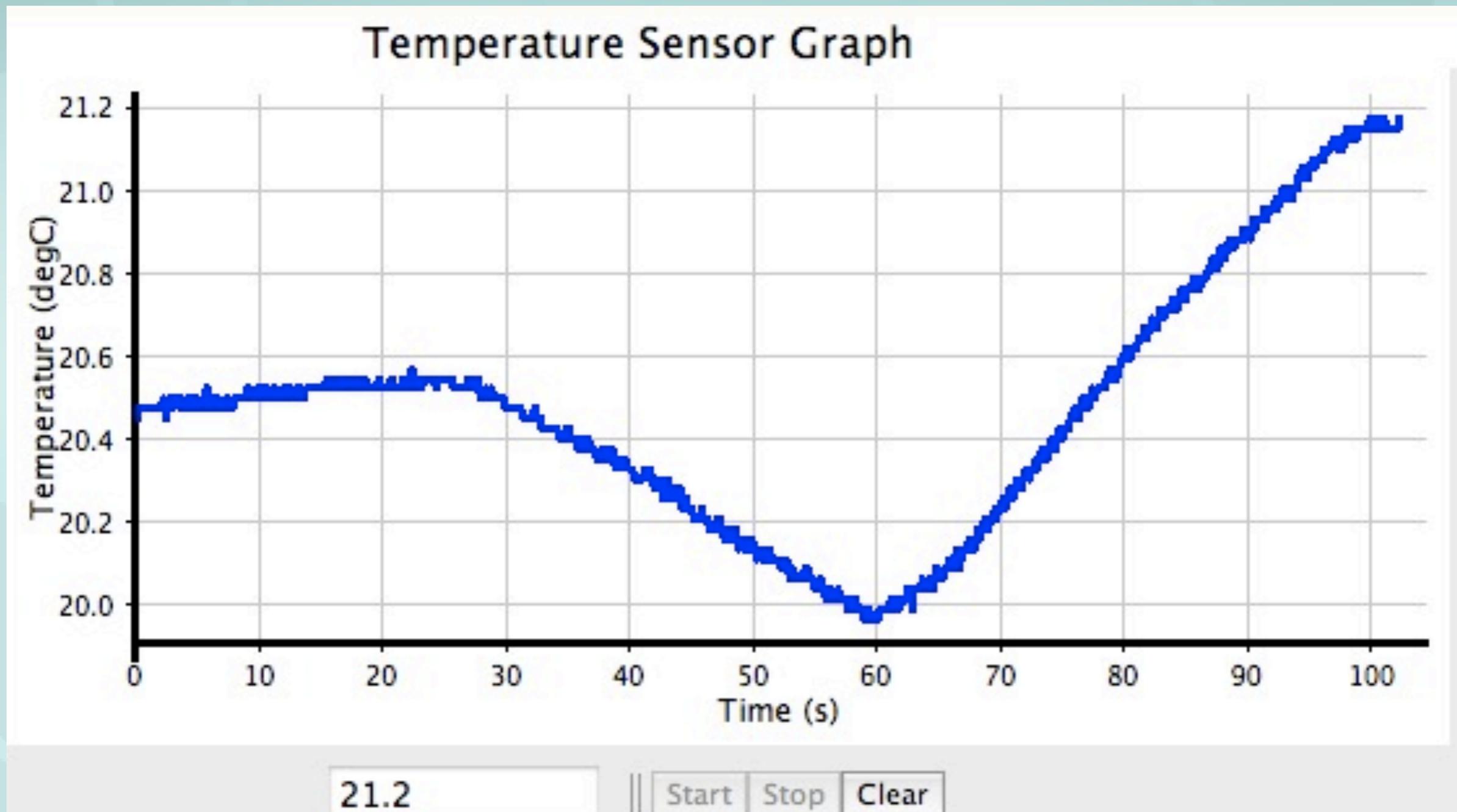


Natural convection - Energy2D

Right side - convection turned off

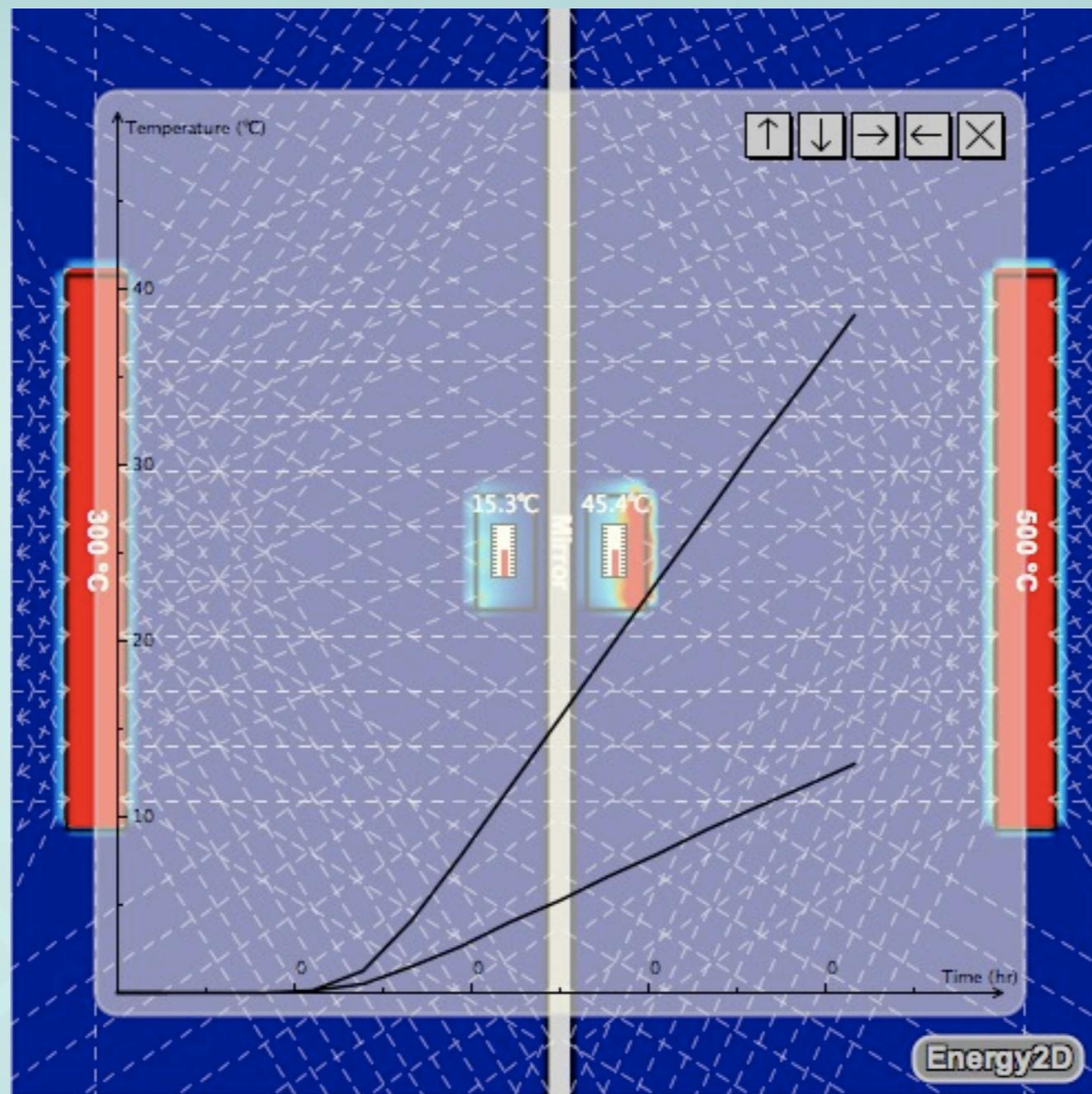


Radiation from hot and cold water jars



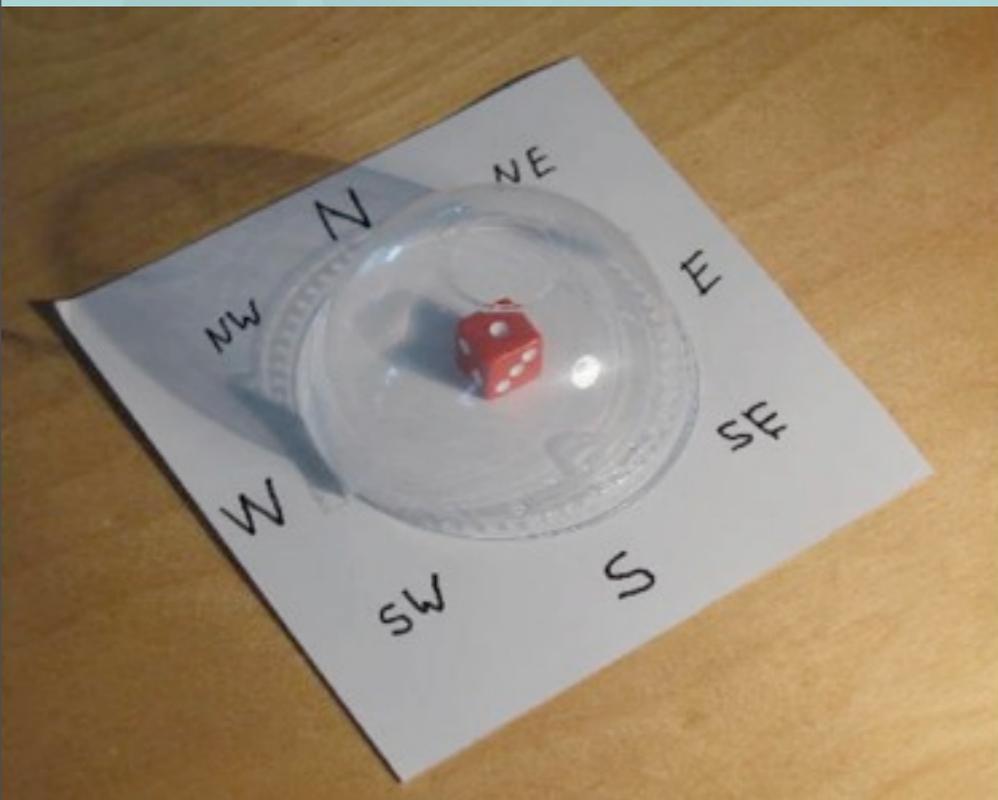
Radiation - Energy2D

Radiation from two objects with different temperatures

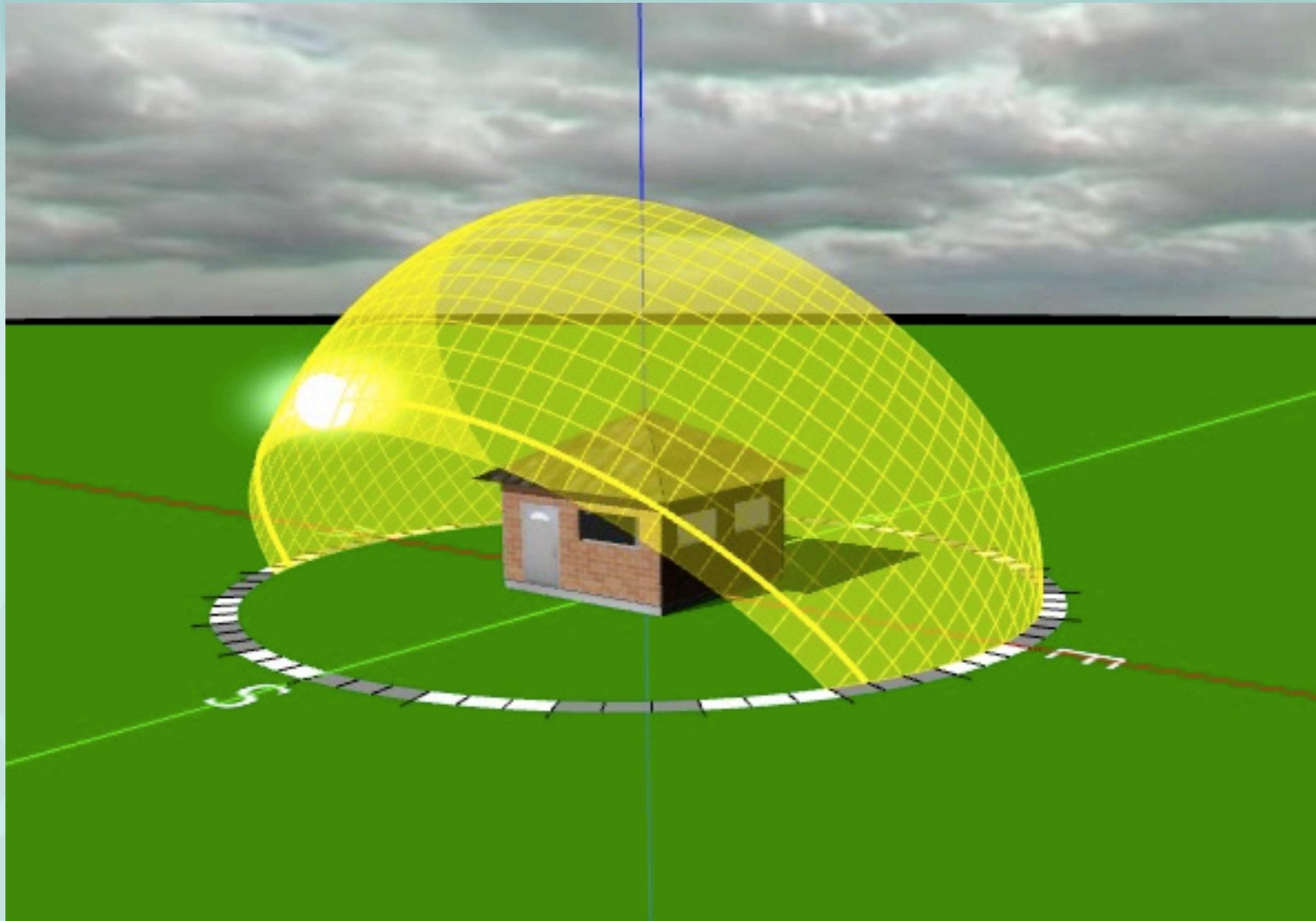


Energy from the sun - Hands-on

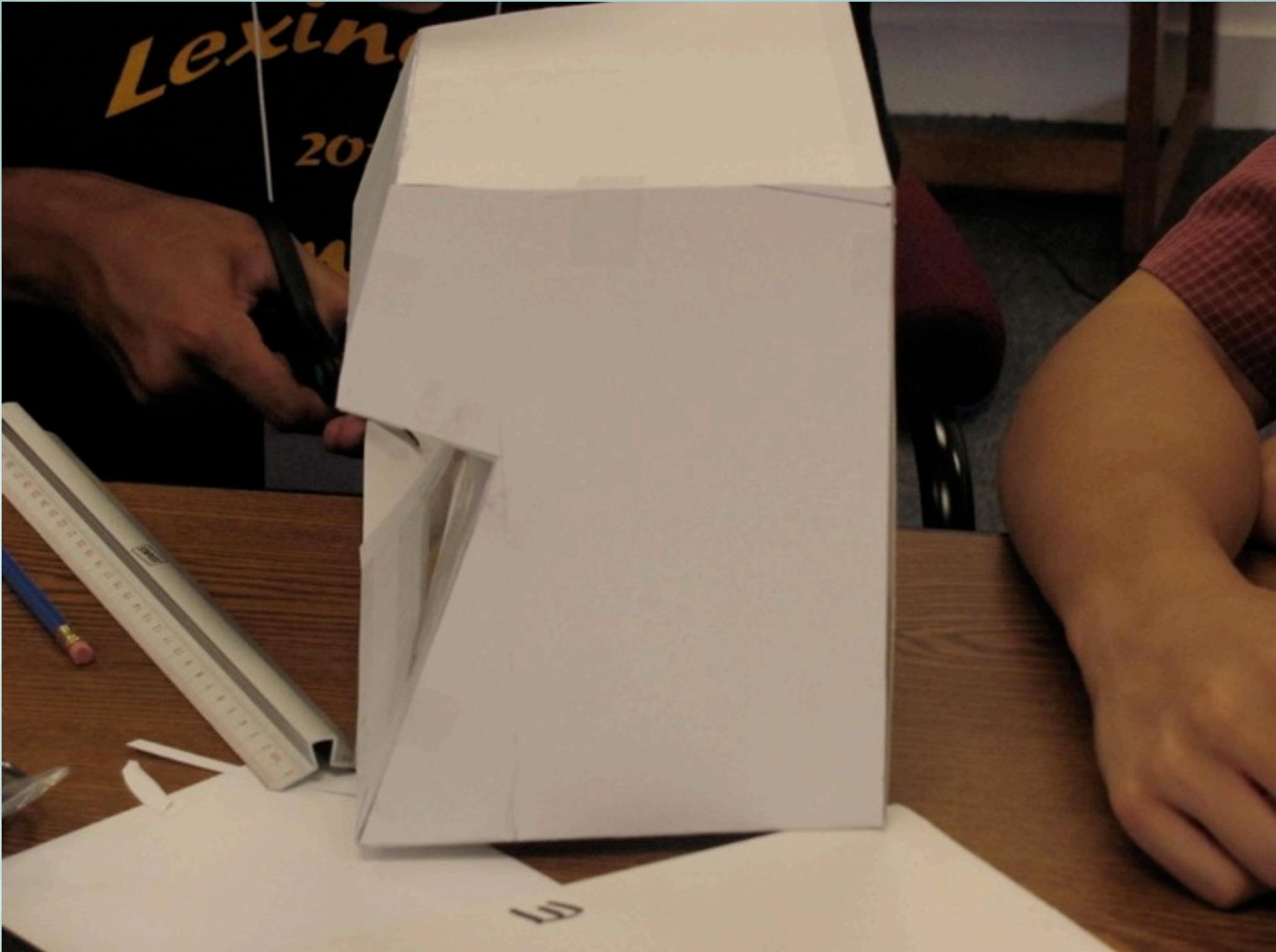
The sun's path in the sky



The sun's path in the sky



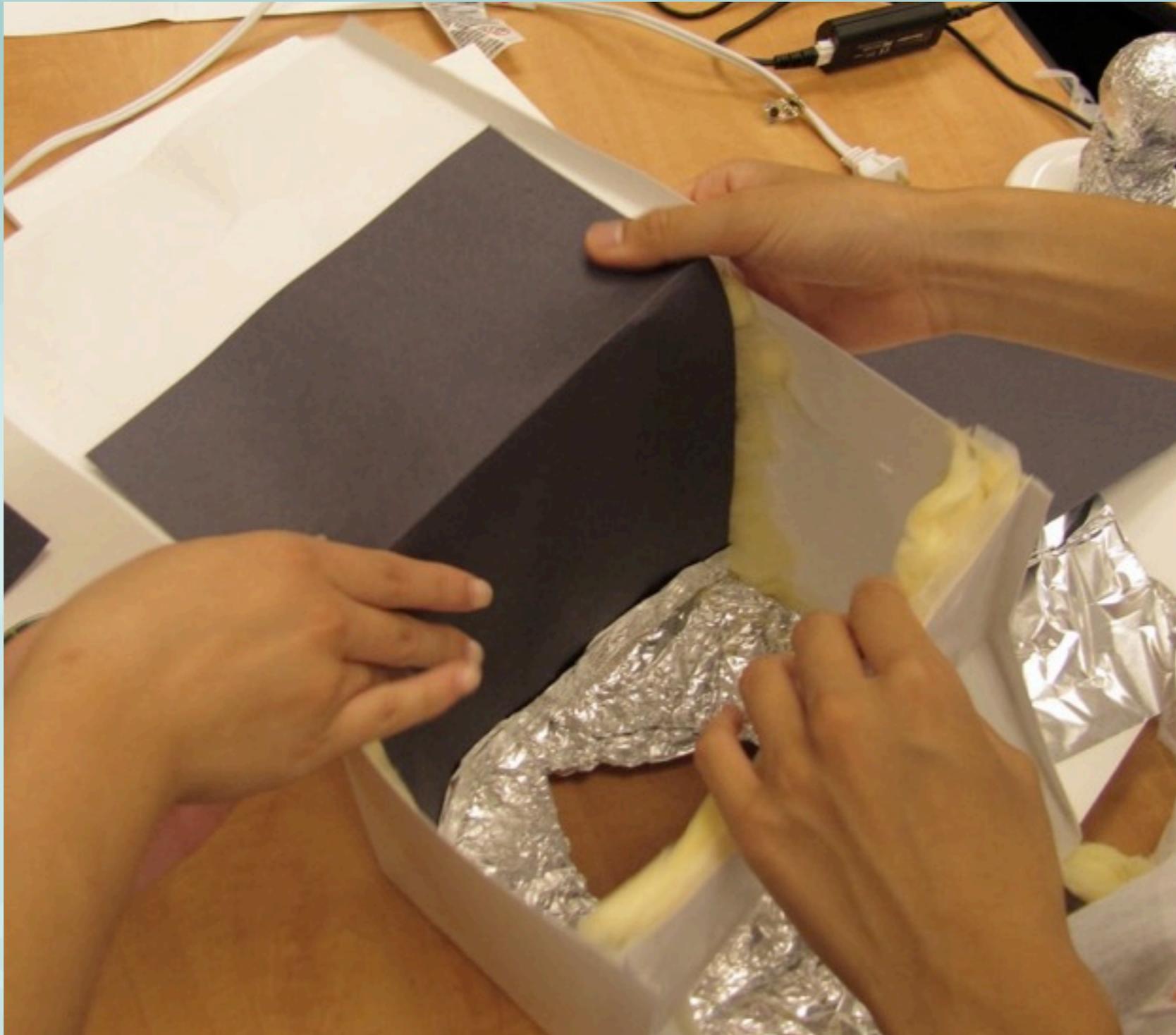
Design, build and test your own house



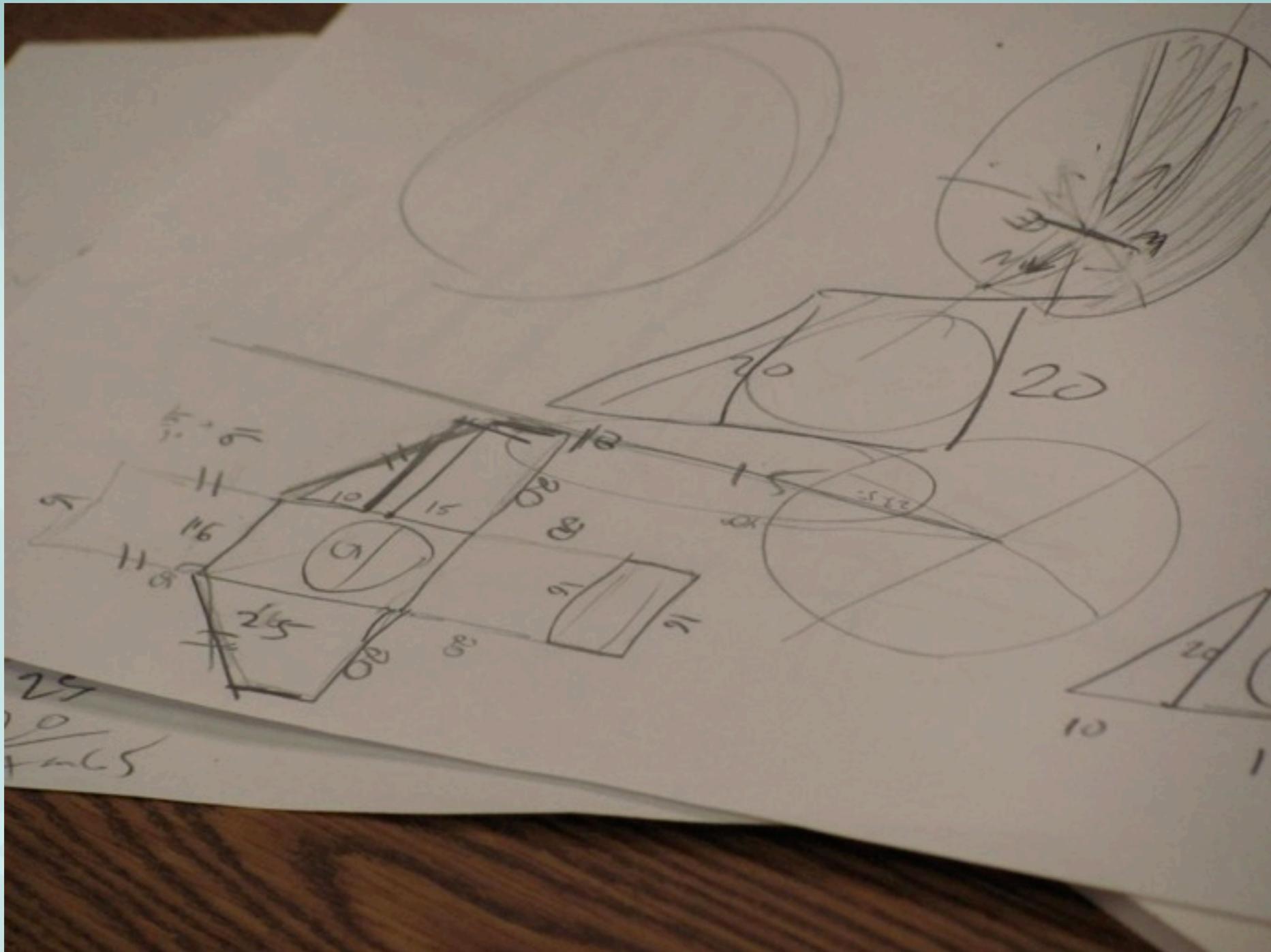
Design, build and test your own house



Modify your house



Streamline the design and testing process



Share and compare data

<u>no sun</u>				<u>SUN</u>				<u>Modified</u>			<u>Initial</u>	
team	before	improved	diff	team	before	modified	diff	no sun	w/ sun	team	no sun	w/ sun
1	19	8.6	-10.4	1	12.7	3.4	-9.3	8.6	3.4	1	19	12.7
2	22.8	12.2	-10.6	2	11	4.7	-6.3	12.2	4.7	2	22.8	11 w
3	15.5	7.3	-8.2	3	10.2	3.4	-6.8	7.3	3.4 w	3	15.5	10.2 w
4	13.8	5.9	-7.9	4	8.3	4.9	-3.4	5.9 w	4.9 w	4	13.8 w	8.3 w
5	19.2	11.2	-8.0	5	11.3	10.4	-.9	11.2	10	5	19.2 w	11.3
6	11.3	4.1	-7.2	6	4.4	2	-2.4			6	9.3 w	4.4 w





Share and compare data - standard house

team	heating up time	power w/o sun (Watts)	power w/ sun	solar input
1	200	24	15.9	8.1
3	265	24.6	20	4.6
4	232	26	19	7
5	234	21	12.4	8.6
6	273	31	25.5	5.5
average	240.8	25.3	18.6	6.8



Share and compare data - standard house

	own house, no sun			
team	initial	modified	improve- ment	
1	19	8.6	10.4	
2	22.8	12.2	10.6	
3	15.5	7.3	8.2	
4	13.8	5.9	7.9	
5	19.2	11.2	8	
6	9.3	4.1	5.2	
average	16.6	8.2	8.4	



Share and compare data - standard house

own house, with sun			
initial	modified	improve- ment	
12.7	3.4	9.3	
11	4.7	6.3	
10.2	3.4	6.8	
8.3	4.9	3.4	
11.3	10.4	0.9	
4.4	2	2.4	
9.7	4.8	4.9	

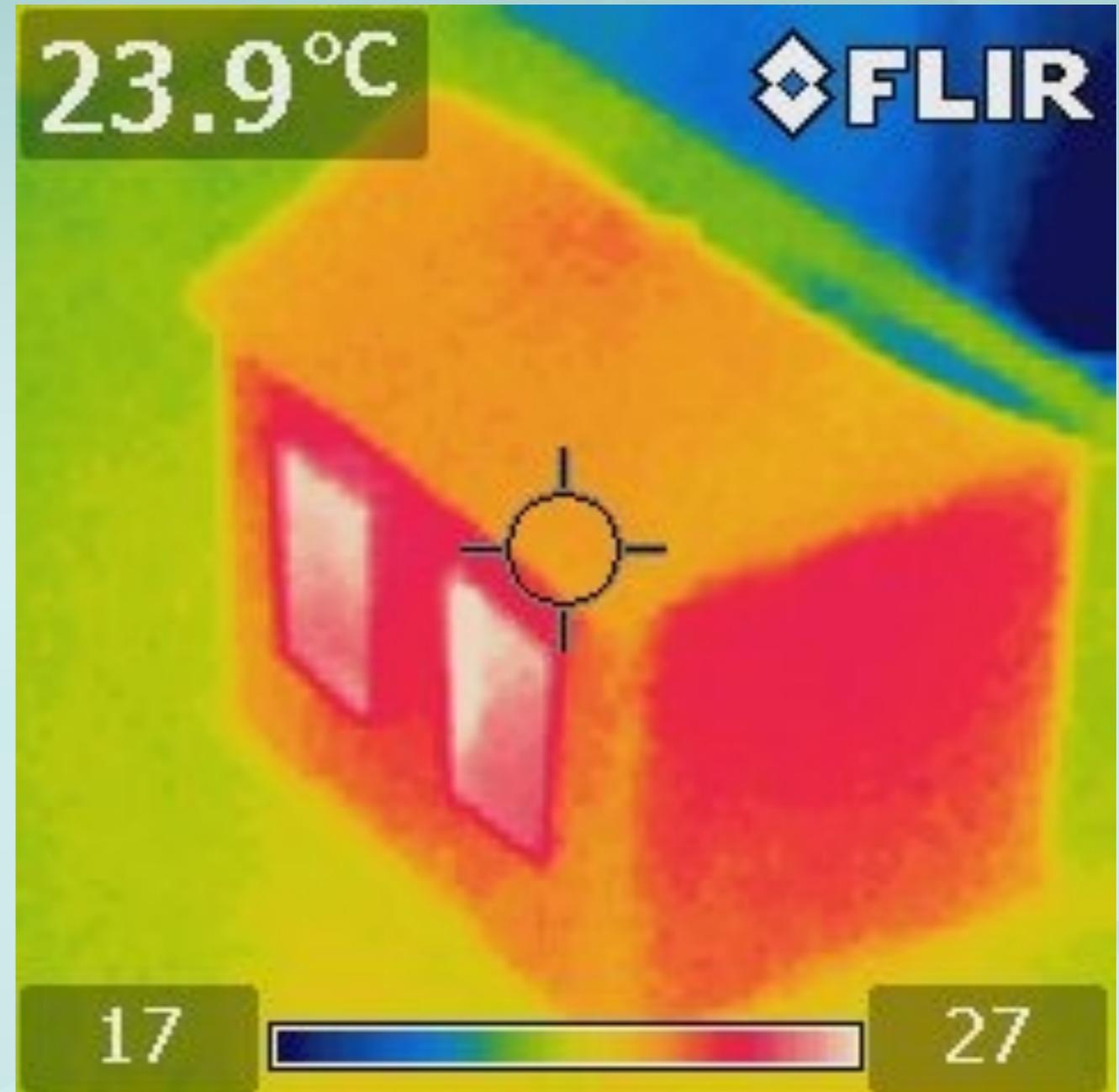
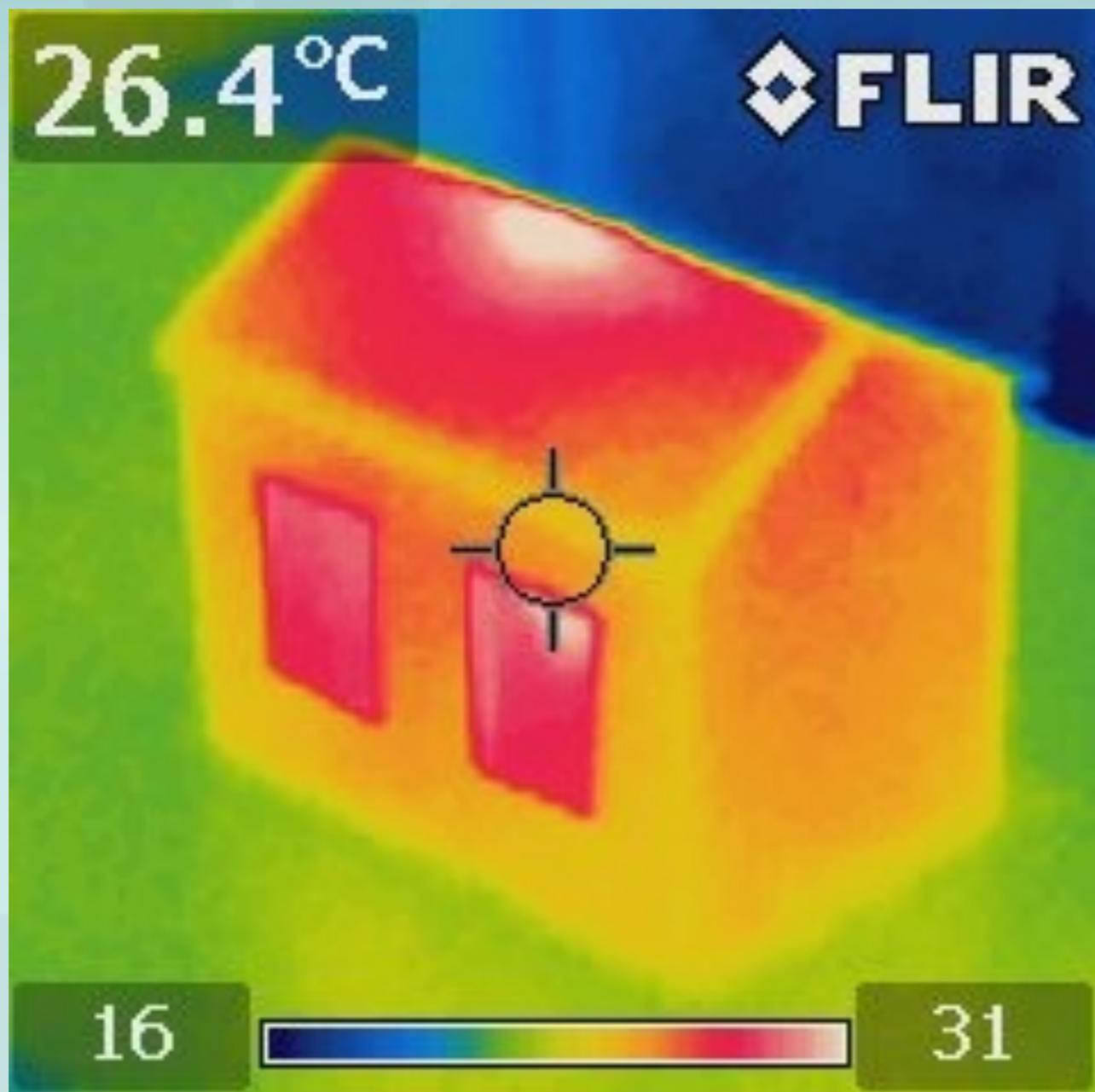


Share and compare data - standard house

summer cooling team	temp rise in 5 min (°C)	
	initial	modified
1	4.5	0.8
2	3.2	0.5
3	1.6	0
4	2.9	0.8
5	0.5	0
6	3.1	0.9
average	2.6	0.5

Infrared camera

A wonderful visualization tool



Try it out

Stations:

- Standard house: keep it warm
- Standard house: solar heating
- Heat transfer experiments:
conduction, convection, radiation
- Infrared camera 1
- Infrared camera 2
- Energy2D: download from USB sticks
(energy2d-simulations.htm)

Report back:

What did you observe?

How would you use this with your students?



Access to materials:
<http://energy.concord.org>

- Download workbook, hands-on version (pdf)
- Download workbook, simulation-enhanced version (pdf & Energy2D in zip file)
- Use individual hands-on or simulation experiments, separate from the workbook
- Run Energy2D, build and save an experiment, share it with students.
- Students run Energy2D and develop their own experiments
- Use Energy3D to study the sun's path (download Energy3D)
- Use Energy3D to build and print houses (write to us)



Further information

<http://www.concord.org>

<http://energy.concord.org>
(engineering energy project)

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