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Heat Transfer & Phase Change

Modeling a skylight

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Background

- The electricity demand for air conditioning is expected to grow tenfold by 2050 in Finland
- Controllability is important due to cold winters
- Radiative cooling with a triple window-skylight system with a green house gas in-between

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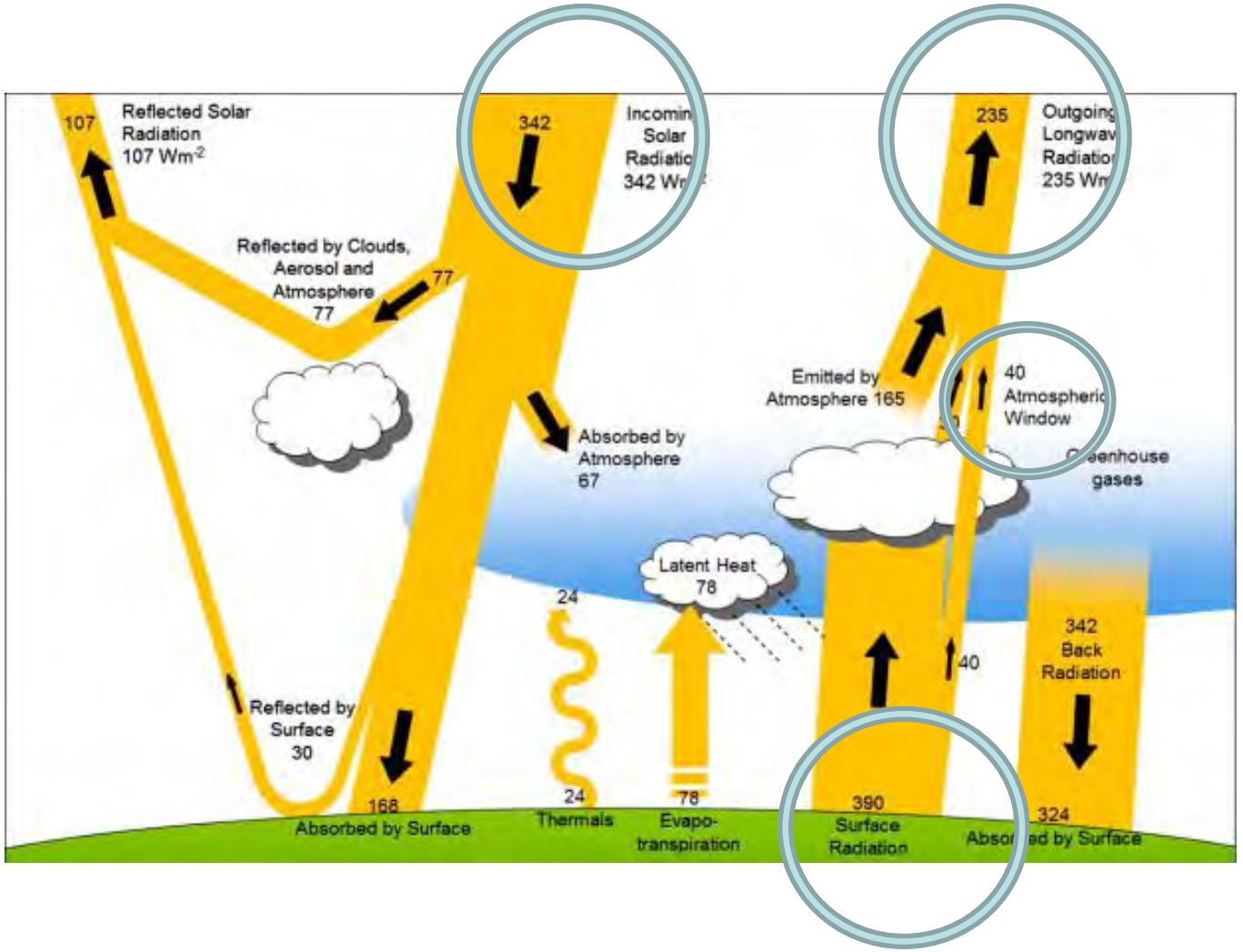
Earth-Atmosphere Energy Balance



Ghoniem, Ahmed F., "Needs, resources and climate change: Clean and efficient conversion technologies" Prog. Energy Combust. Sci. 37 ((2009) 15-51

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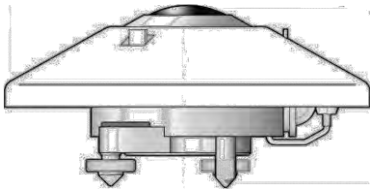
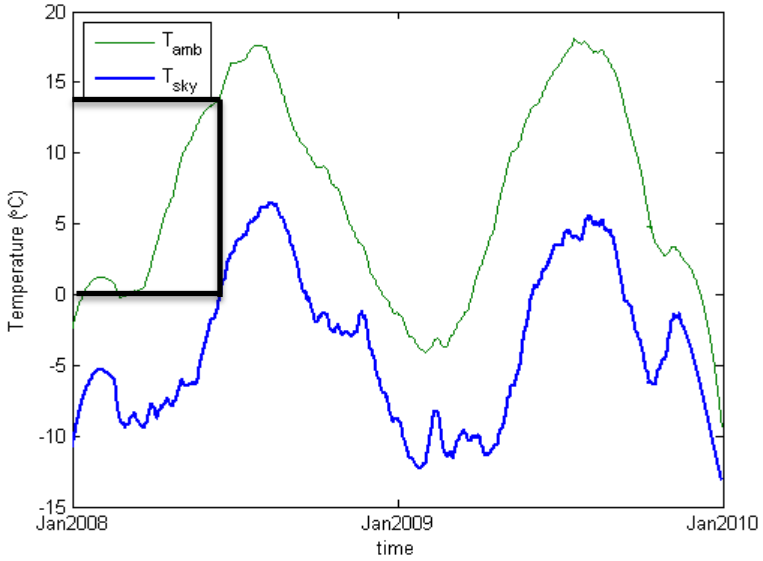
Temperature of sky?



- The sky temperature can be measured with a pyrgeometer.
- It measures the energy flow in the interval 4.5-42µm as a single value
- Here the ambient and the sky temperatures are plotted
- $\dot{Q} = \sigma(286^4 - 273^4)$ $= 70\ ^{W}/_{m^2}$



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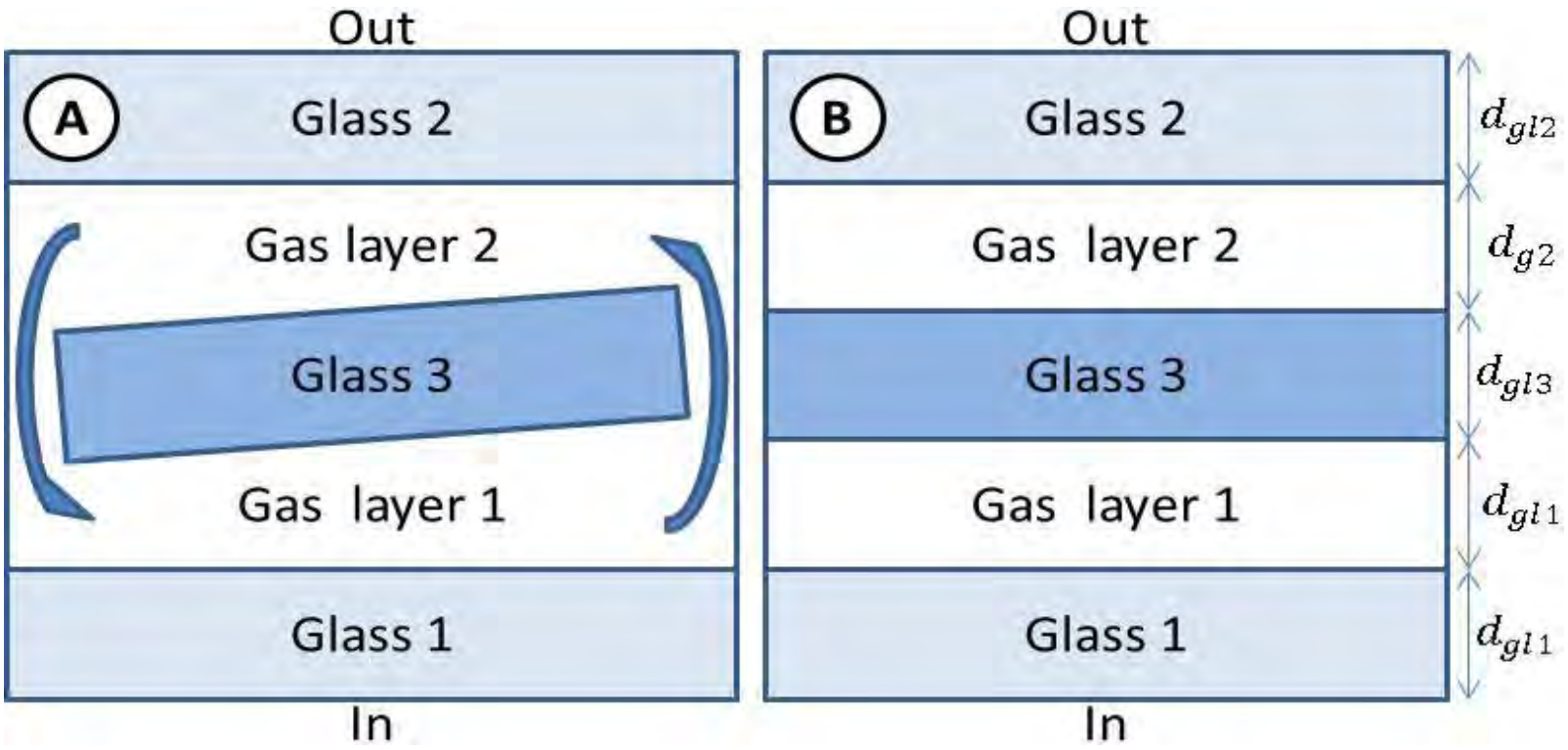
System Description of the skylight System

- Cooling mode
- Insulating mode



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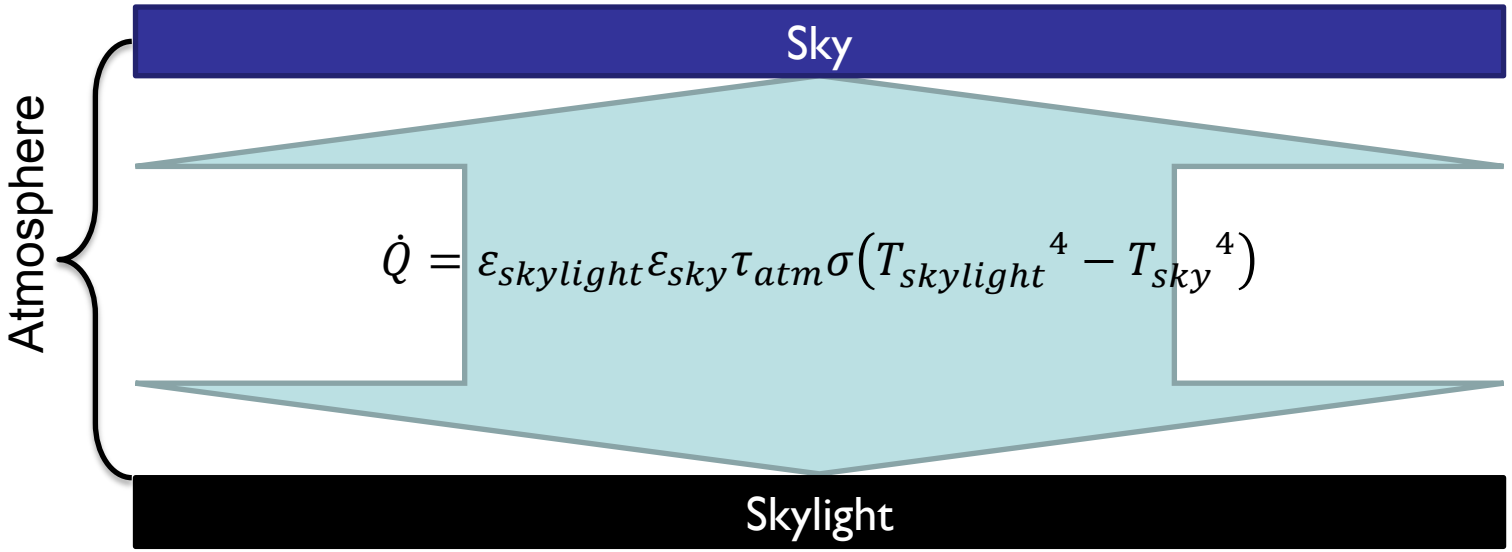
Calculation model

- The calculations are done by using the simulation software Comsol 4.1
- The calculations are done with gray media in 2-D



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Results from earlier modeling

[W/m^2]	CO_2	Air
Summer Cooling	117	15
Winter Insulating	966	983
Summer Insulating	88	19
Winter Cooling	883	655

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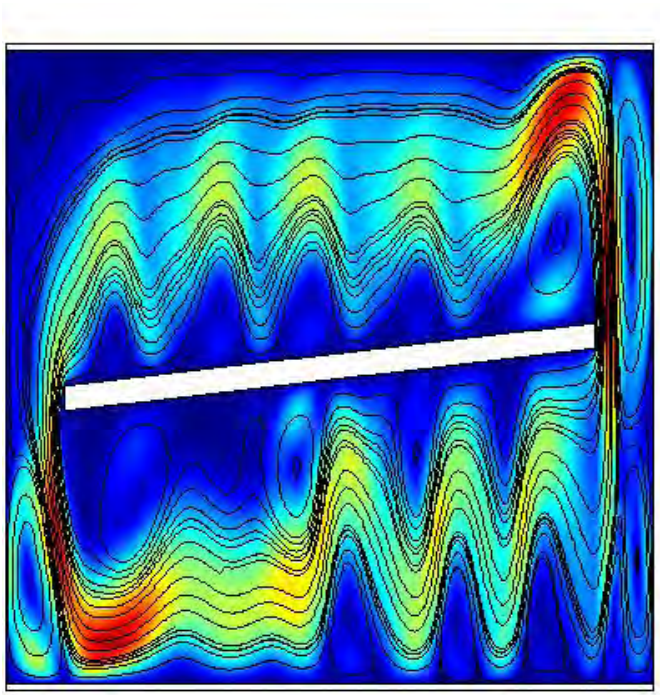
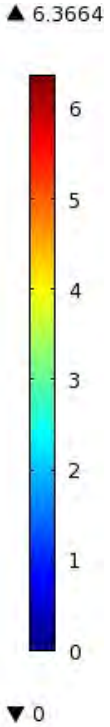
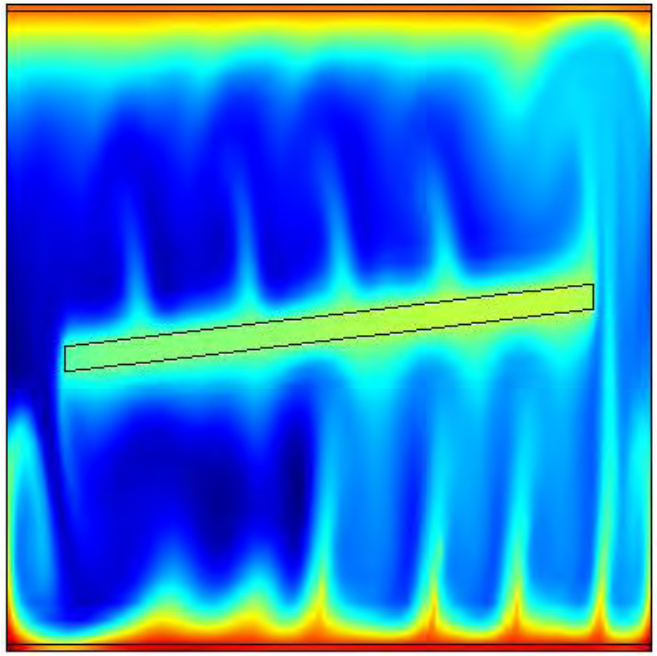
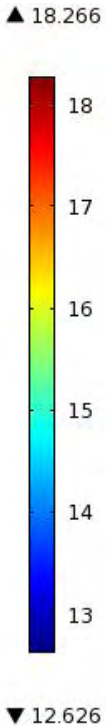
Skylight filled with participating media

- Velocity profile in cm/s
- Temperature profile in °C









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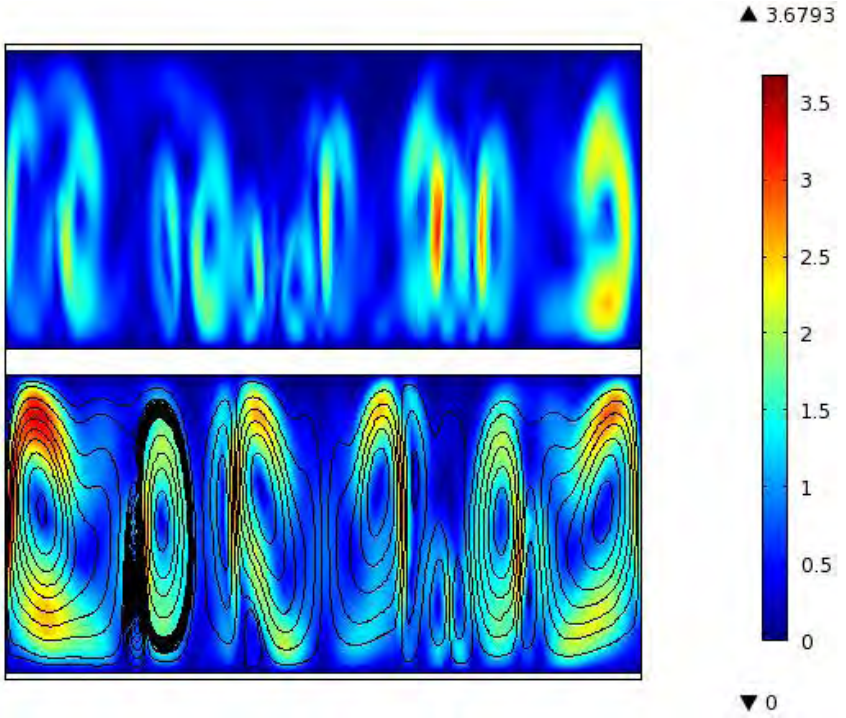

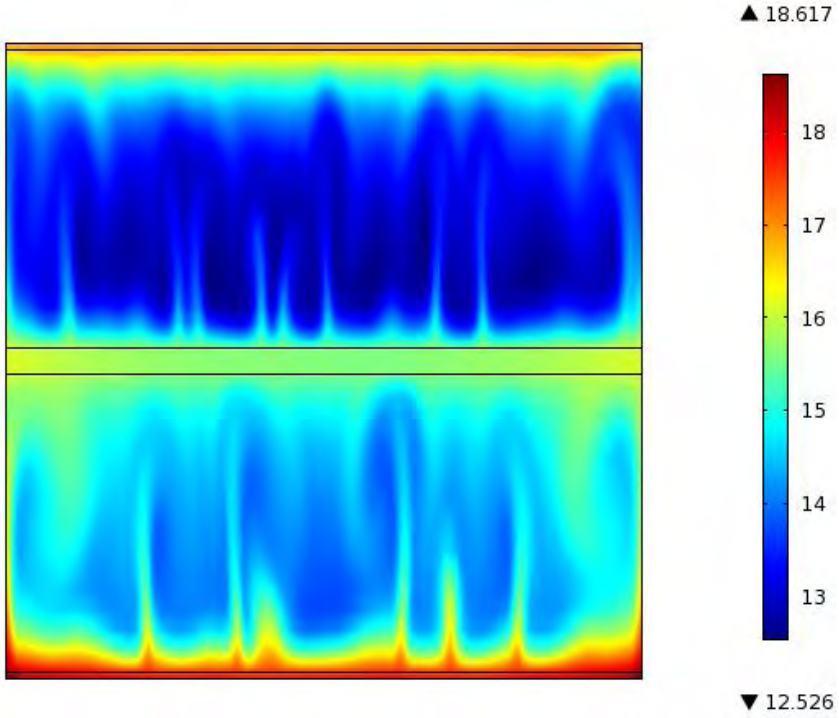

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Experimentation

Description

- To asses the cooling effect two gas tight containers have been constructed
- This allows for comparative studies of different gases and constructions

Physical set-up

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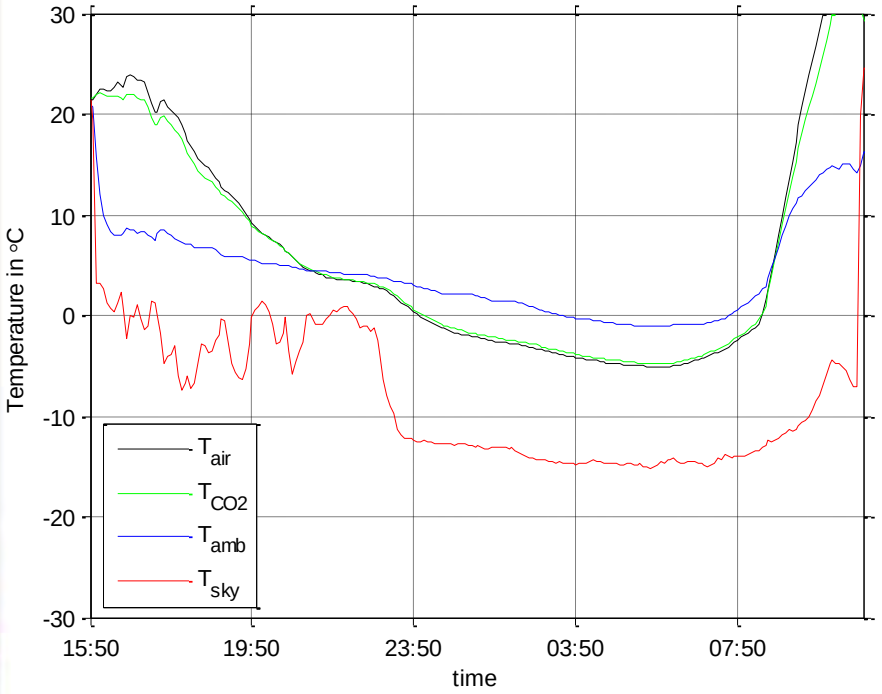
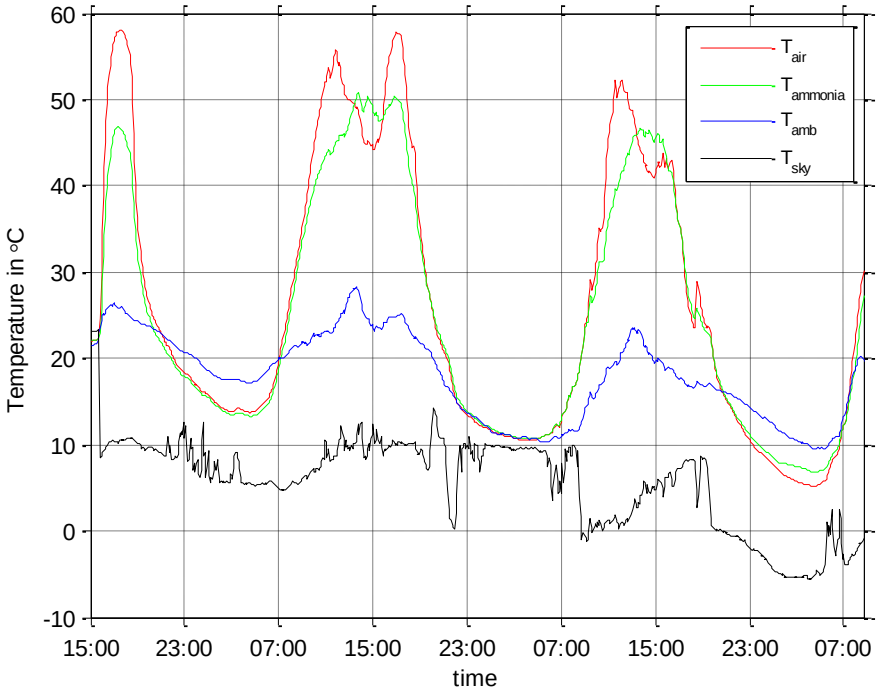
Results

- Carbon dioxide 21.4.2011



- Ammonia 3.6.2011



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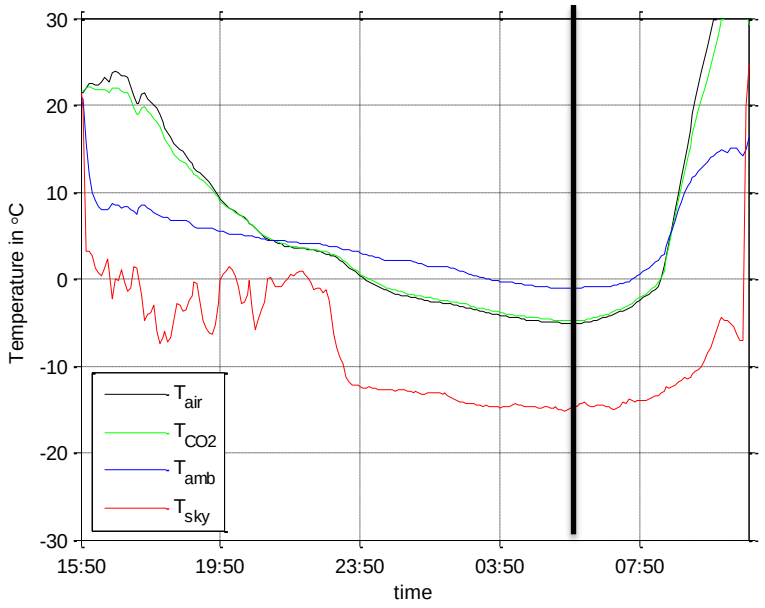
Setting up the model

- No difference in Temp. between gases, why?
- Measured vs. actual Temp. of the gas?
- A singular event from the CO_2 experiment was modeled with Comsol 4.2



[°C]	T_{amb}	T_{sky}	T_{CO2}	T_{air}
5.35am	-1.1	-15.15	-4.80	-5.1

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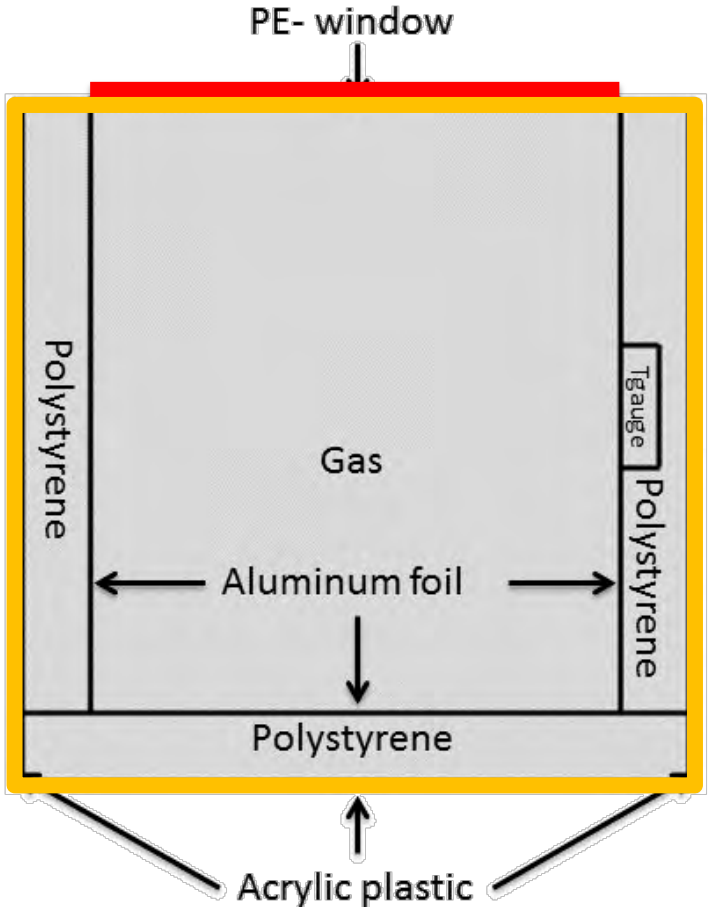
Modeling experiment

Heat flows:

1. "surface to ambient radiation" Here, the "ambient" temperature for radiation is set to be the measured sky-temperature.

2. Convective Cooling that is the wind, a wind speed of 4 m/s is assumed.

- Computationally heavy → 2-D
- Time-dependent model to avoid unstable equilibrium points



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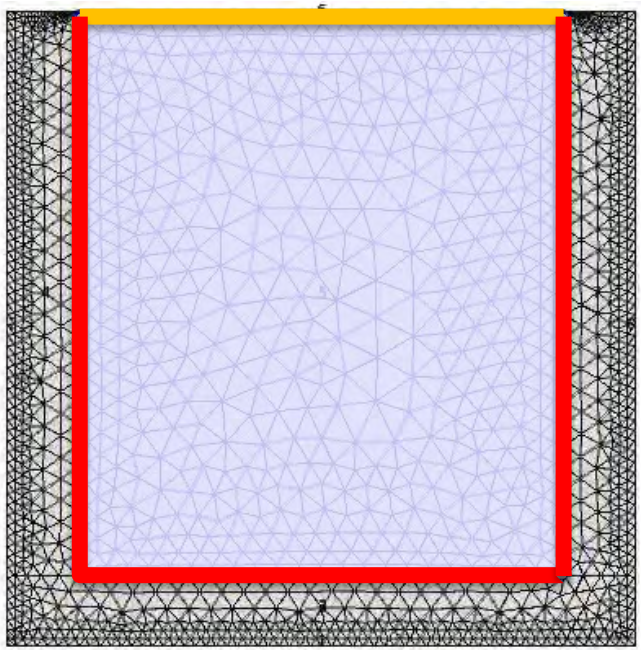
Modeling experiment

- The PE-film is assumed to have a τ=0.2
- The aluminum foil is assumed to have and absorptance of α=0.04
- CO_2 was calculated to have a total α=0.16



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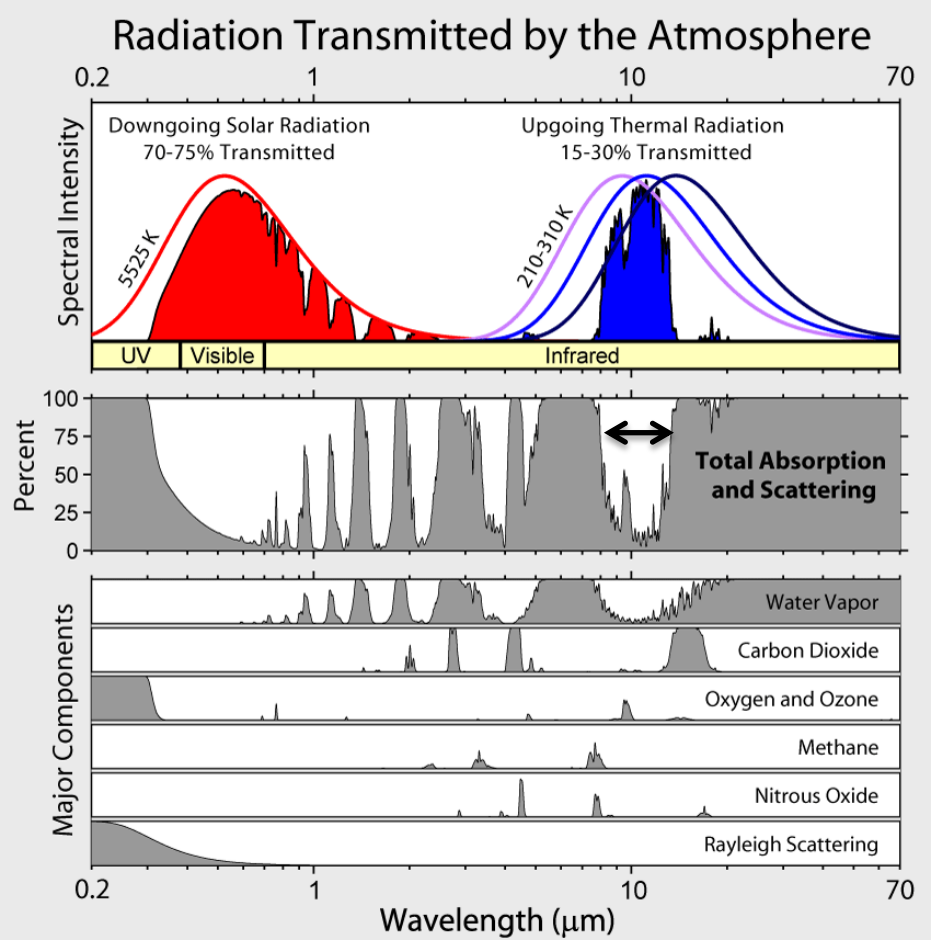
Radiation Transmitted by the Atmosphere

- For an object to be cooled by radiative cooling needs it to emit heat radiation in the ~8-13µm interval (sky window)
- This interval depends on such weather condition as cloudiness and air moisture.
- CO_2 lies on one corner of the interval



http://chriscolose.wordpress.com/2010/02/18/greenhouse-effect-revisited/

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Results from modeling

- Temperatures are taken at the last time step (1500 s.)
- Modeled results coincide with experimental results

[°C]	T_{amb}	T_{sky}	T_{air}	T_{CO2} (α=0)	T_{CO2} (α=0,16)
Exp.	-1.1	-15.15	-5.1	-4.80	-4.80
T_{gauge}	Input	Input	-4,50	-4,50	-4.42
T_{gas}	Input	Input	-5,32	-5,43	-5.27

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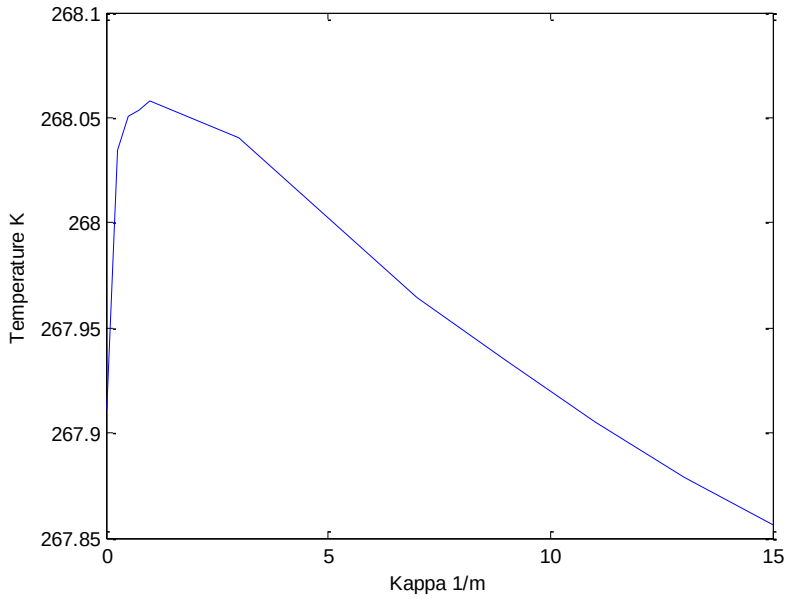
The influence of gas absorptance

- The absorptance of the gas was varied from 0 to more than 10 times that of CO_2
- The effect on gas temperature is neglible



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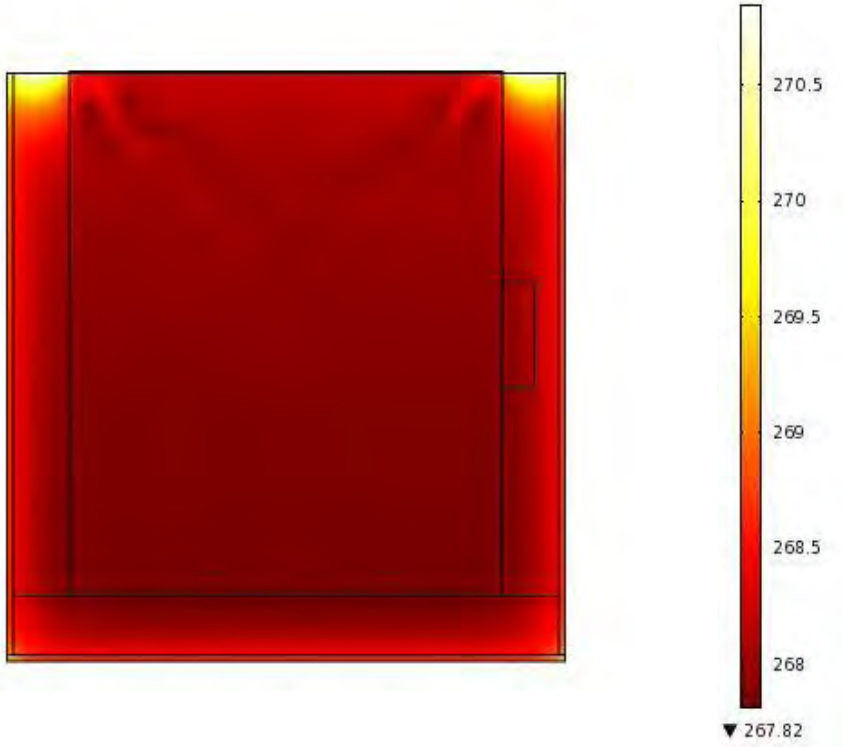
Conclusions

- Thicker insulation
- Reflectance the walls needs to be minimized
- Heating of the gas could increase temperature differences between gas and air temp.
- Calculations need to be done spectrally dependent
- Evaluation of different gases



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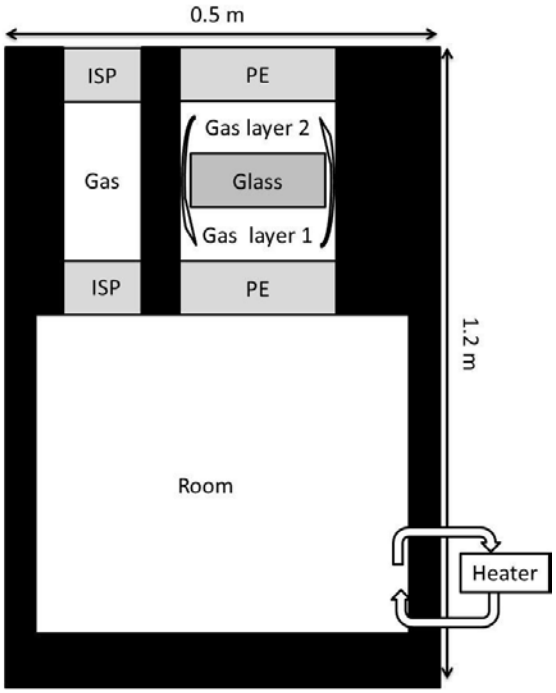
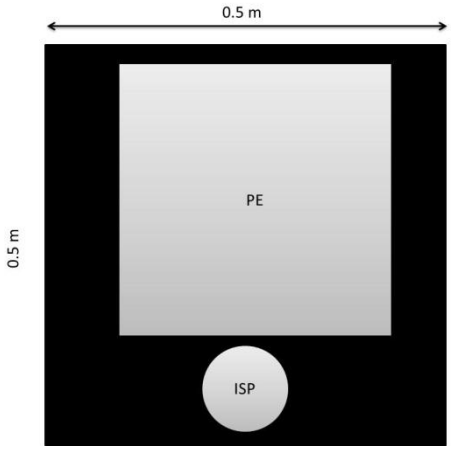
Future Work



Cross-section of the rig



View of rig from above

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