Passive thermal control of enclosures

Developing applications for passive thermal actuators

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The Bartlett School of Architecture

Speaker

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- Architect
- Research investigator
  - Passive thermal actuators
  - Design representation software
  - Digital manufacturing
- Expertise in
  - Prototyping techniques
  - Experiment design
  - Measurement and instrumentation

Pre-COVID 19

Based in UCL @ HereEast

3500 m^2 facility shared between:

- The Bartlett School of Architecture
- Dept. Computer Science / UCL Robotics
- Faculty of Engineering
- Institute of Sustainable Heritage
- Civil Environmental & Geomatic Eng.

Workshop facility

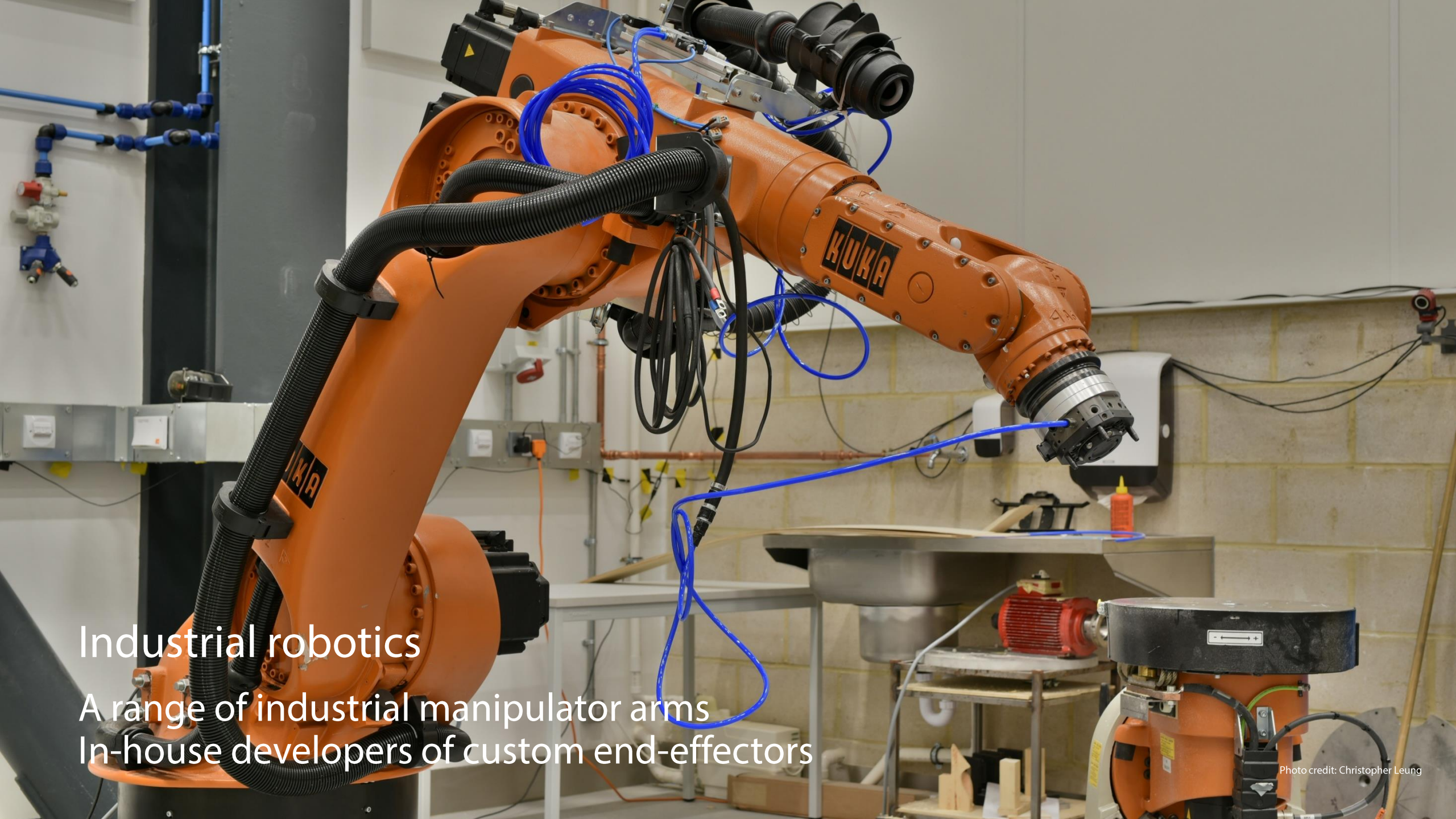
An industrial workspace with extensive workshop facilities

Photo credit: Christopher Leung

Manufacturing capability

Tool shop CNC machinery for 2.5D milling
3 and 4-axis milling and mill-turning center

Photo credit: Christopher Leung



Industrial robotics

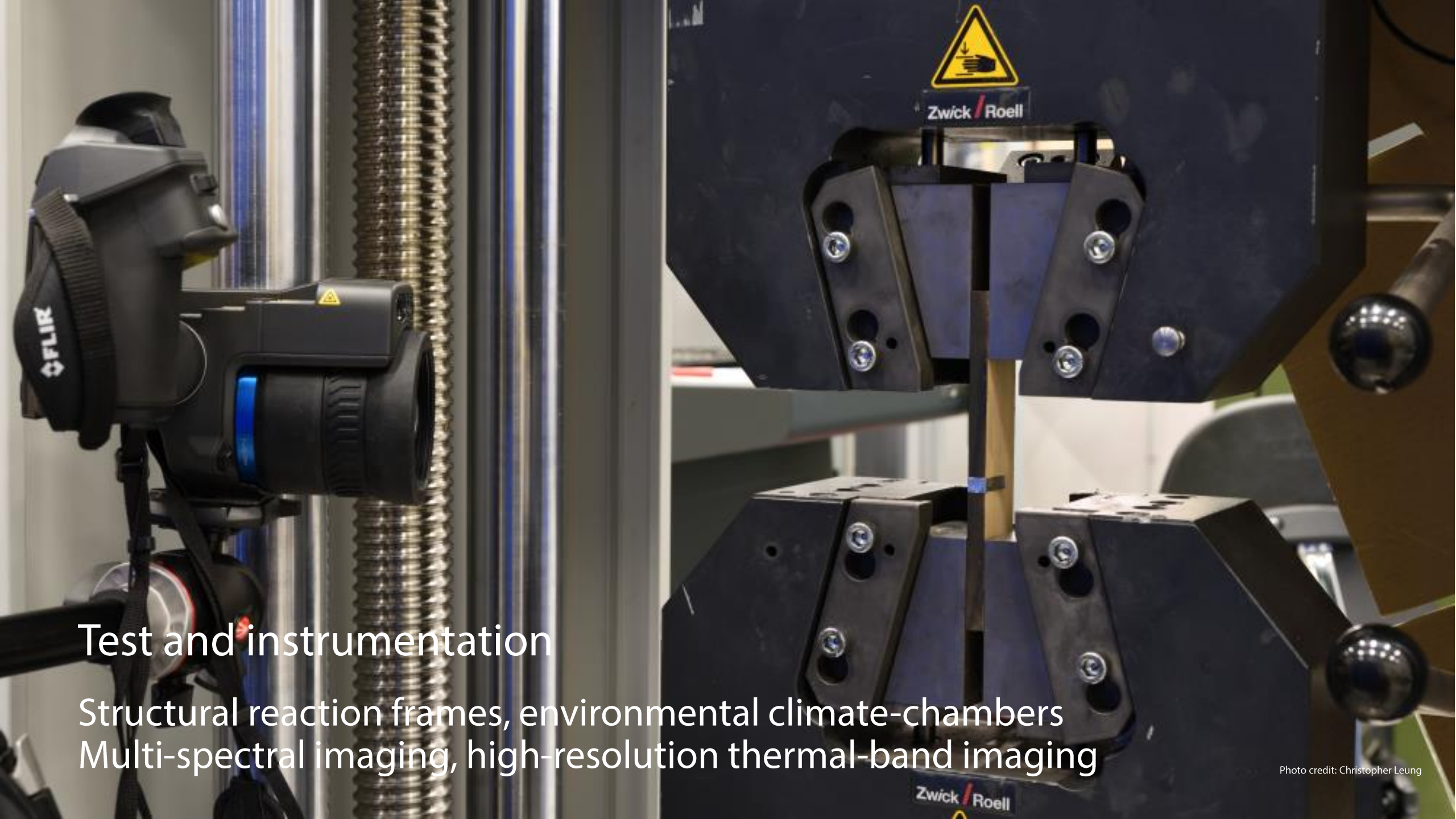
A range of industrial manipulator arms
In-house developers of custom end-effectors

Photo credit: Christopher Leung

Metrology

Capturing large-scale spatial data
Close-range photogrammetry and inspection

Photo credit: Christopher Leung

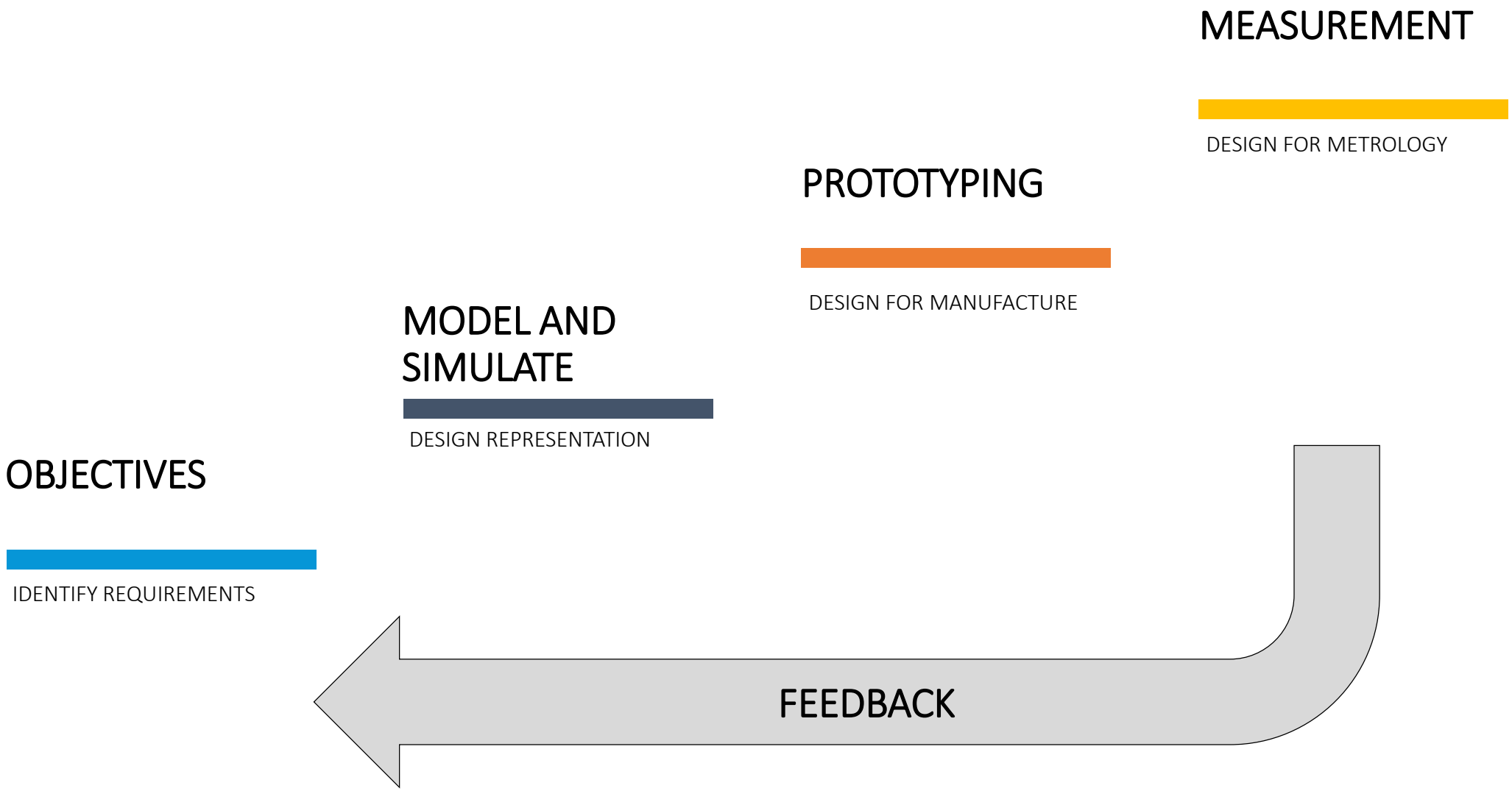


Test and instrumentation

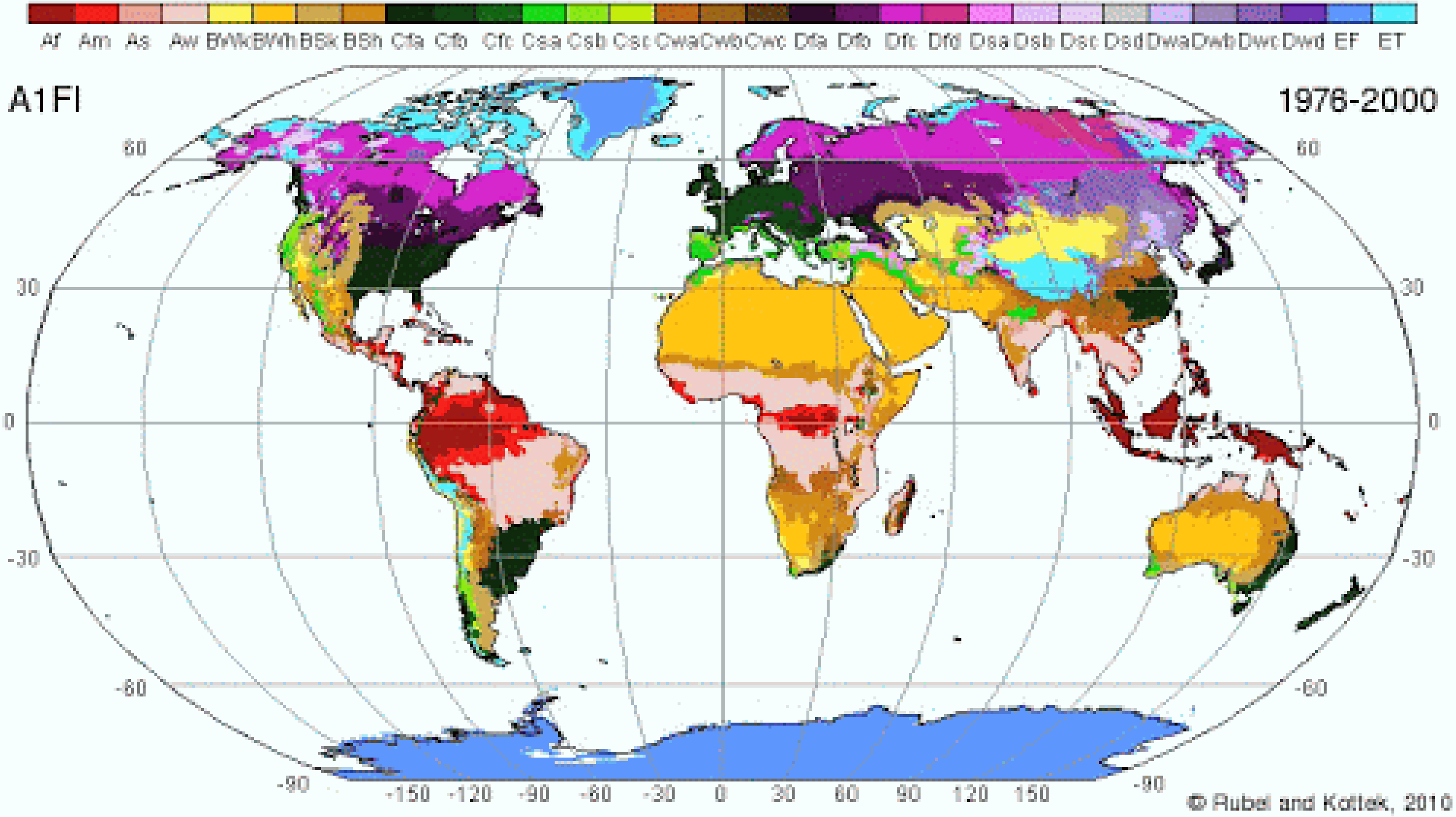
Structural reaction frames, environmental climate-chambers
Multi-spectral imaging, high-resolution thermal-band imaging

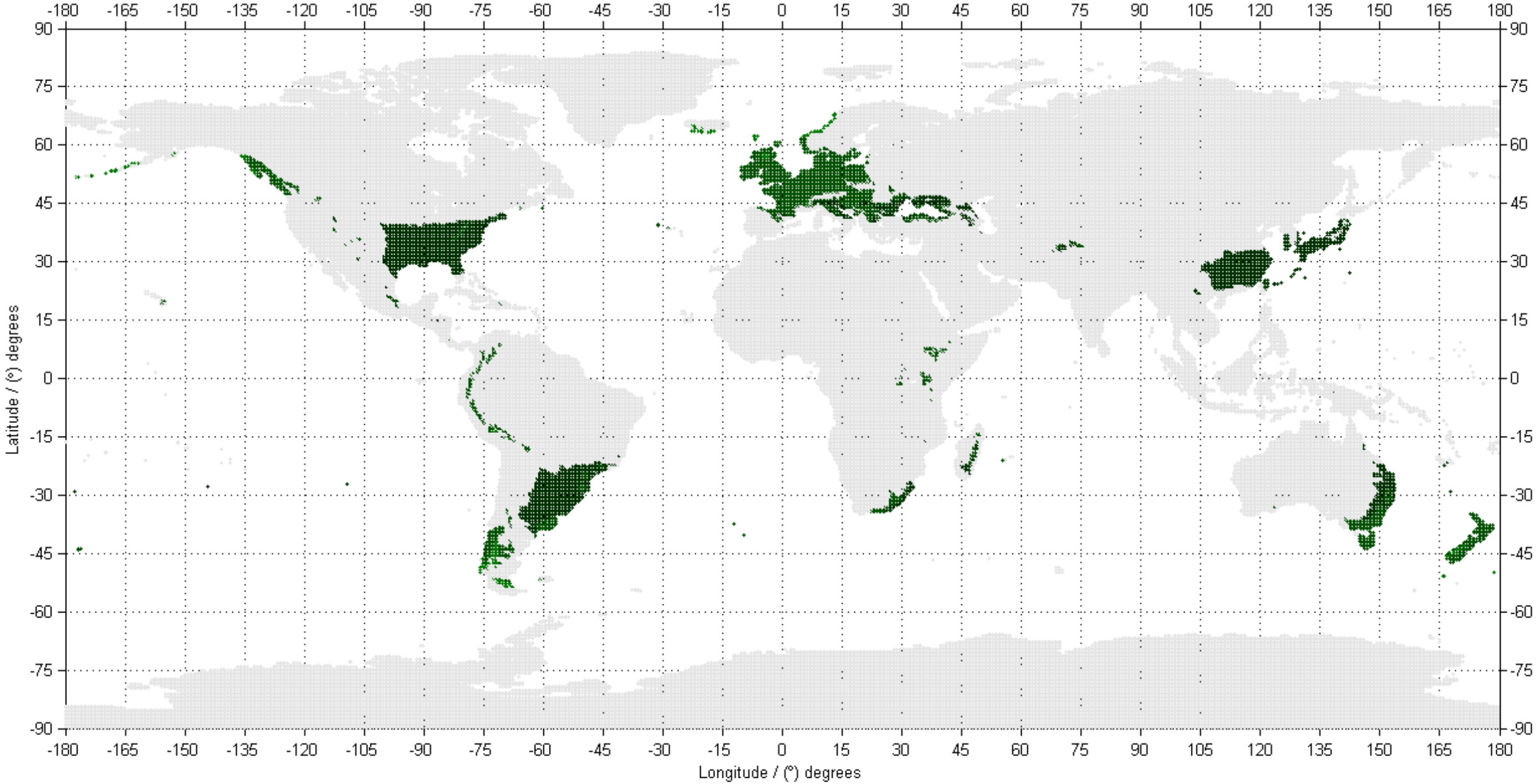
Photo credit: Christopher Leung

Modus Operandi


MEASUREMENT
DESIGN FOR METROLOGY
PROTOTYPING
DESIGN FOR MANUFACTURE
MODEL AND SIMULATE
DESIGN REPRESENTATION
OBJECTIVES
IDENTIFY REQUIREMENTS
FEEDBACK

Context

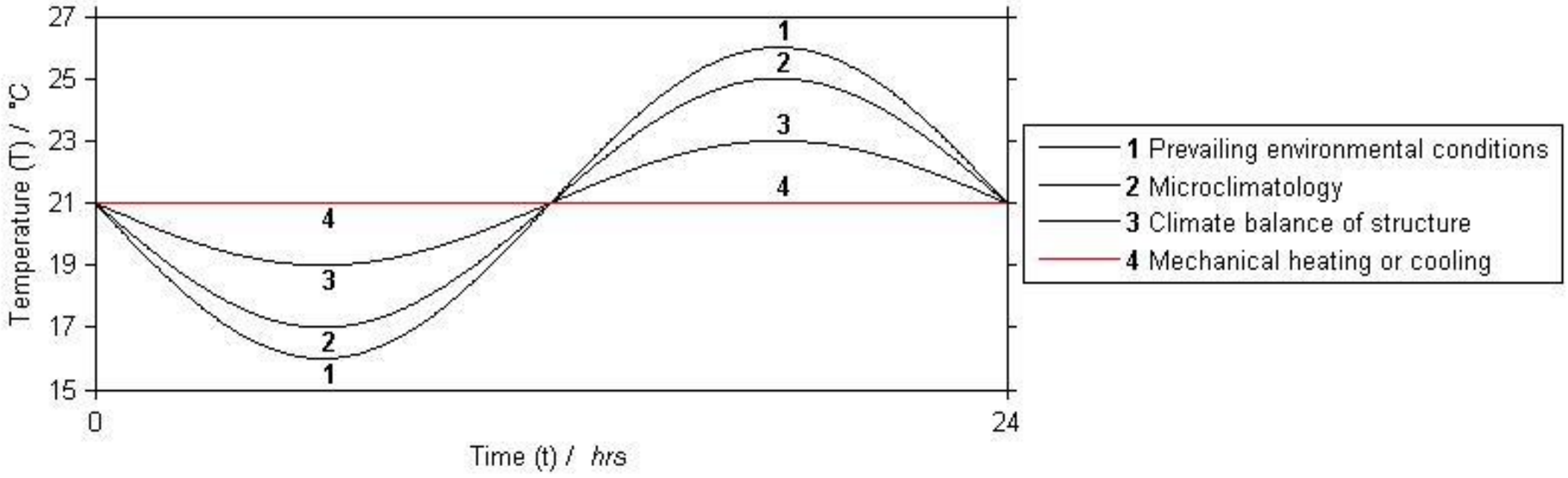

Af Am As Aw BWk BWh BSk BSh Cfa Cfb Cfc Csa Csb Csc Cwa Cwb Cwc Dfa Dfb Dfc Dfd Dsa Dsb Dsc Dsd Dwa Dwb Dwc Dwd EF ET
A1FI
1976-2000
60
30
0
-30
-60
-90
-150 -120 -90 -60 -30 0 30 60 90 120 150
© Rubel and Kottek, 2010



Af	Am	As	Aw	BWk	BWh	BSk	BSh	Cfa	Cfb	Cfc	Csa	Csb	Csc	Cwa	Cwb	Cwc	Dfa	Dfb	Dfc	Dfd	Dsa	Dsb	Dsc	Dsd	Dwa	Dwb	Dwc	Dwd	EF	ET
2.91	2.05	0.34	6.63	2.01	7.95	3.59	3.42	3.26	2.61	0.22	1.22	0.80	0.01	1.64	0.61	0.01	0.82	4.87	12.02	1.54	0.09	0.22	0.28	0.00	0.35	0.71	1.42	0.11	29.72	8.58

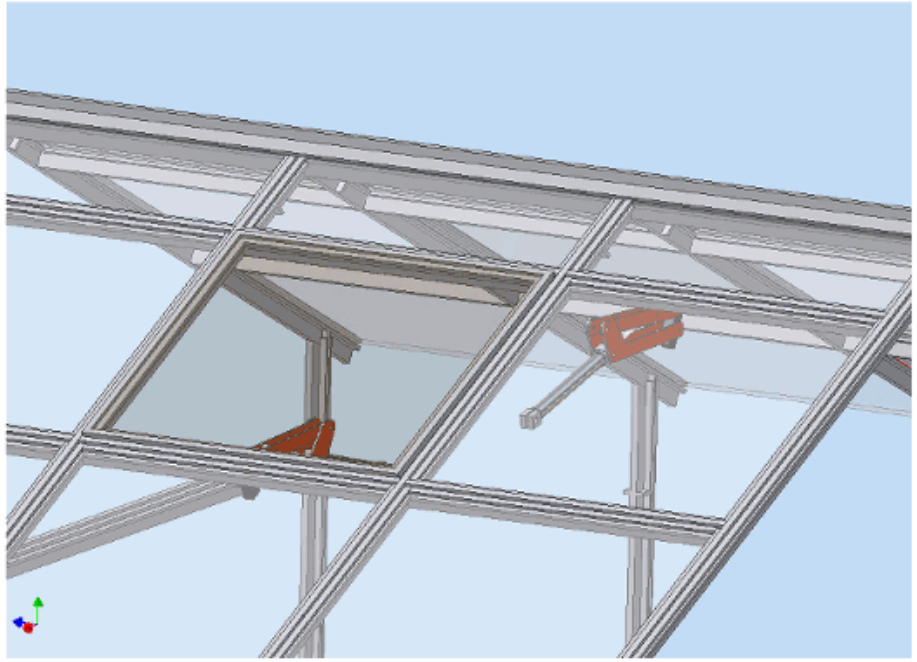
Climate type by temperature, humidity and precipitation and cooresponding percentage of global land areas / Köppen classifications after (Kottek,2006) and (%)

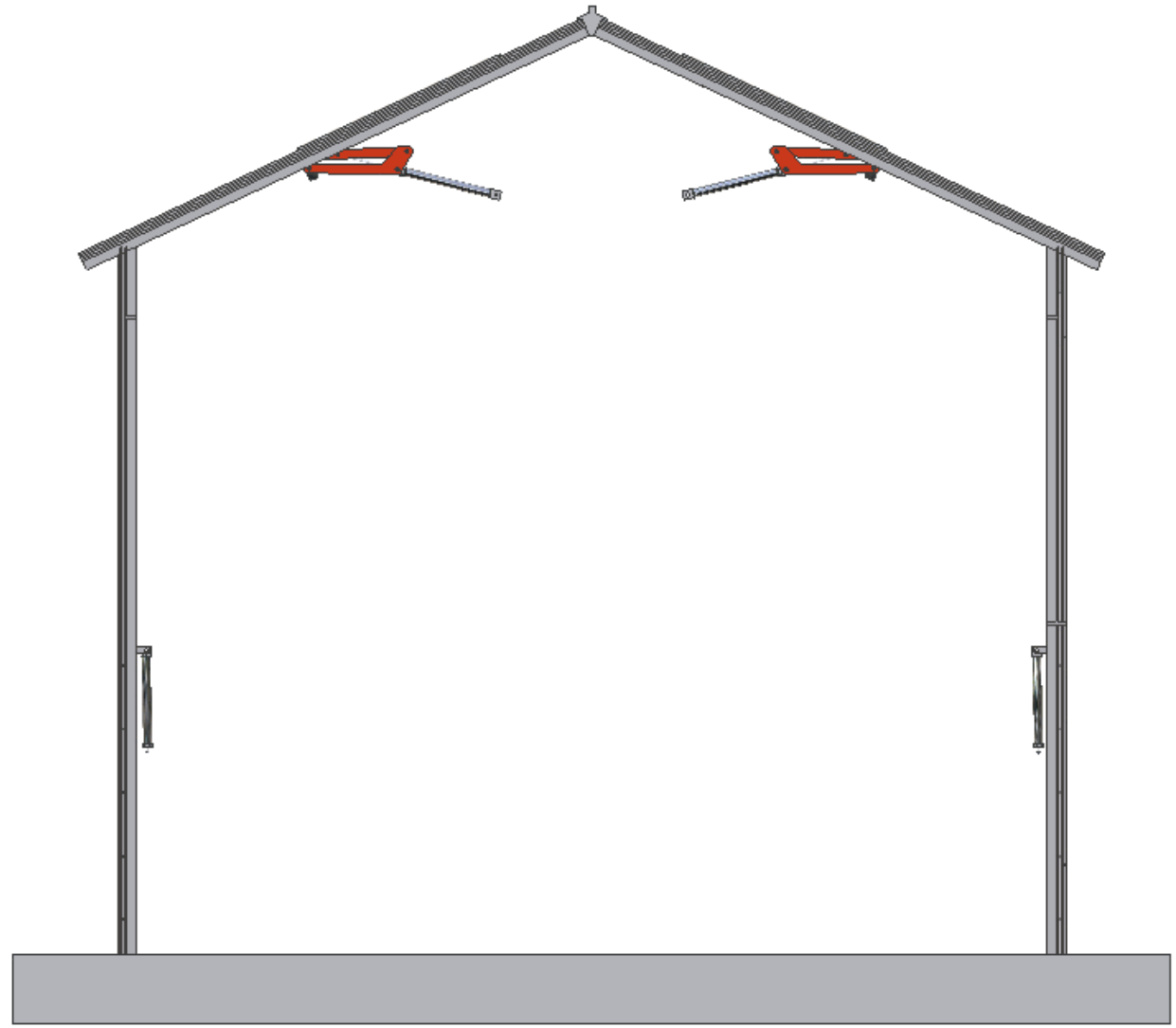
Passive thermal design of buildings



After Fig. 30 'Flattening the curve' on p. 11 in *Design with climate* by (Olgyay, 1963)

Variable performance building enclosures





Extremely simple thermal energy responsive device used to operate ventilators in greenhouses

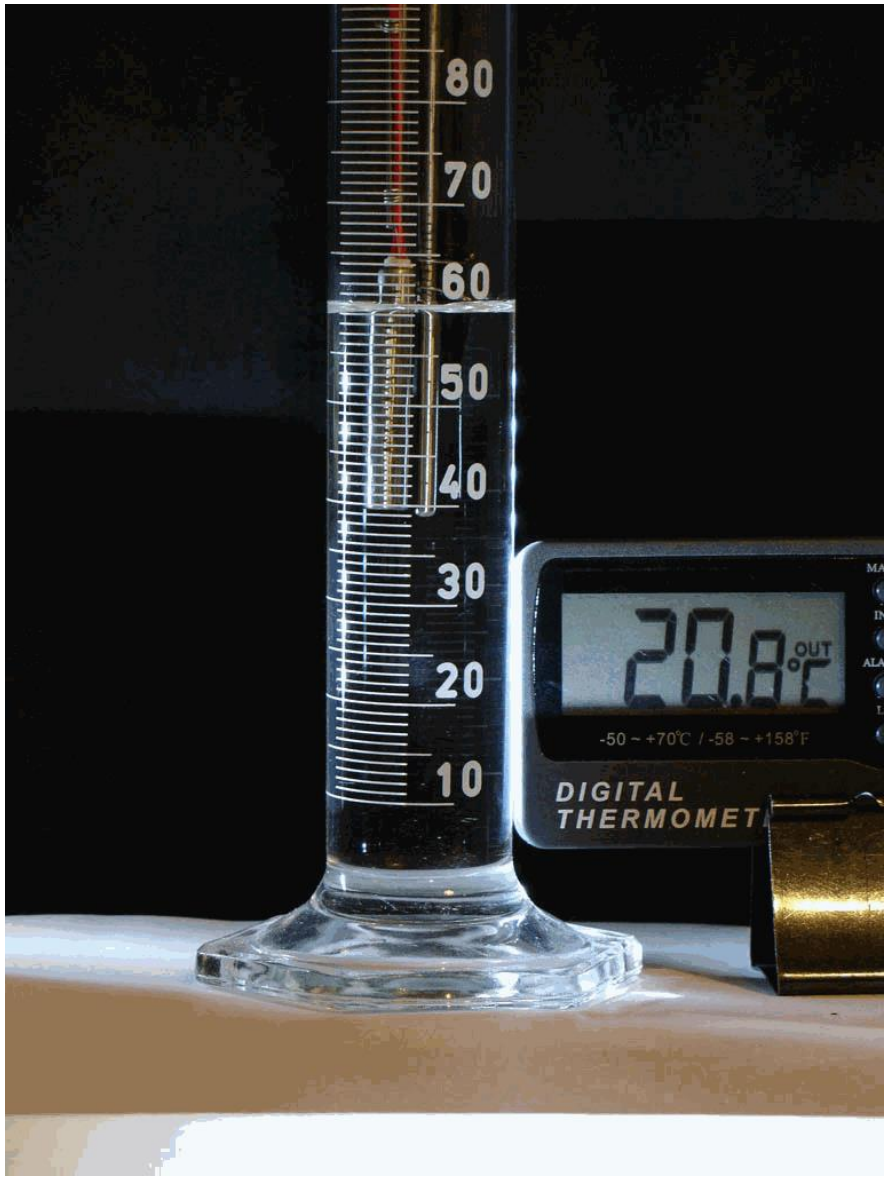
Challenges

- Generate the large forces needed to operate building components
  - Component mass (10s to 100s)kg
- Operate with passive low-energy
  - Small temperature differences (-10 to +30) °C
  - Solar radiation has low density (500 to 1000) W/m²
- Self-regulation
  - Independence from powered electronic control systems
- Robustness with long endurance
  - Design life 30 years (22,000 diurnal duty-cycles)
- Autonomous and self-contained
  - Avoid clashes in services coordination and out-of-sequence construction

Wax

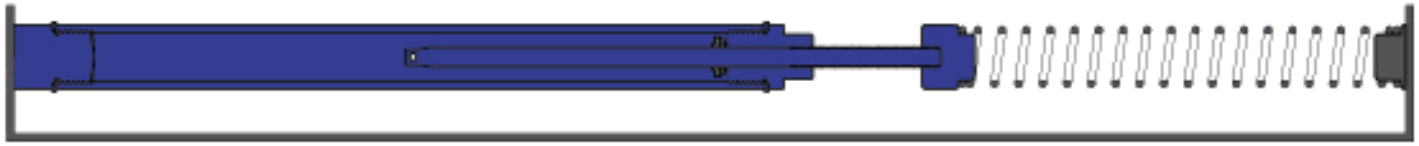
Heating - expansion

Wax



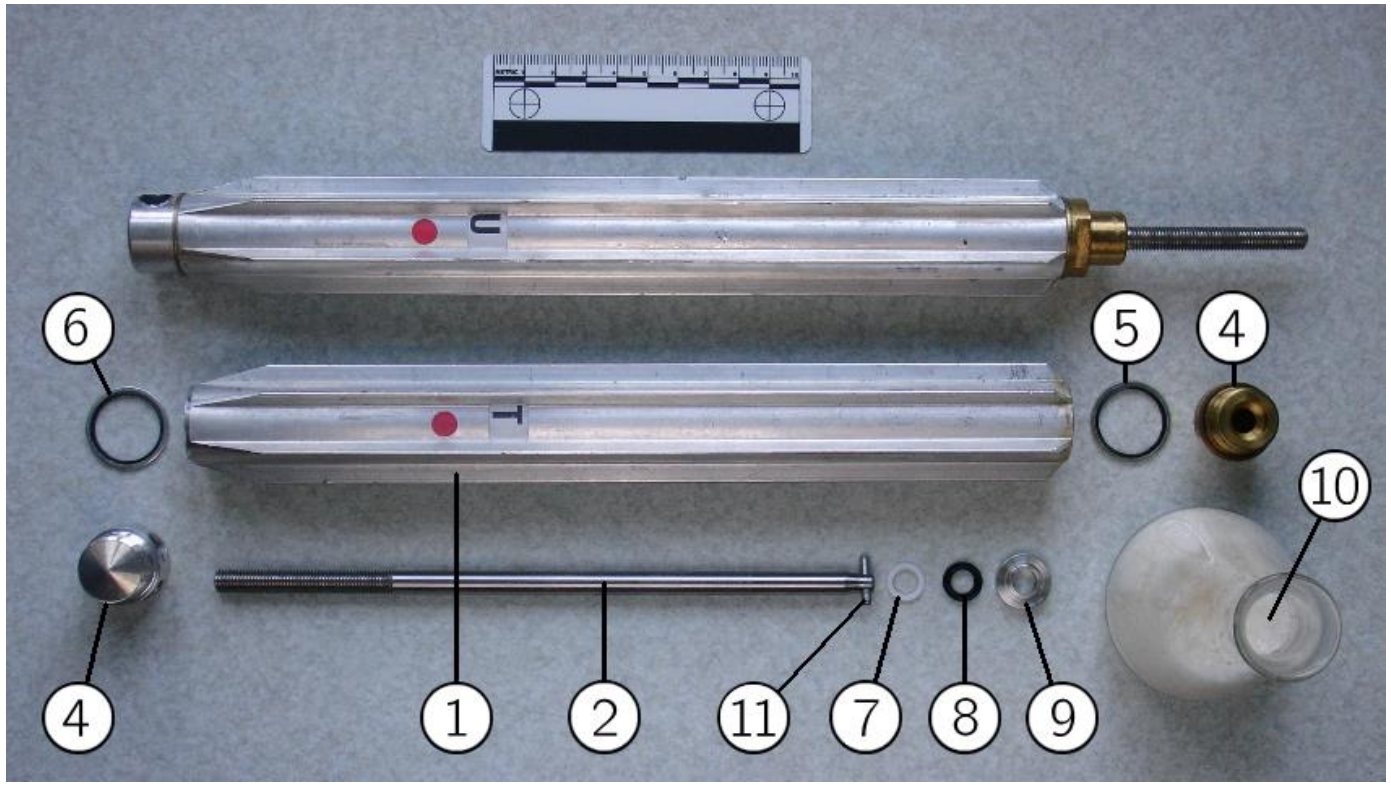
Solidification - shrinkage

Thermal actuator

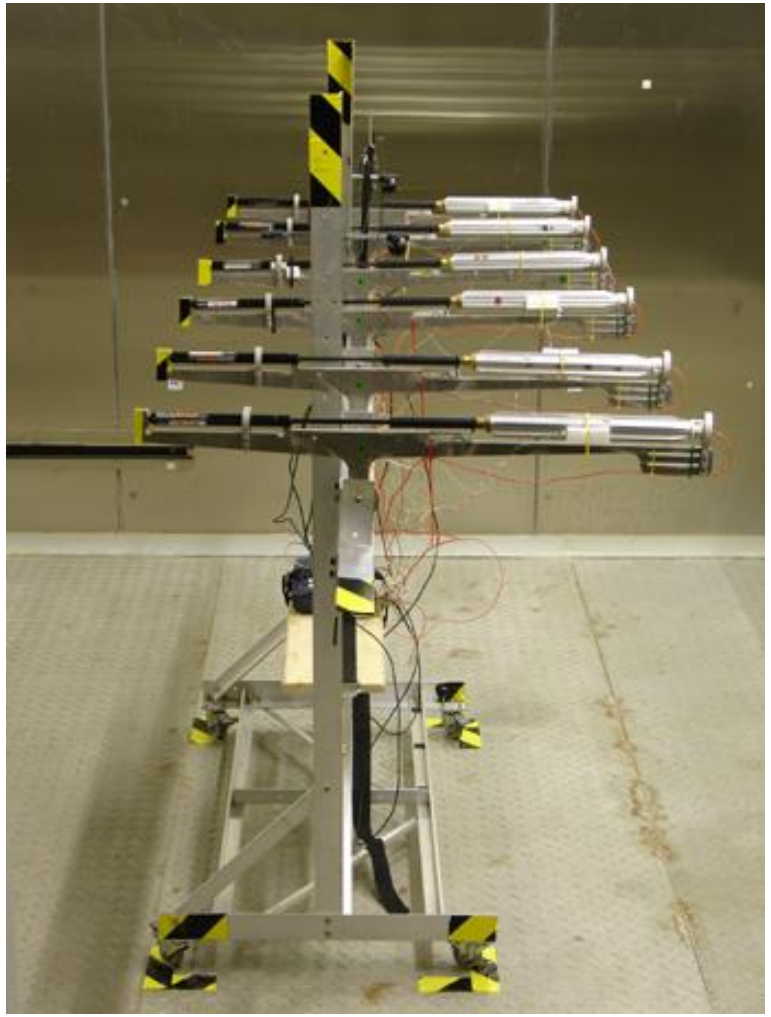


Temperature of wax < melting-point

(1)

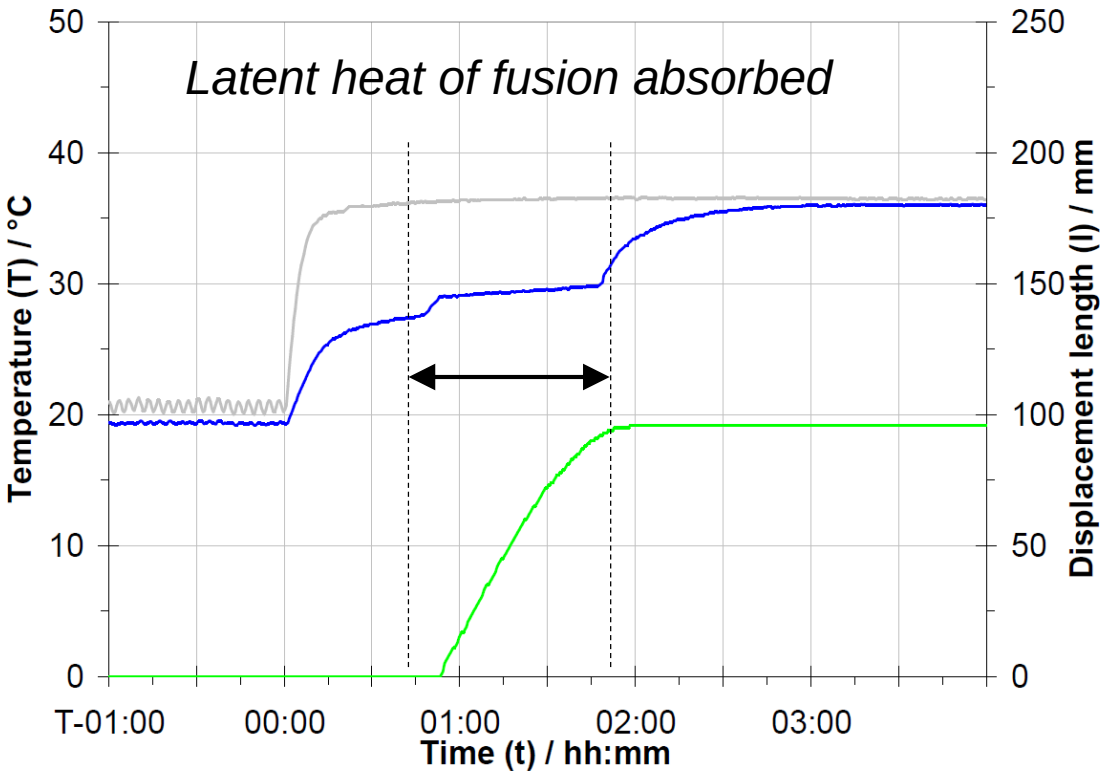


Characterisation

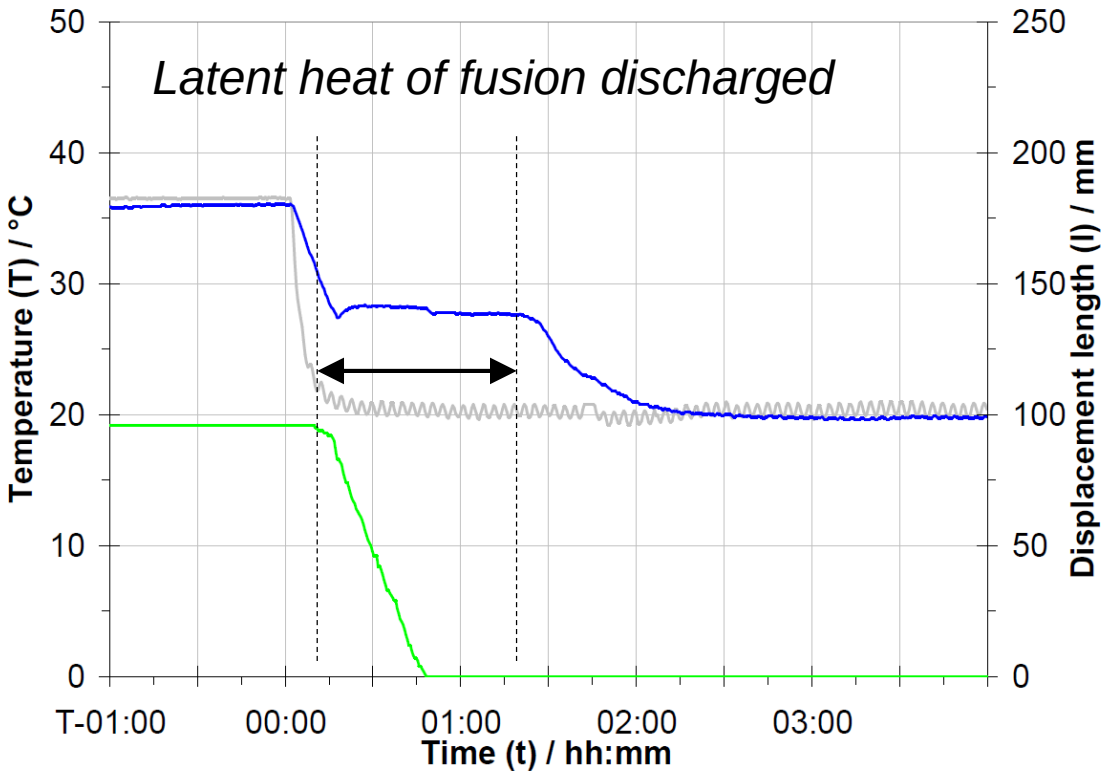


Climate-chamber studies at the Bartlett School of Architecture (Cycle temperature range 5 to 30 degrees Celsius)

Thermo-mechanical behaviour



Melting - expansion



Solidification - shrinkage

From p.58 in (Leung, 2014) https://discovery.ucl.ac.uk/id/eprint/1431882/

Approach

Observation

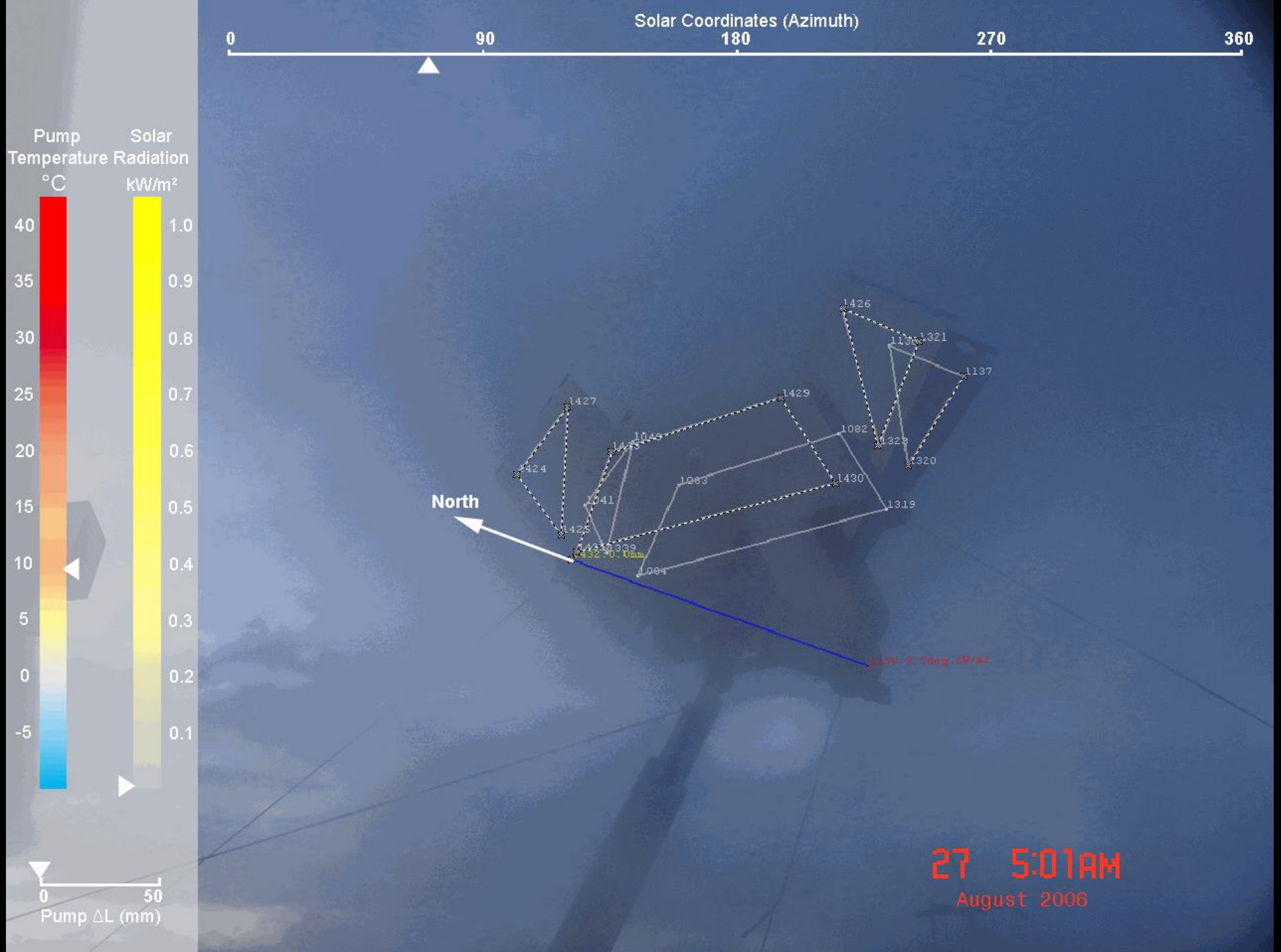
The bio-physics in living systems on Earth directs energy to reorganise matter for the purposeful end of sustaining metabolic activity …

Question

What techniques could be devised to direct the passive flow of thermal energy through these reciprocating actuators to operate mechanisms in synchronisation with prevailing meteorological conditions during the day and across seasons to sustain thermal comfort in buildings?

Sixteen*(makers)

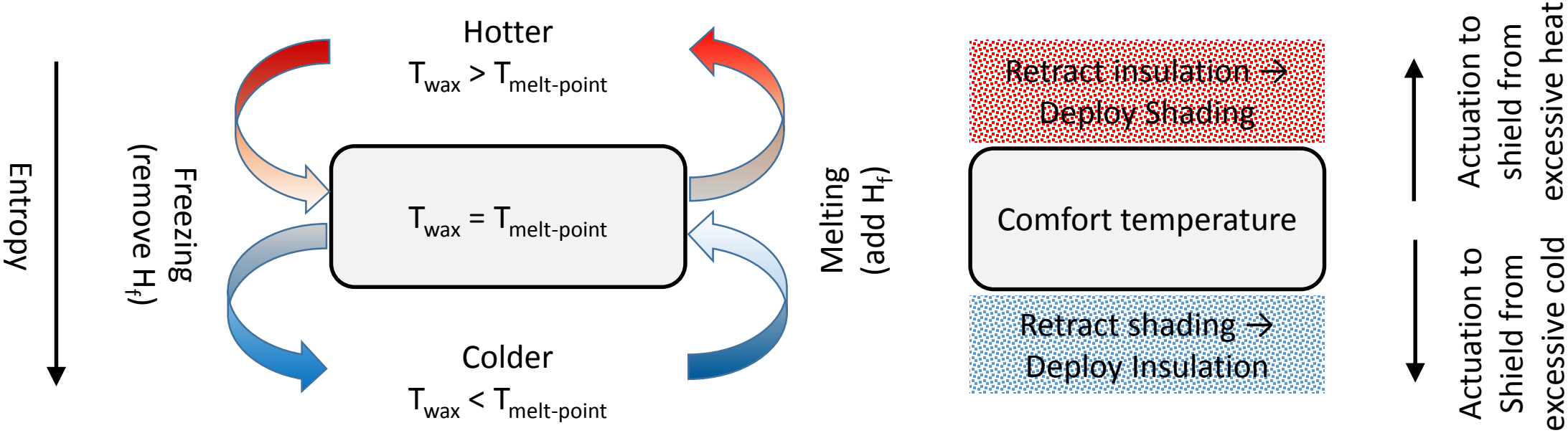

Sixteen*(makers)
Photo credit: Christopher Leung



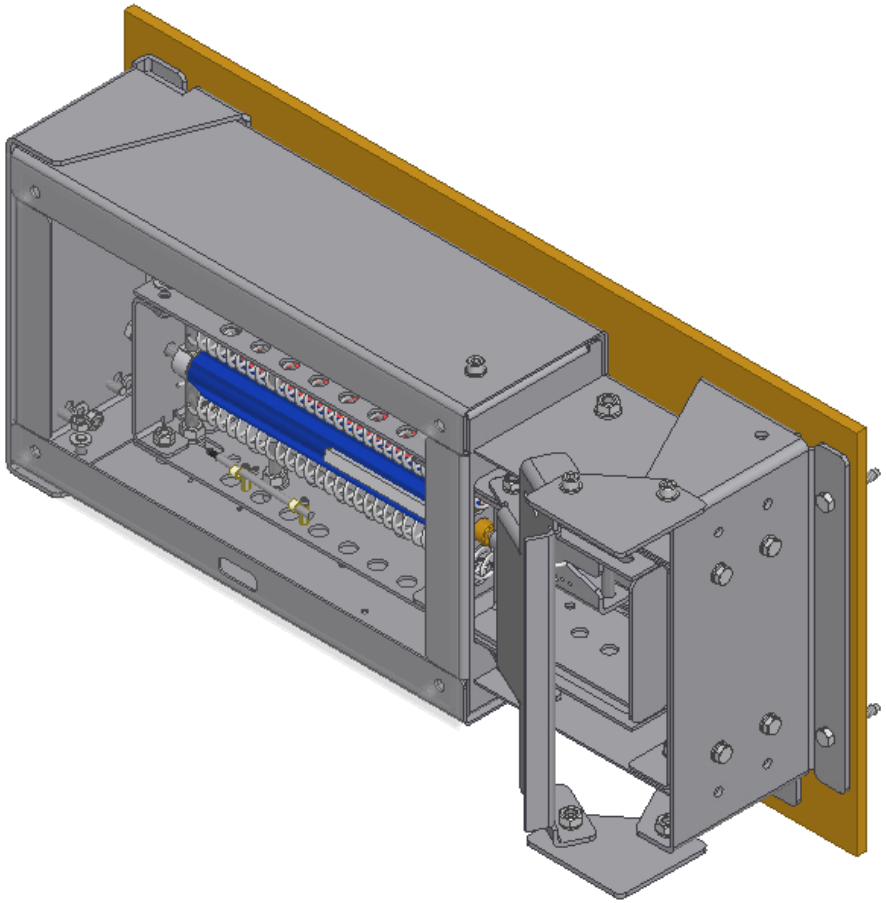
Film credit: Christopher Leung

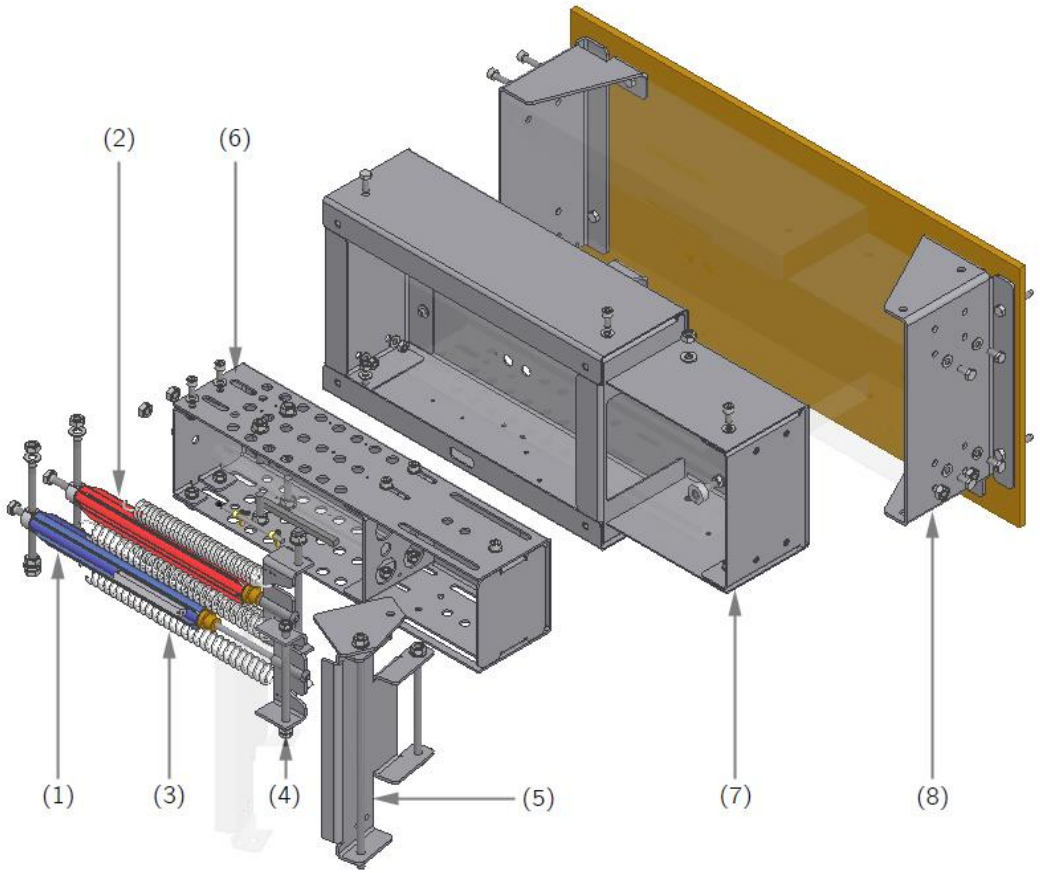
Research

Investigate methods to exploit thermo-mechanical actuators by guiding the passive flow of thermal energy to physically adjust variable performance building facades by capturing heat-gains from solar radiant energy to offset heat-losses to the cooler ambient to *match* the energy-balance of the actuator with the building enclosure's needs

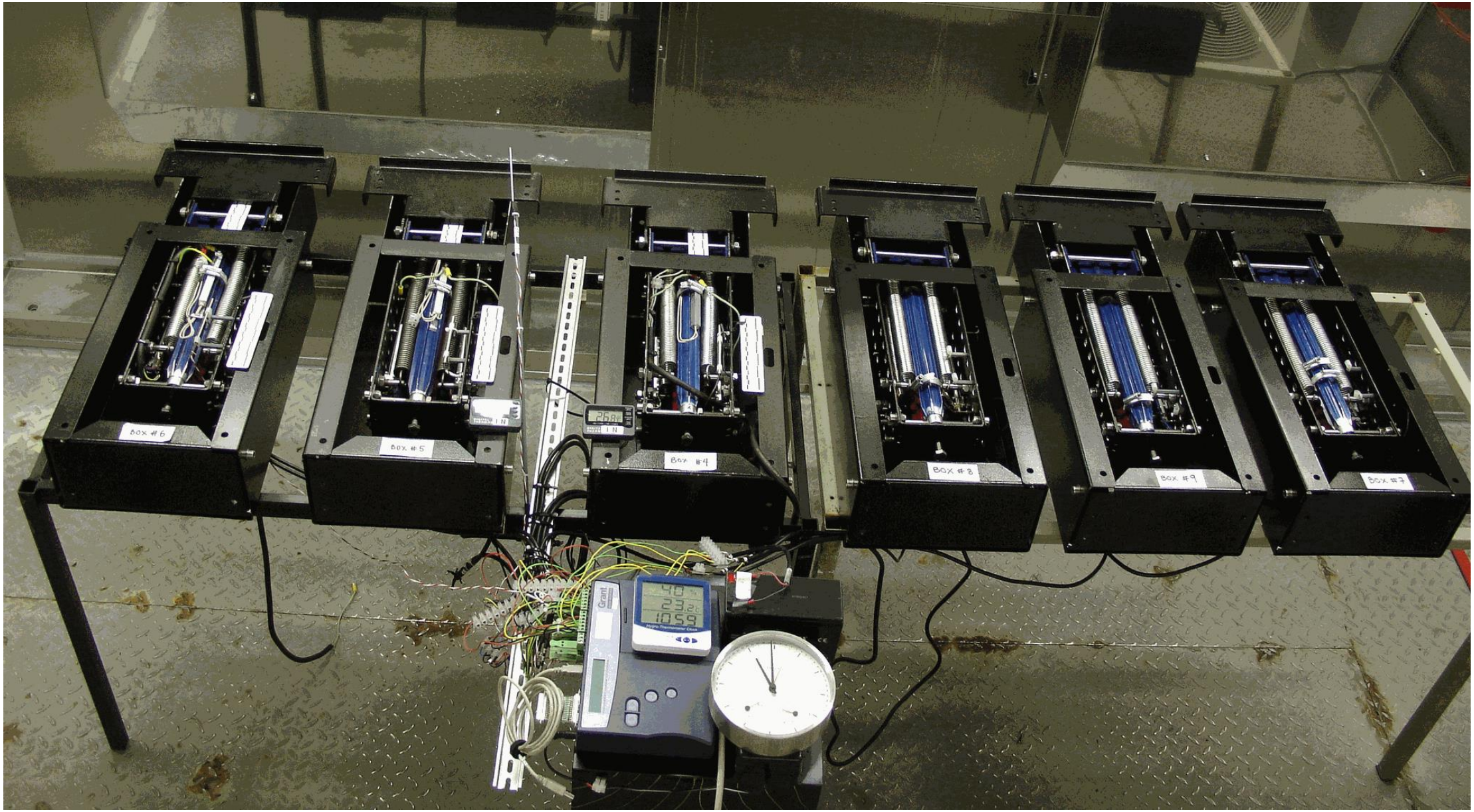


Mechanism development

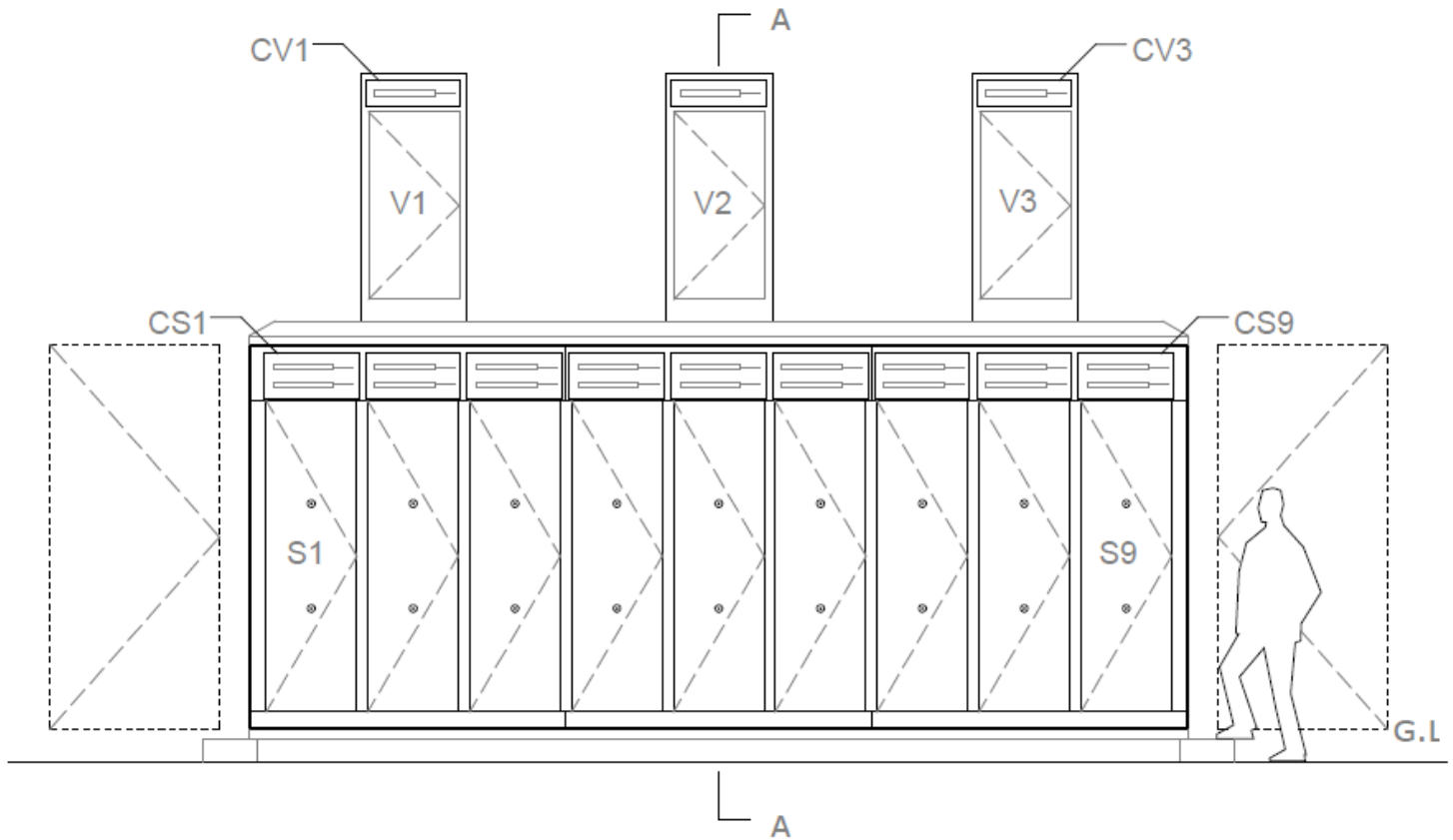


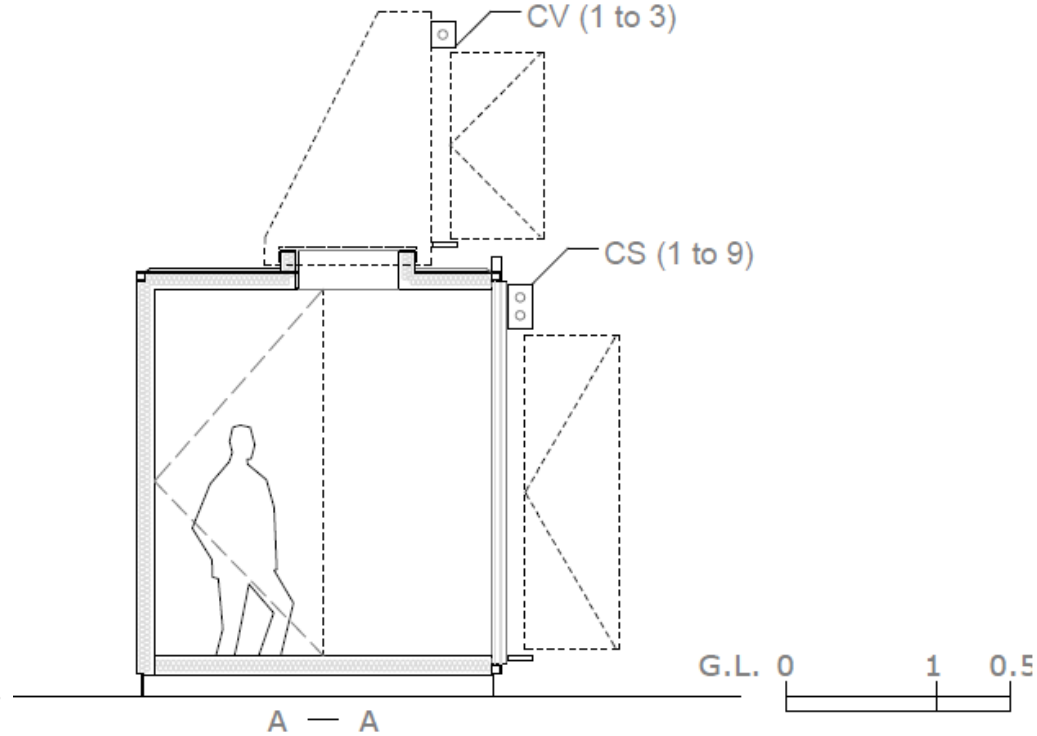


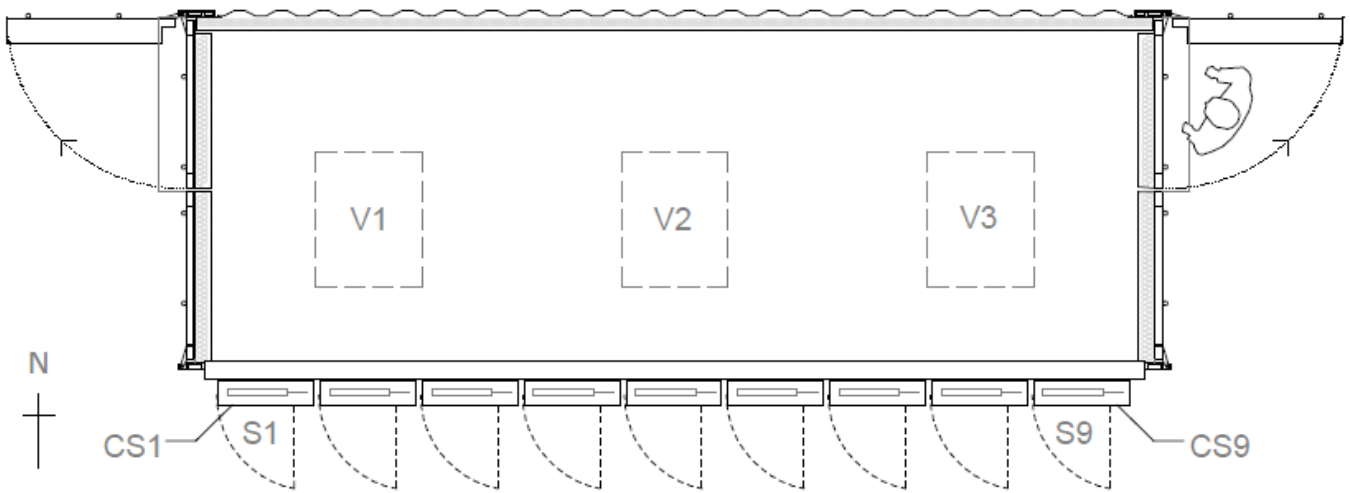
Proprietary device developed at the Bartlett School of Architecture, Patent application GB 0803947.1 (Gage and Leung, 2008)



Lab work: Climate-chamber studies at the Bartlett School of Architecture


A
CV1
CV3
V1
V2
V3
CS1
CS9
S1
S9
G.L
A


CV (1 to 3)
CS (1 to 9)
G.L.
0
1
0.5
A — A

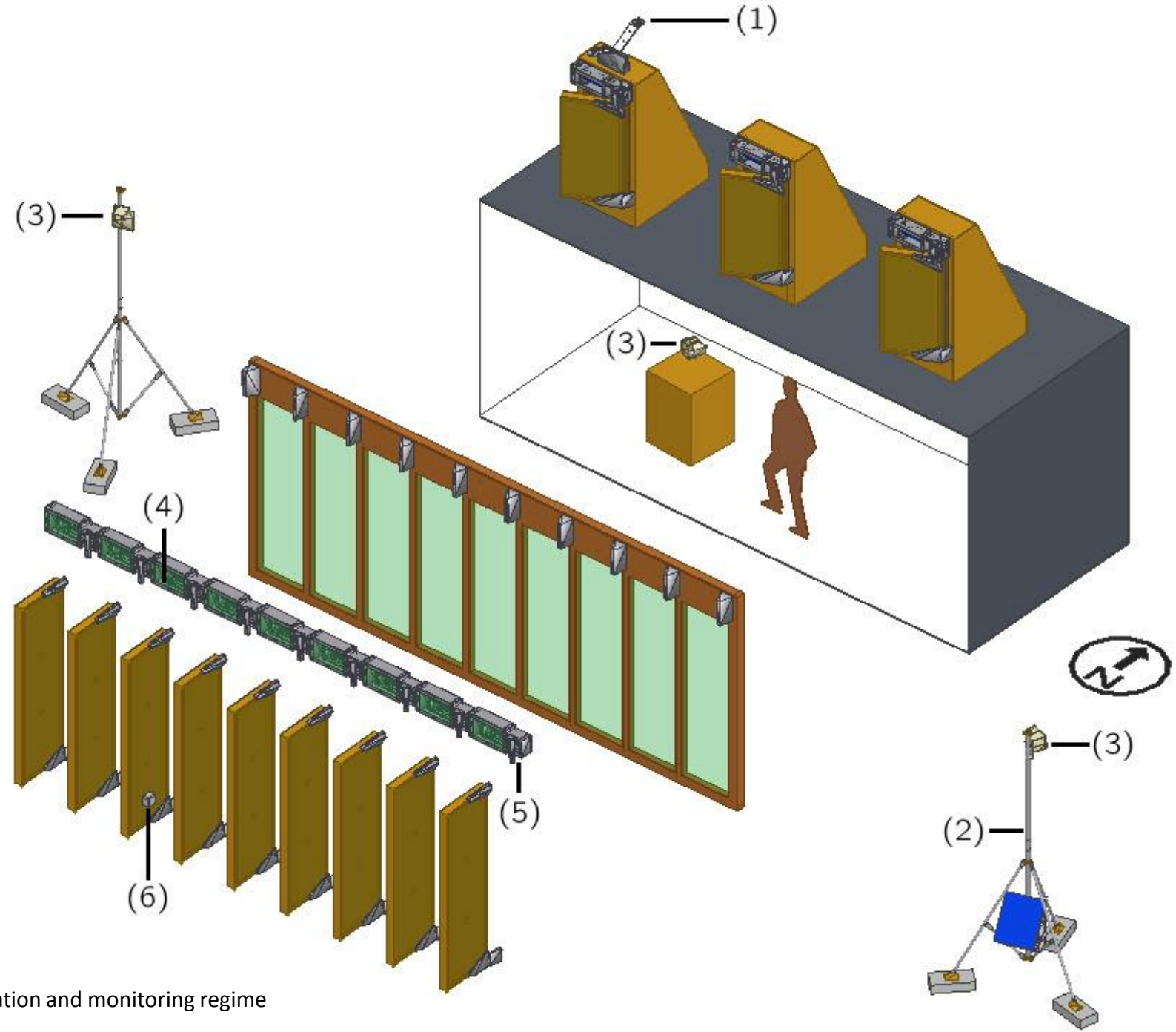

V1
V2
V3
N
CS1
S1
S9
CS9

Demonstration pavilion, UCL Quadrangle

Photo credit: Christopher Leung

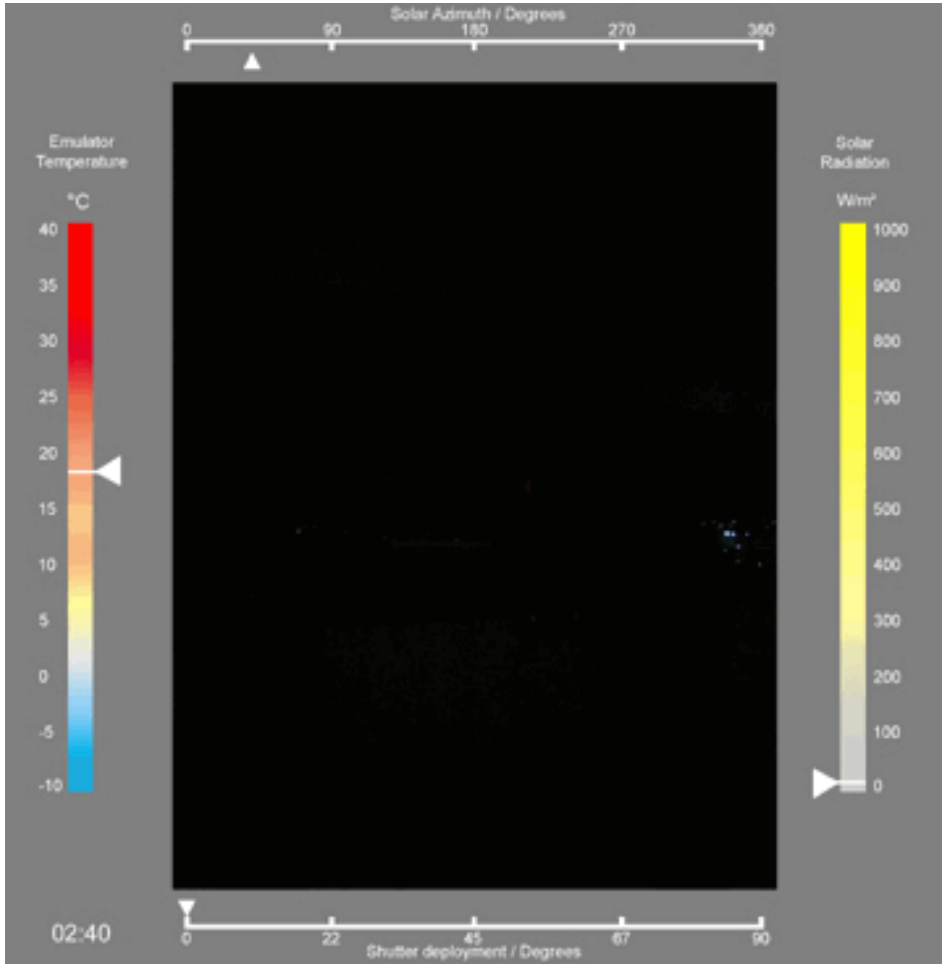
Photo credit: Christopher Leung

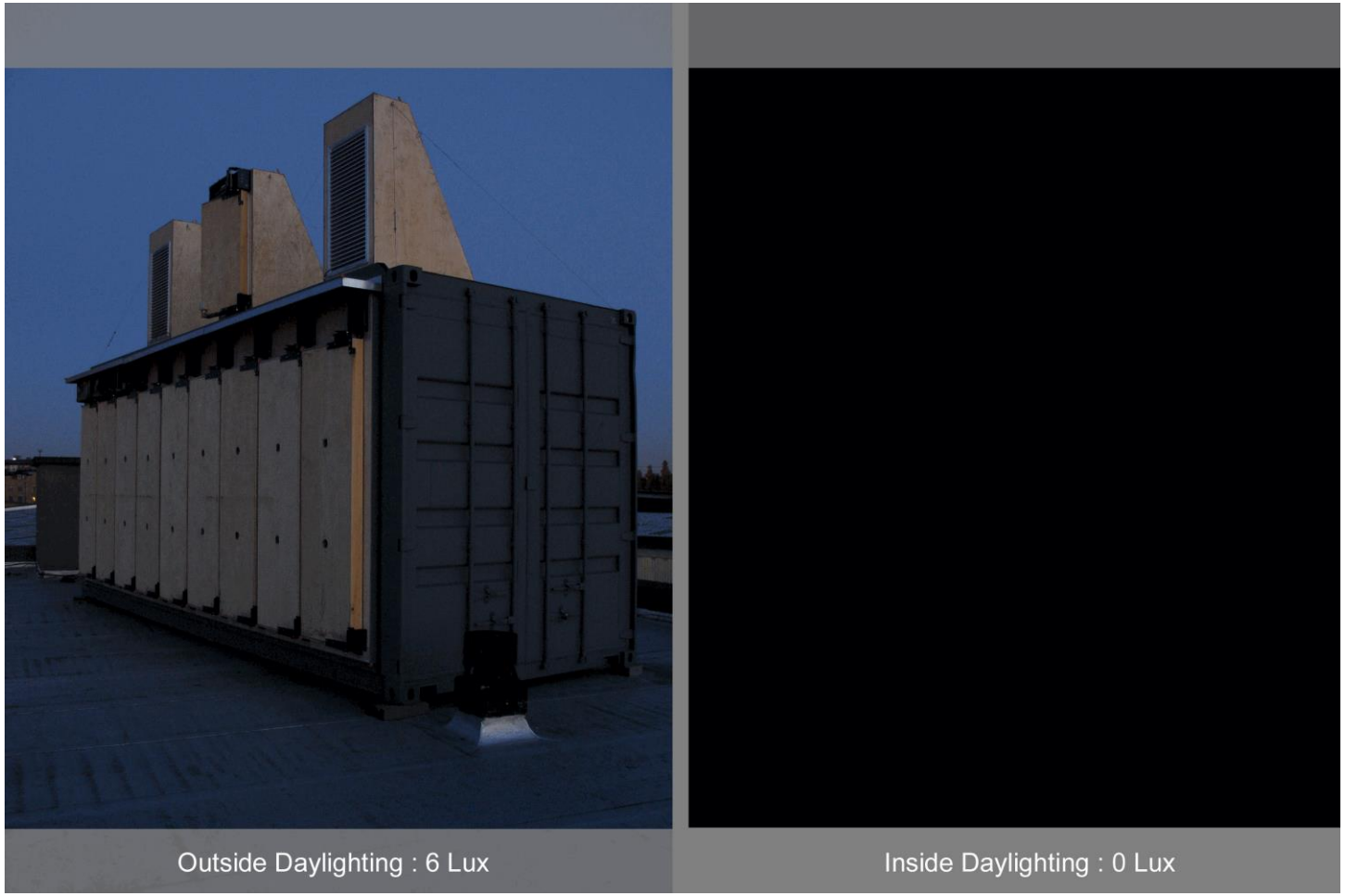
Photo credit: Christopher Leung



Field work: Instrumentation and monitoring regime

Field trials





Field work: Observation study carried out at Trinity Wharf site in London

Energy balance models

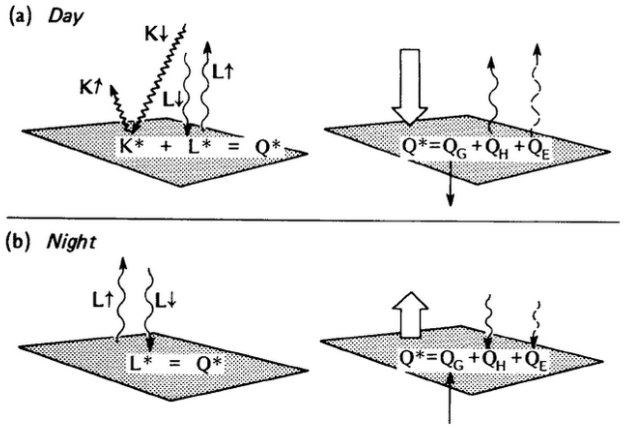
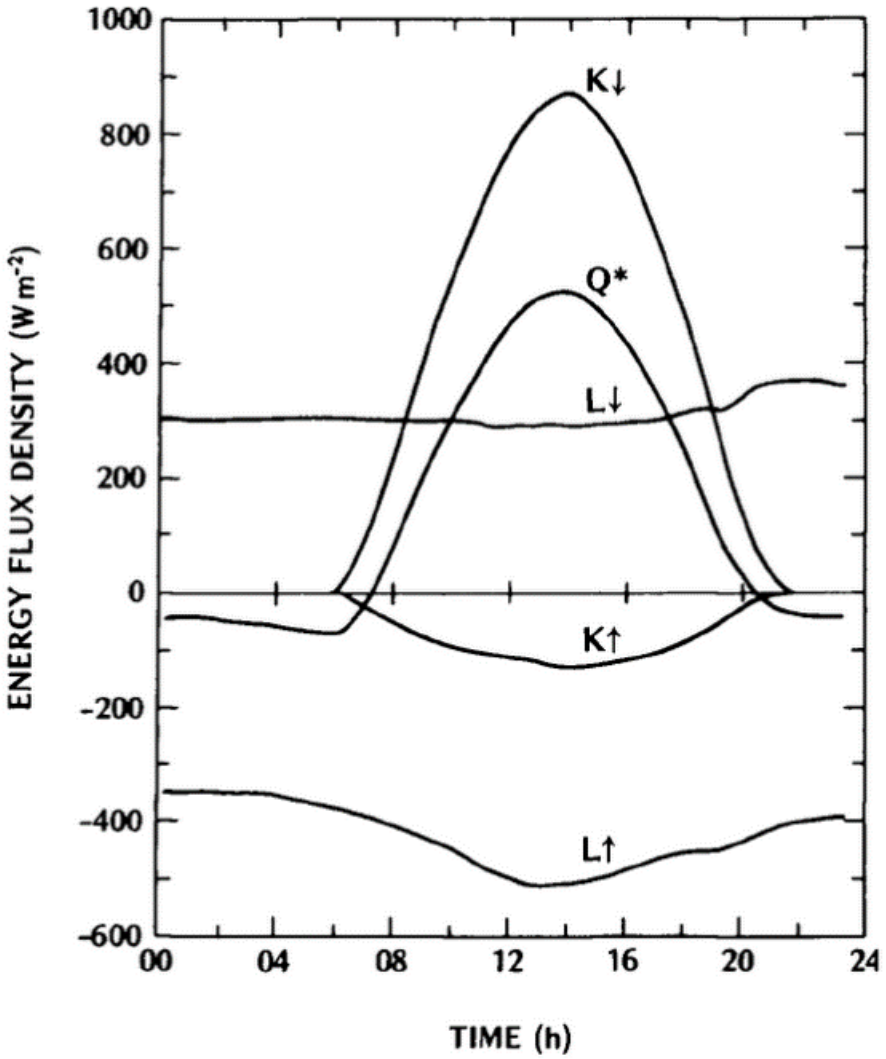


Figure 1.11 Schematic summary of the fluxes involved in the radiation budget and energy balance of an 'ideal' site, (a) by day and (b) at night.

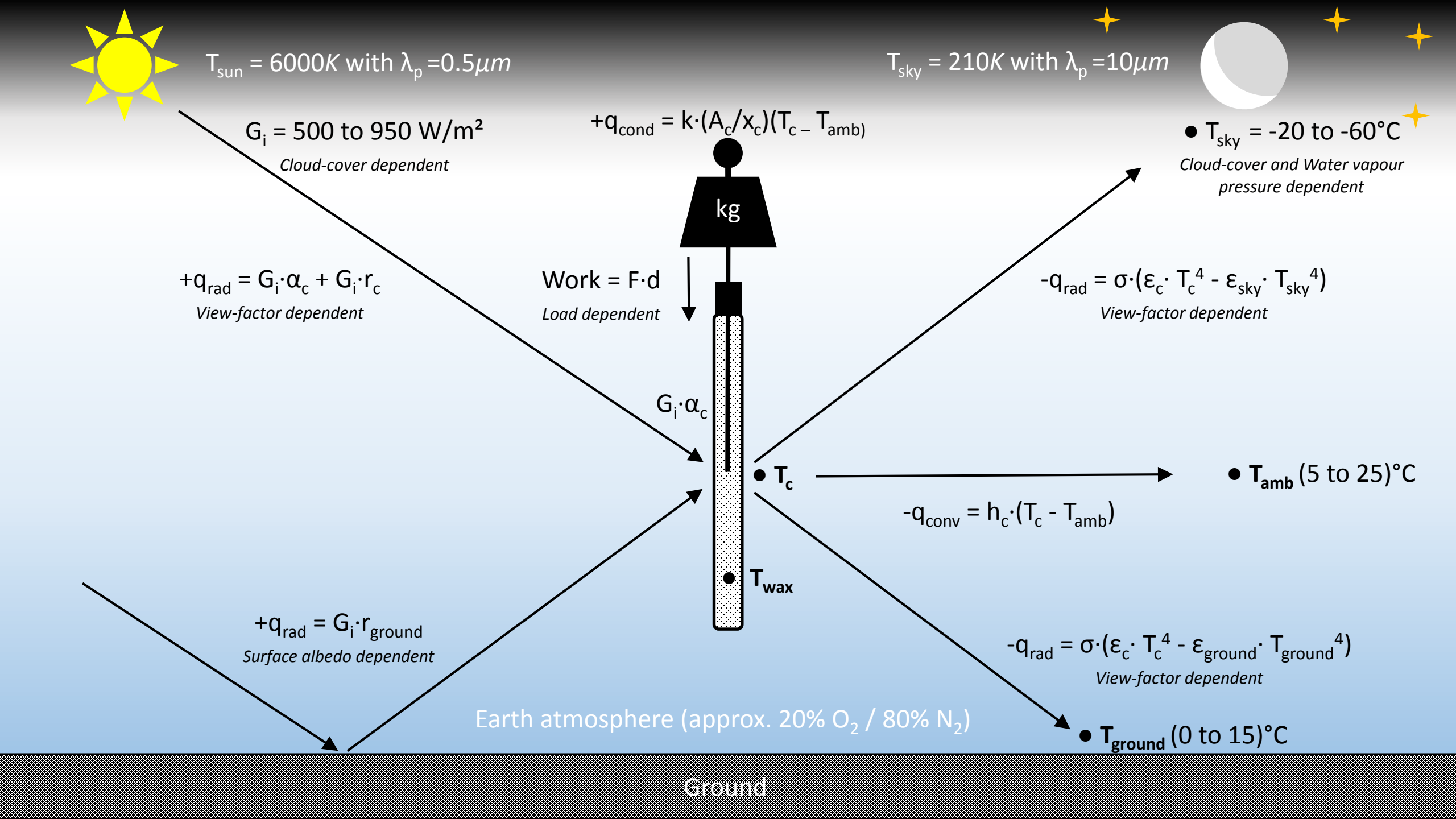
Figure 1.9 Radiation budget components for 30 July 1971, at Matador, Saskatchewan (50°N) over a 0·2 m stand of native grass. Cloudless skies in the morning, increasing cloud in the later afternoon and evening (after Ripley and Redmann, 1976). (*Note*—In the text no signs have been given to individual radiation fluxes, only to net fluxes (K^*, L^* and Q^*). However, in figures such as this radiative inputs to the surface ($K\downarrow$, $L\downarrow$) have been plotted as positive, and outputs ($K\uparrow$, $L\uparrow$) as negative to aid interpretation.) The following table gives the radiation totals for the day (MJ m^{-2}day^{-1}).

$K\downarrow$	27·3	$L\downarrow$	27·5
$K\uparrow$	4·5	$L\uparrow$	36·8
K^*	22·7	L^*	−9·3
$\alpha^\dagger$	0·16	Q^*	13·4

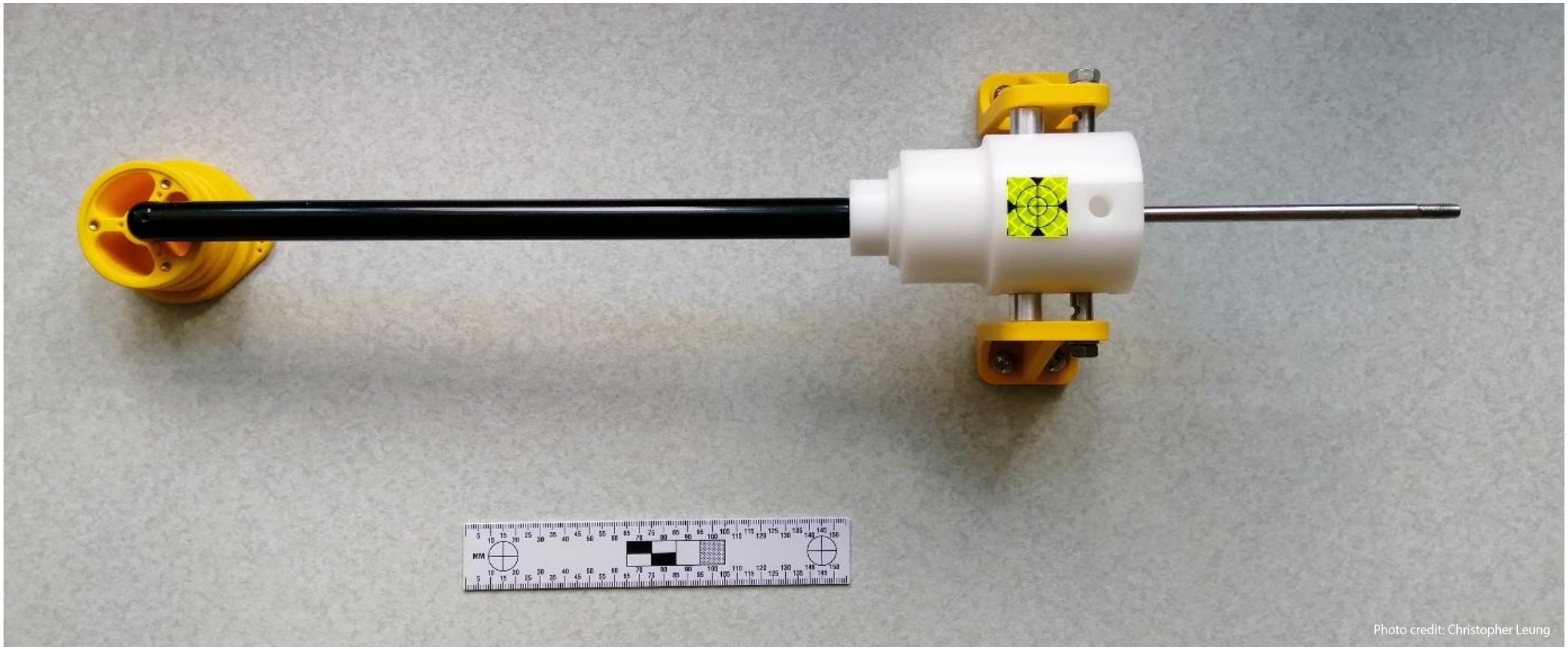
† Dimensionless

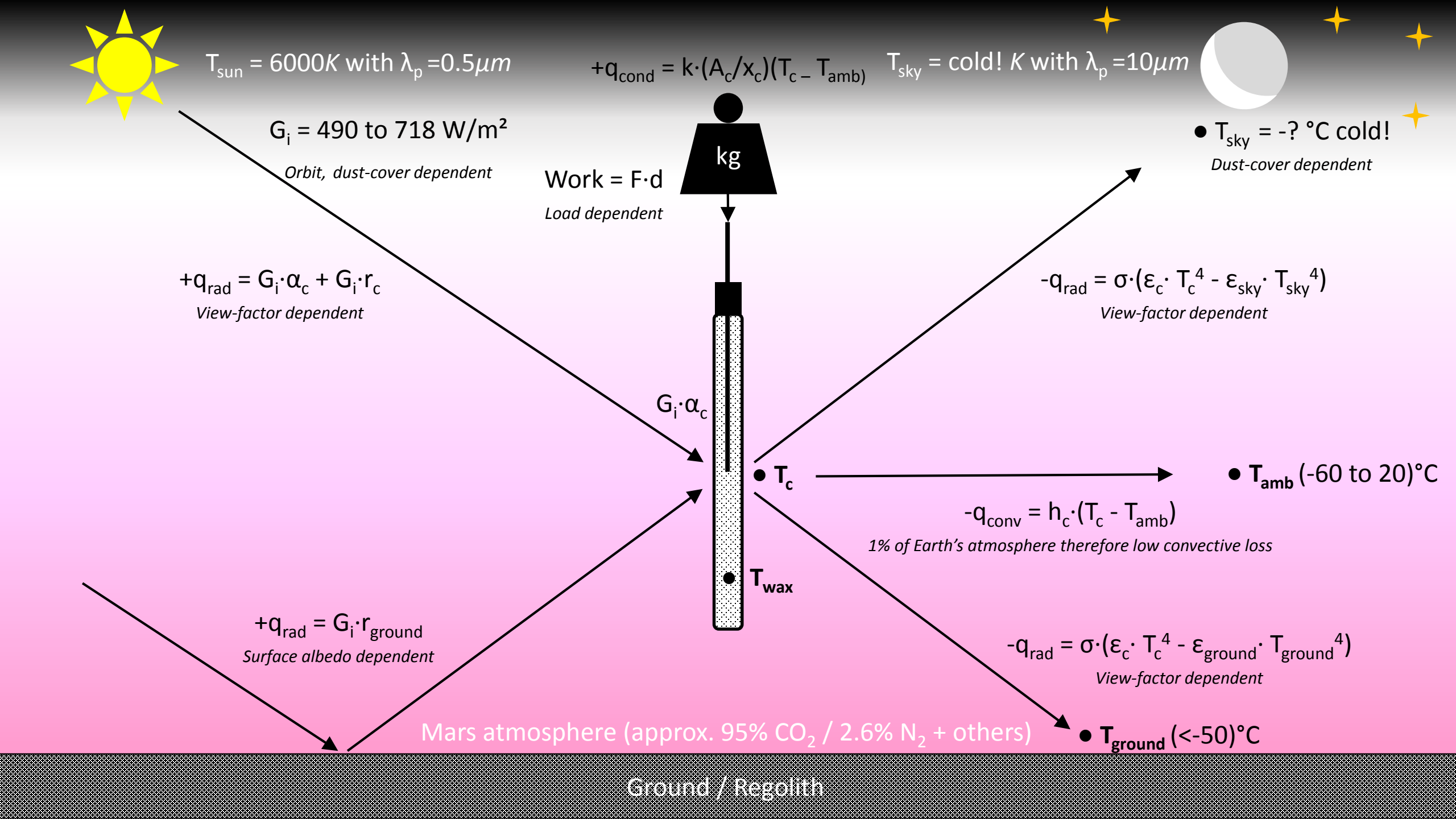


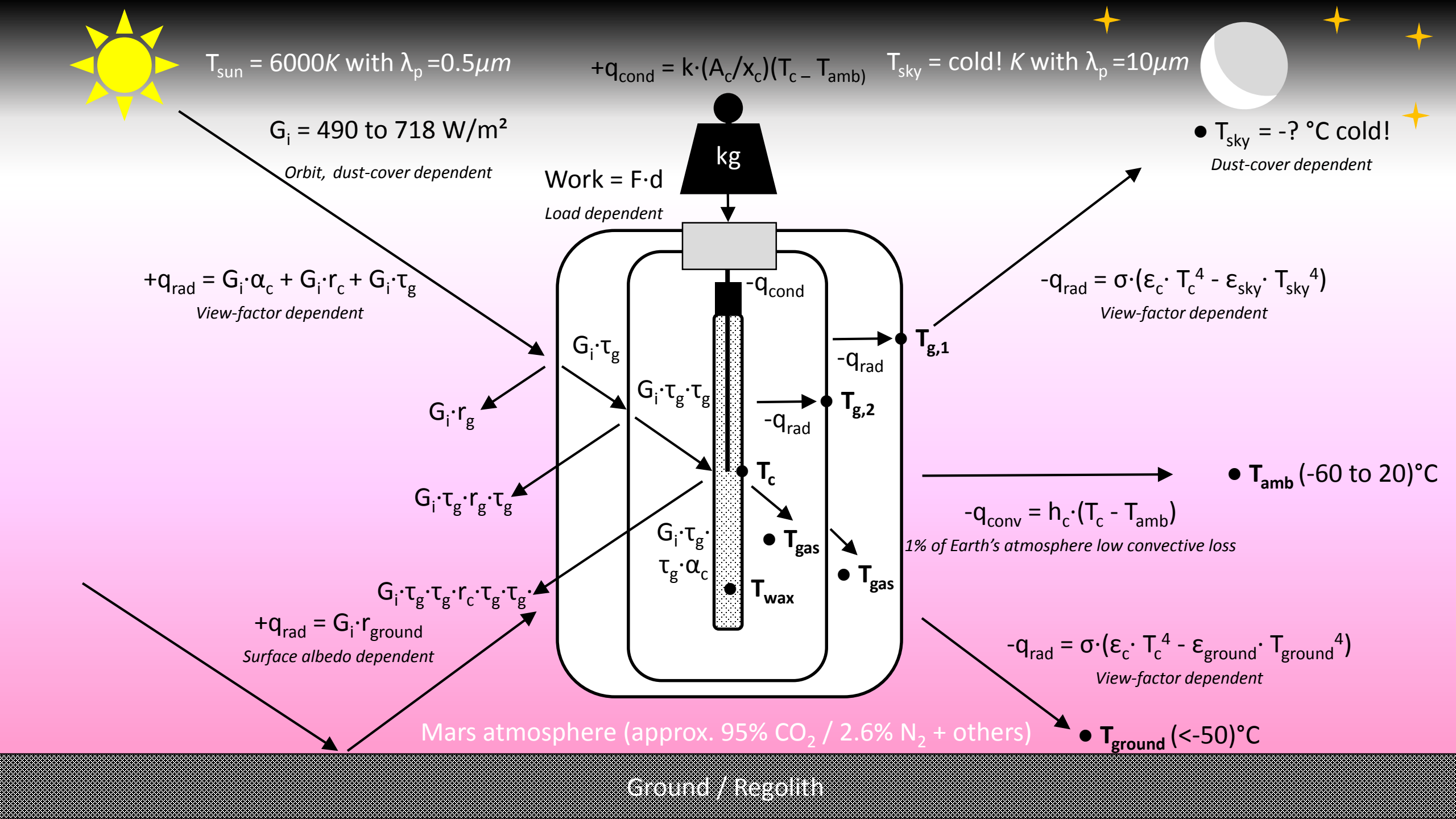
p. 21 and 26 in "Boundary Layer Climates", (Oke, T.,1987)


T_{sun} = 6000K with λ_p =0.5μm
T_{sky} = 210K with λ_p =10μm
G_i = 500 to 950 W/m²
Cloud-cover dependent
$+q_{cond} = k\cdot(A_c/x_c)(T_c - T_{amb})$
kg
T_{sky} = -20 to -60°C
Cloud-cover and Water vapour pressure dependent
$+q_{rad} = G_i\cdot\alpha_c + G_i\cdot r_c$
View-factor dependent
Work = F·d
Load dependent
$-q_{rad} = \sigma\cdot(\varepsilon_c\cdot T_c^4 - \varepsilon_{sky}\cdot T_{sky}^4)$
View-factor dependent
$G_i\cdot\alpha_c$
T_c
T_{amb} (5 to 25)°C
$-q_{conv} = h_c\cdot(T_c - T_{amb})$
T_{wax}
$+q_{rad} = G_i\cdot r_{ground}$
Surface albedo dependent
$-q_{rad} = \sigma\cdot(\varepsilon_c\cdot T_c^4 - \varepsilon_{ground}\cdot T_{ground}^4)$
View-factor dependent
Earth atmosphere (approx. 20% O_2 / 80% N_2)
T_{ground} (0 to 15)°C
Ground

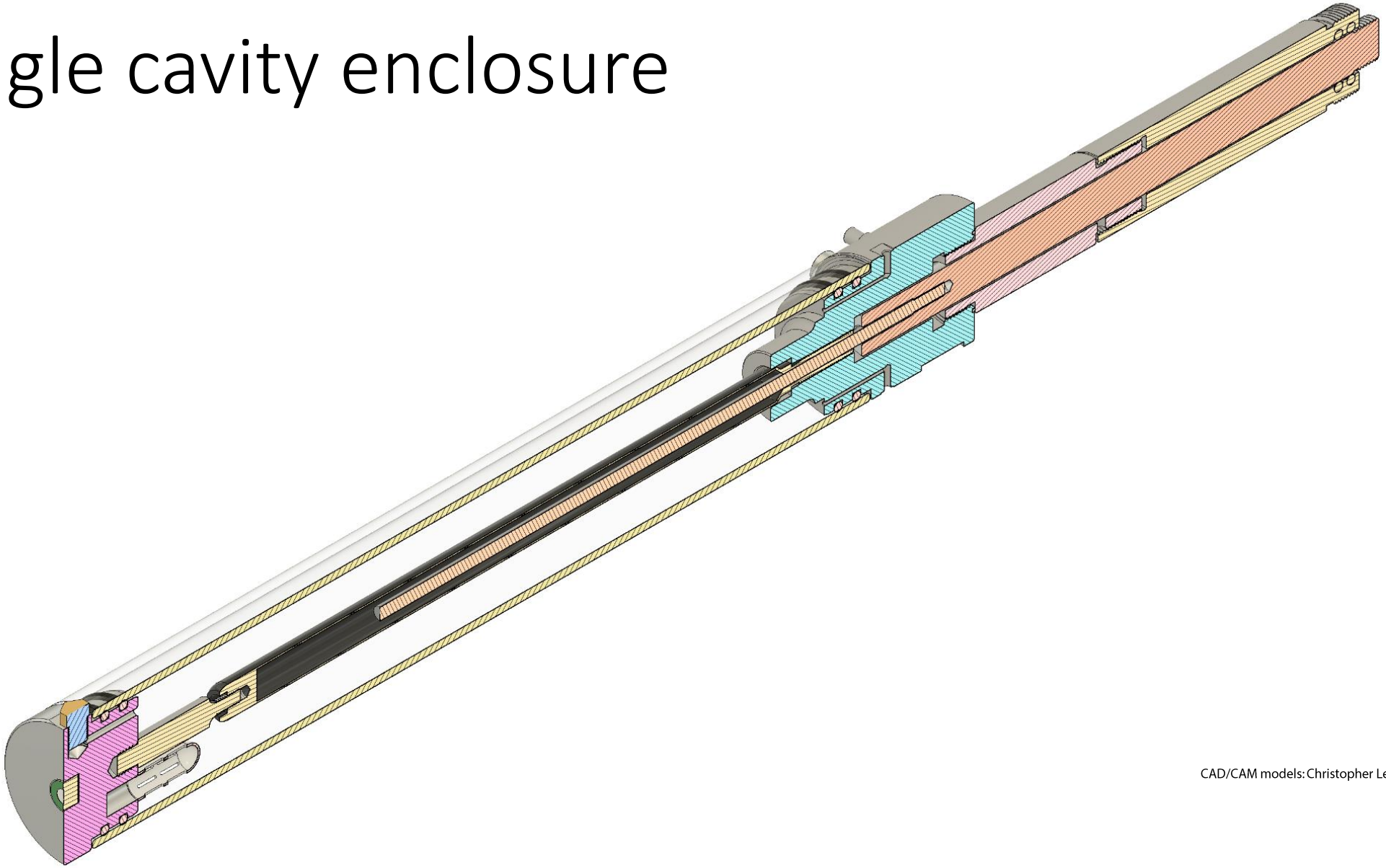
No enclosure




T_{sun} = 6000*K* with λ_p =0.5*μm*
$+q_{cond} = k\cdot(A_c/x_c)(T_c - T_{amb})$
T_{sky} = cold! *K* with λ_p =10*μm*
G_i = 490 to 718 W/m²
Orbit, dust-cover dependent
Work = F·d
Load dependent
kg
• T_{sky} = -? °C cold!
Dust-cover dependent
$+q_{rad} = G_i\cdot\alpha_c + G_i\cdot r_c$
View-factor dependent
$-q_{rad} = \sigma\cdot(\varepsilon_c\cdot T_c^4 - \varepsilon_{sky}\cdot T_{sky}^4)$
View-factor dependent
$G_i\cdot\alpha_c$
• T_c
• T_{amb} (-60 to 20)°C
$-q_{conv} = h_c\cdot(T_c - T_{amb})$
1% of Earth's atmosphere therefore low convective loss
• T_{wax}
$+q_{rad} = G_i\cdot r_{ground}$
Surface albedo dependent
$-q_{rad} = \sigma\cdot(\varepsilon_c\cdot T_c^4 - \varepsilon_{ground}\cdot T_{ground}^4)$
View-factor dependent
Mars atmosphere (approx. 95% CO_2 / 2.6% N_2 + others)
• T_{ground} (<-50)°C
Ground / Regolith


T_{sun} = 6000*K* with λ_p =0.5*μm*
$+q_{cond} = k\cdot(A_c/x_c)(T_c - T_{amb})$
T_{sky} = cold! *K* with λ_p =10*μm*
G_i = 490 to 718 W/m²
Orbit, dust-cover dependent
Work = F·d
Load dependent
kg
• T_{sky} = -? °C cold!
Dust-cover dependent
$+q_{rad} = G_i\cdot\alpha_c + G_i\cdot r_c + G_i\cdot\tau_g$
View-factor dependent
$-q_{cond}$
$-q_{rad} = \sigma\cdot(\varepsilon_c\cdot T_c^4 - \varepsilon_{sky}\cdot T_{sky}^4)$
View-factor dependent
$G_i\cdot\tau_g$
$T_{g,1}$
$-q_{rad}$
$G_i\cdot\tau_g\cdot\tau_g$
$G_i\cdot r_g$
$T_{g,2}$
$-q_{rad}$
T_c
• T_{amb} (-60 to 20)°C
$G_i\cdot\tau_g\cdot r_g\cdot\tau_g$
$-q_{conv} = h_c\cdot(T_c - T_{amb})$
1% of Earth's atmosphere low convective loss
$G_i\cdot\tau_g\cdot$
$\tau_g\cdot\alpha_c$
• T_{gas}
• T_{gas}
T_{wax}
$G_i\cdot\tau_g\cdot\tau_g\cdot r_c\cdot\tau_g\cdot\tau_g\cdot$
$+q_{rad} = G_i\cdot r_{ground}$
Surface albedo dependent
$-q_{rad} = \sigma\cdot(\varepsilon_c\cdot T_c^4 - \varepsilon_{ground}\cdot T_{ground}^4)$
View-factor dependent
Mars atmosphere (approx. 95% CO_2 / 2.6% N_2 + others)
• T_{ground} (<-50)°C
Ground / Regolith

Single cavity enclosure

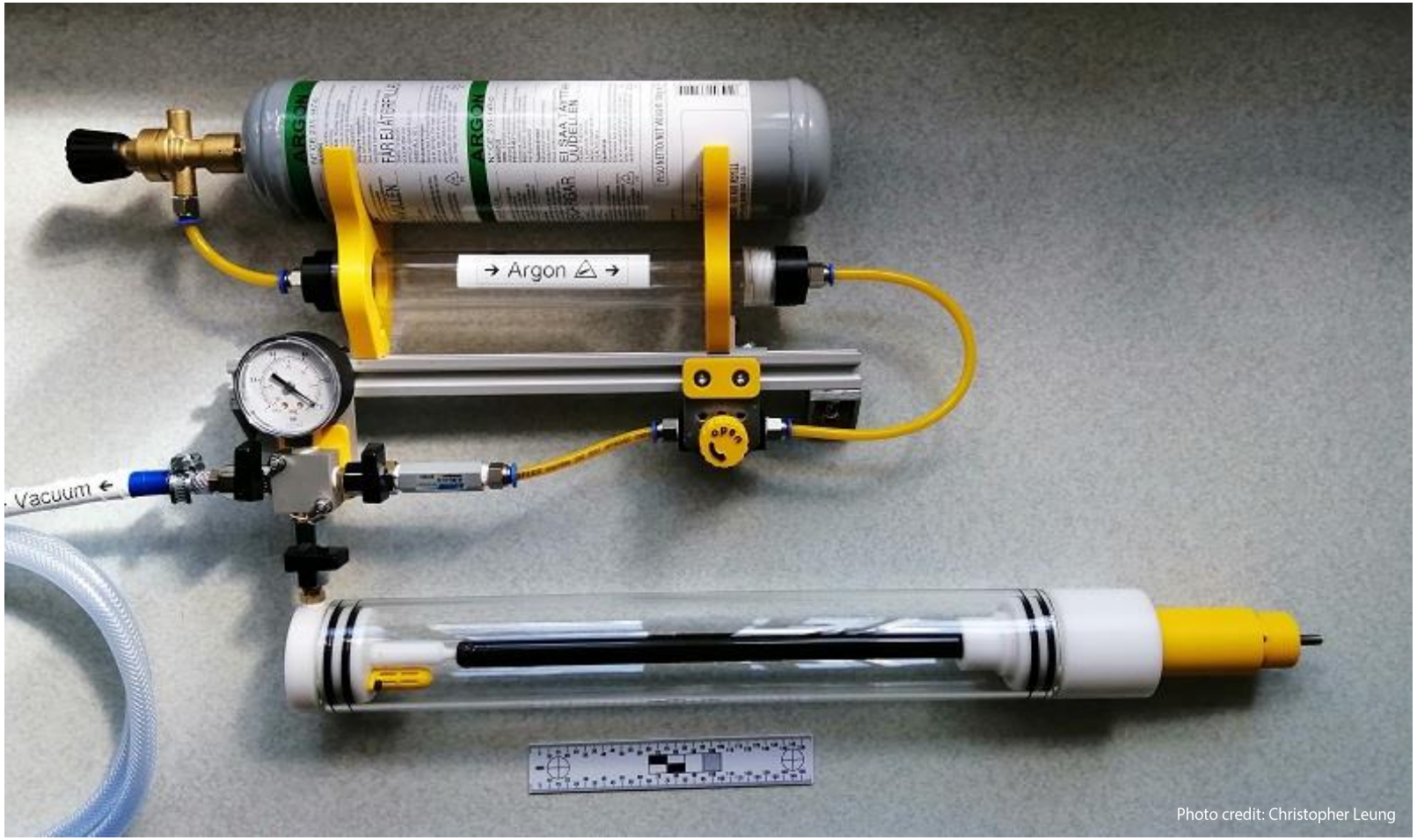


CAD/CAM models: Christopher Leung

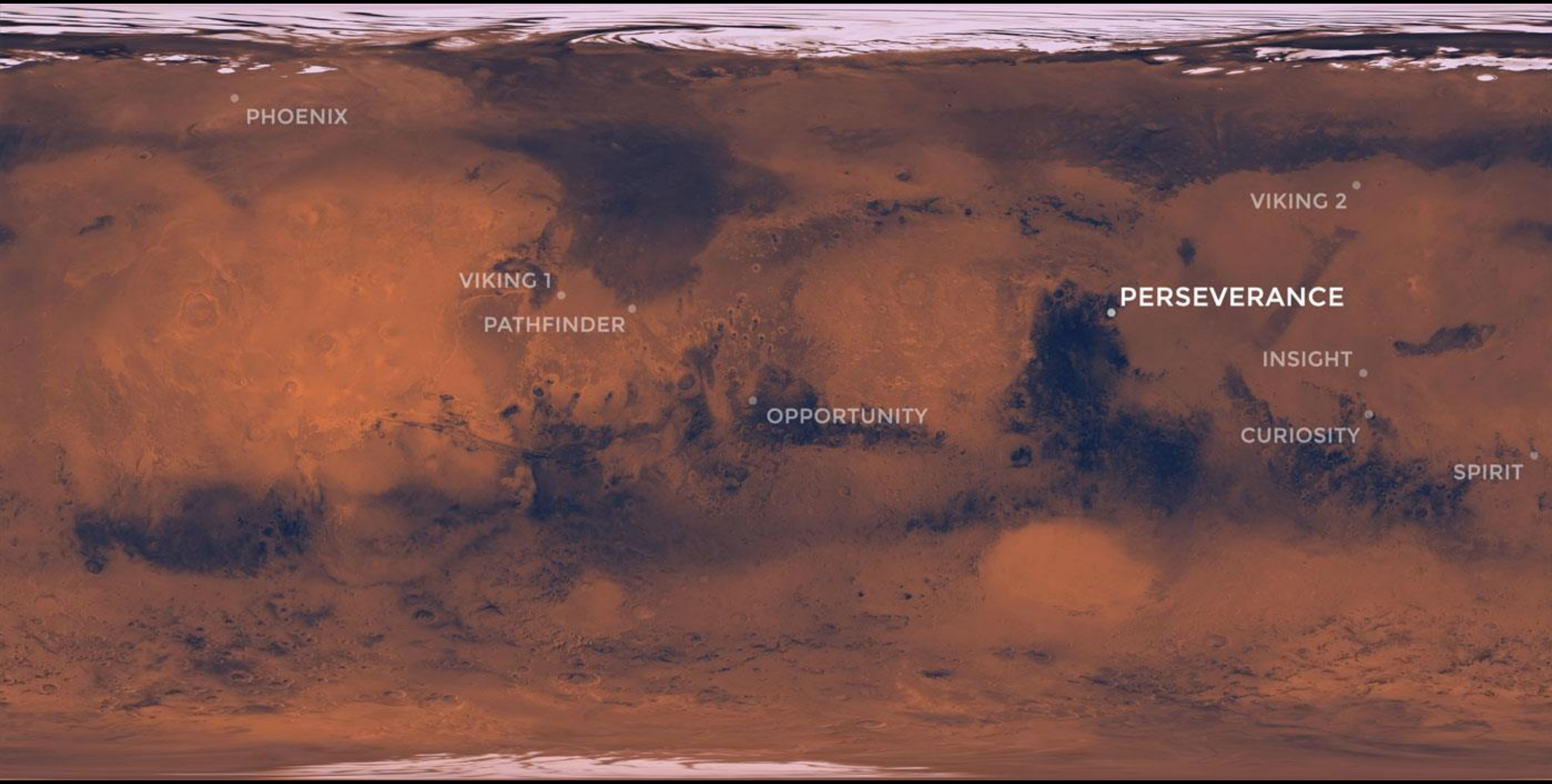
Single cavity enclosure

Double cavity enclosure

Thermal performance of cavity



Technical apparatus for modifying the thermal behavior of the cavity with vacuum or partial-pressure of inert gas


PHOENIX
VIKING 2
VIKING 1
PERSEVERANCE
PATHFINDER
INSIGHT
OPPORTUNITY
CURIOSITY
SPIRIT

Advantages

- Generates large hydraulic force solely from passive solar heat gain
- Capable of physical repositioning movable construction elements e.g. panels, shades, insulation,
- Selective adjustment of variable performance construction
- Mechanical and material resilience when exposed to challenging radiation and thermal conditions
- Autonomous self-regulating operation independently of a powered control system

Opportunities

- Investigating feasibility in low temperature environments:
  - Mars - Cold with low intensity/seasonal sunlight
  - Lunar– Very cold with high intensity and reliable sunlight
  - Prototyping for setting-up experiments to verify thermal models and validate simulation of thermo-mechanical behaviour in Lunar and Mars environment
  - Address the design, engineering, manufacturing and testing challenges
- Exploring possible applications for thermal actuators:
  - Reposition movable panels in response to diurnal or seasonal needs for habitat or/and equipment enclosures
  - Re-configure multiple-use components / devices / optical surfaces

Contribution to OWLI

- In the calculus of resilience to respond to climate-change on Earth, the pursuit and development of robust, self-reliant, self-contained passively self-powered means to support the operation of building enclosures may be transferrable to the extreme operating conditions and constraints that OWLI aims to support