Passive thermal control of enclosures

Developing applications for passive thermal actuators

Dr Christopher Leung
Speaker

christopher.leung@ucl.ac.uk

• 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 m² 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
Manufacturing capability
Tool shop CNC machinery for 2.5D milling
3 and 4-axis milling and mill-turning center
Industrial robotics
A range of industrial manipulator arms
In-house developers of custom end-effectors
Metrology
Capturing large-scale spatial data
Close-range photogrammetry and inspection
Test and instrumentation

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

Photo credit: Christopher Leung
Modus Operandi
OBJECTIVES

IDENTIFY REQUIREMENTS

MODEL AND SIMULATE

DESIGN REPRESENTATION

PROTOTYPING

DESIGN FOR MANUFACTURE

MEASUREMENT

DESIGN FOR METROLOGY

FEEDBACK
Context
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

Latent heat of fusion absorbed

Latent heat of fusion discharged

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)
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.

\[ T_{\text{wax}} = T_{\text{melt-point}} \]

- Hotter: \( T_{\text{wax}} > T_{\text{melt-point}} \)
- Colder: \( T_{\text{wax}} < T_{\text{melt-point}} \)

Retract insulation → Deploy Shading

Comfort temperature

Retract shading → Deploy Insulation

Actuation to shield from excessive heat

Actuation to shield from excessive cold
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
Demonstration pavilion, UCL Quadrangle
Field work: Instrumentation and monitoring regime
Field trials

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

Figure 1.9 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$^{-1}$).

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>$K\downarrow$</td>
<td>27.3</td>
<td>$L\downarrow$</td>
<td>27.5</td>
</tr>
<tr>
<td>$K\uparrow$</td>
<td>4.5</td>
<td>$L\uparrow$</td>
<td>36.8</td>
</tr>
<tr>
<td>$K^*$</td>
<td>22.7</td>
<td>$L^*$</td>
<td>-9.3</td>
</tr>
<tr>
<td>$a^1$</td>
<td>0.16</td>
<td>$Q^a$</td>
<td>13.4</td>
</tr>
</tbody>
</table>

* Dimensionless

p. 21 and 26 in "Boundary Layer Climates", (Oke, T., 1987)
\( T_{\text{sun}} = 6000K \text{ with } \lambda_p = 0.5\mu m \)

\( G_i = 500 \text{ to } 950 \text{ W/m}^2 \)

Cloud-cover dependent

\( +q_{\text{rad}} = G_i \cdot \alpha_c + G_i \cdot r_c \)

View-factor dependent

\( \text{Work} = F \cdot d \)

Load dependent

\( G_i \cdot \alpha_c \)

\( +q_{\text{cond}} = k \cdot (A_c / x_c) (T_c - T_{\text{amb}}) \)

\( T_{\text{amb}} = 5 \text{ to } 25^\circ C \)

\( T_{\text{sky}} = 210K \text{ with } \lambda_p = 10 \mu m \)

\( T_{\text{ground}} = 0 \text{ to } 15^\circ C \)

\( -q_{\text{rad}} = \sigma \cdot (\varepsilon_c \cdot T_c^4 - \varepsilon_{\text{ground}} \cdot T_{\text{ground}}^4) \)

View-factor dependent

\( -q_{\text{conv}} = h_c \cdot (T_c - T_{\text{amb}}) \)

\( -q_{\text{rad}} = G_i \cdot r_{\text{ground}} \)

Surface albedos dependent

Earth atmosphere (approx. 20% \( \text{O}_2 \) / 80% \( \text{N}_2 \))

\( T_{\text{sky}} = -20 \text{ to } -60^\circ C \)

Cloud-cover and Water vapour pressure dependent

\( T_{\text{sky}} = 210K \text{ with } \lambda_p = 10 \mu m \)
No enclosure
\( T_{\text{sun}} = 6000 \text{K with } \lambda_p = 0.5 \mu m \)

\( G_i = 490 \text{ to } 718 \text{ W/m}^2 \)

\[ +q_{\text{rad}} = G_i \cdot \alpha_c + G_i \cdot r_c \]

View-factor dependent

\[ +q_{\text{cond}} = k \cdot (A_c/x_c) (T_c - T_{\text{amb}}) \]

\( T_{\text{sky}} = \text{cold! } K \text{ with } \lambda_p = 10 \mu m \)

\[ -q_{\text{rad}} = \sigma \cdot (\varepsilon_c \cdot T_c^4 - \varepsilon_{\text{sky}} \cdot T_{\text{sky}}^4) \]

View-factor dependent

\[ -q_{\text{conv}} = h_c \cdot (T_c - T_{\text{amb}}) \]

1% of Earth’s atmosphere therefore low convective loss

\[ -q_{\text{rad}} = \sigma \cdot (\varepsilon_c \cdot T_c^4 - \varepsilon_{\text{ground}} \cdot T_{\text{ground}}^4) \]

View-factor dependent

\( T_{\text{amb}} = (-60 \text{ to } 20) \degree C \)

\( T_{\text{ground}} = (-50) \degree C \)

\( \bullet T_{\text{sky}} = -? \degree C \text{ cold! Dust-cover dependent} \)

\( \bullet T_{\text{amb}} = (-60 \text{ to } 20) \degree C \)

\( \bullet T_{\text{ground}} = (-50) \degree C \)

\( \bullet T_{\text{sky}} = -? \degree C \text{ cold! Dust-cover dependent} \)

\( \bullet T_{\text{amb}} = (-60 \text{ to } 20) \degree C \)

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\( T_{\text{sun}} = 6000\, \text{K} \) with \( \lambda_p = 0.5\, \mu\text{m} \)

\( G_i = 490 \text{ to } 718 \, \text{W/m}^2 \)

\( +q_{\text{rad}} = G_i \cdot \alpha_c + G_i \cdot r_c + G_i \cdot \tau_g \)

\( +q_{\text{cond}} = k \cdot (A_c / x_c)(T_c - T_{\text{amb}}) \)

\( T_{\text{sky}} = \text{cold!} \, K \) with \( \lambda_p = 10\, \mu\text{m} \)

\( T_{\text{sky}} = -? \, ^\circ\text{C} \) cold!

\( \bullet \, T_{\text{amb}} (-60 \text{ to } 20) ^\circ\text{C} \)

\( -q_{\text{rad}} = \sigma \cdot (\epsilon_c \cdot T_c^4 - \epsilon_{\text{sky}} \cdot T_{\text{sky}}^4) \)

\( -q_{\text{conv}} = h_c \cdot (T_c - T_{\text{amb}}) \)

1% of Earth’s atmosphere low convective loss

\( -q_{\text{rad}} = \sigma \cdot (\epsilon_c \cdot T_c^4 - \epsilon_{\text{ground}} \cdot T_{\text{ground}}^4) \)

\( \bullet \, T_{\text{ground}} (<-50) ^\circ\text{C} \)

\( \text{Mars atmosphere (approx. 95% CO}_2 / 2.6\% \text{ N}_2 + \text{ others) } \)

\( \text{Ground / Regolith} \)
Single cavity enclosure
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
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.