



# Intelligent Building Facades

9th International Vacuum Insulation Symposium

Royal Institution, London  
September 18<sup>th</sup> 2009

Prof Derek Clements-Croome

# Preview

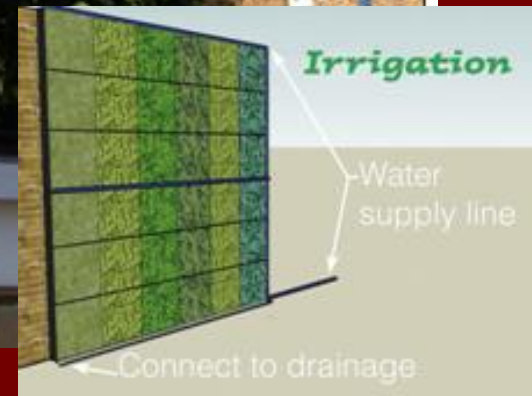
- Facades around the world
- Functions of facades
- Lessons from Nature
- Vernacular solutions
- Modern trends
- Greening
- Some innovations
- Solutions
- Desirable properties for facades

With the façade embodying up to 35% of the construction costs as well as being hugely accountable for the buildings' response to climate change, it has never been so important to understand which façade solutions deliver not only a cost effective and sustainable façade, but also one that is aesthetically pleasing and technically performing.

CIBSE Society of Facade Engineering  
September 10th 2009



# Aldingbourne Nurseries





# Clapham Manor Primary School, July 2009, dRMM Architects



# The Crooked House (Sopot, Poland)





# The Basket Building (Ohio, United States)



# Kansas City Public Library (Missouri, United States)

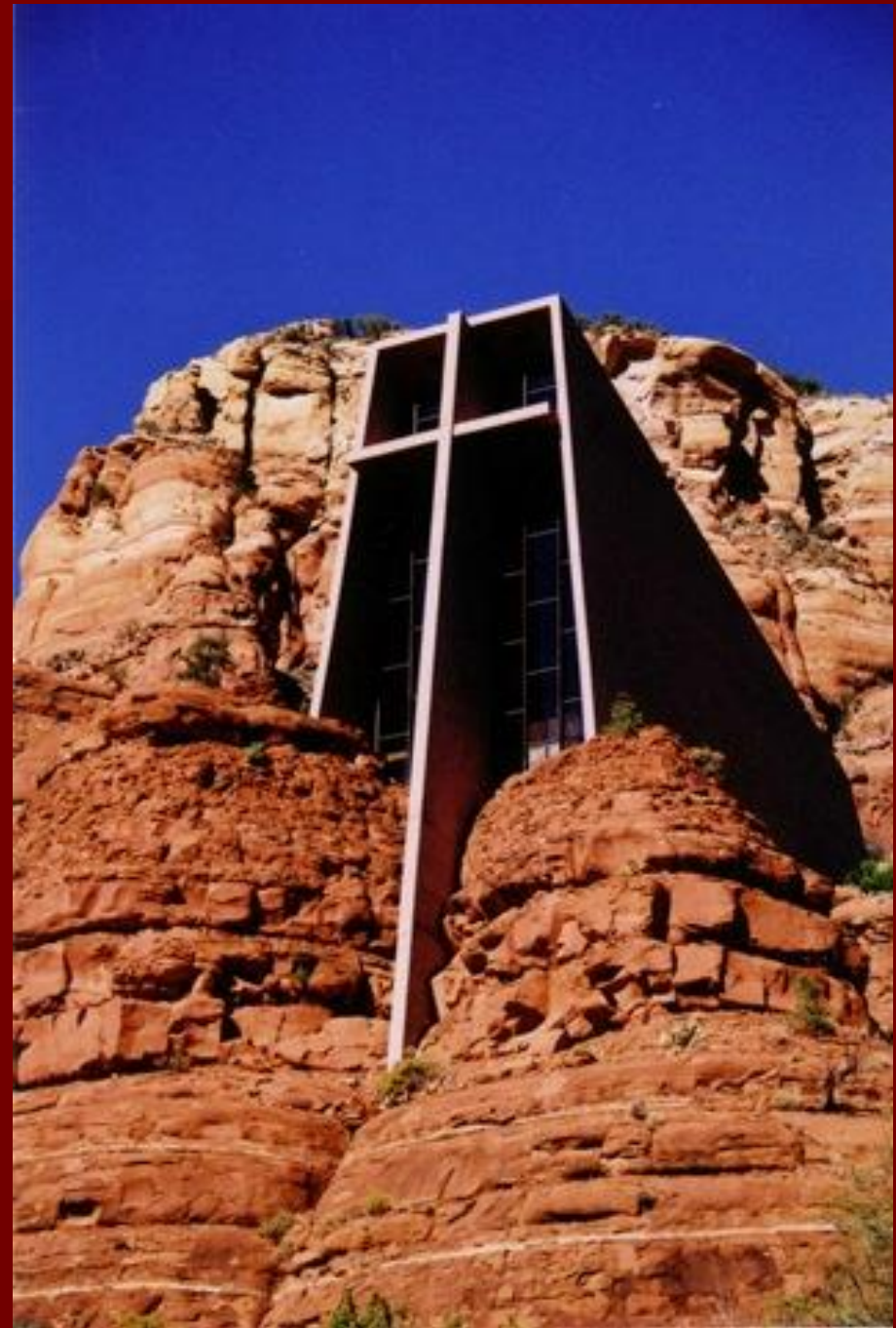




# Cubic Houses (Rotterdam, Netherlands)



# Chapel in the Rock (Arizona, US)





# Dancing Building (Prague, Czech Republic)



# Manchester Civil Justice Centre (Manchester, UK)





# The Hole House (Texas, United States)



# Grand Lisboa (Macao)





# Wall House (Groningen, Netherlands)



# Bahá'í House of Worship a.k.a Lotus Temple (Delhi, India)





# Wooden Gagster House (Archangelsk, Russia)



# Air Force Academy Chapel (Colorado, United States)

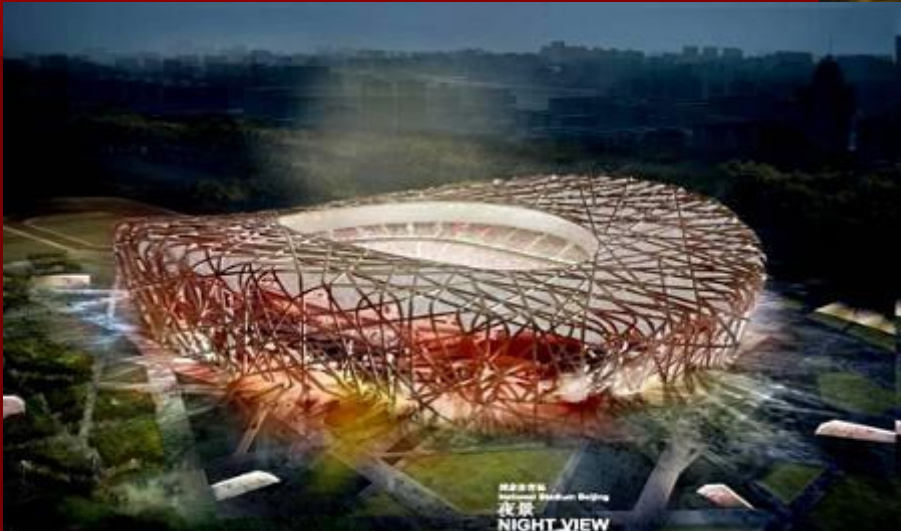




# Solar Furnace (Odeillo, France)



# Birds Nest Olympic Stadium Beijing 2008





# Civic Center (Santa Monica)



# Gherkin Building (London City, UK)



Lawrie Cate



# Nord LB building (Hannover, Germany)



# Lloyd's Building (London City, UK)





# Agar Tower (Barcelona, Spain)





The Leadenhall Building,  
London Arch. Richard Rogers

201 Bishopsgate and The  
Broadgate Tower, London  
Arch. Kohn Pederson Fox



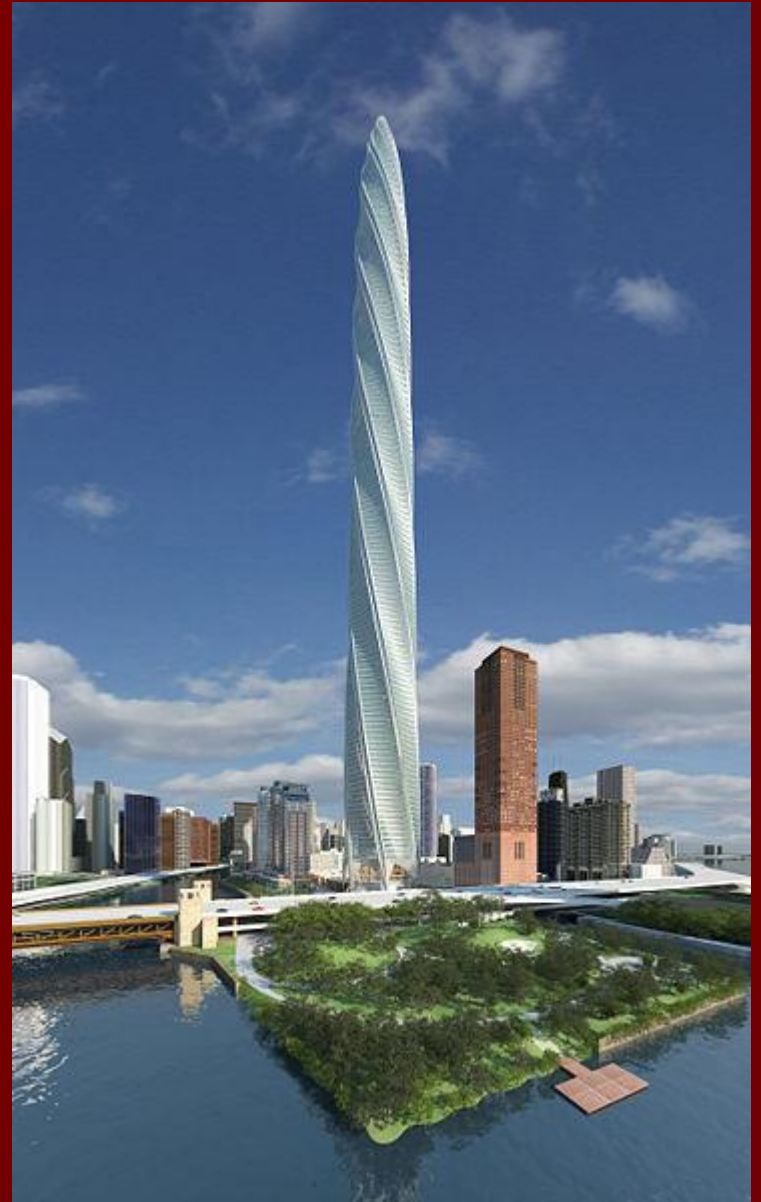


# Crystal Island, Moscow



The World's Biggest Building by Foster

# The Chicago Spire, Foster







Rectilinear panels at  
the Sage Centre

Panel installation at the Sage Centre



# Santiago Calatrava



Tenerife Opera House - Spain



Valencia Opera House - Spain





# Frank Gehry Walt Disney Concert Hall LA



# CCTV Headquarters, China



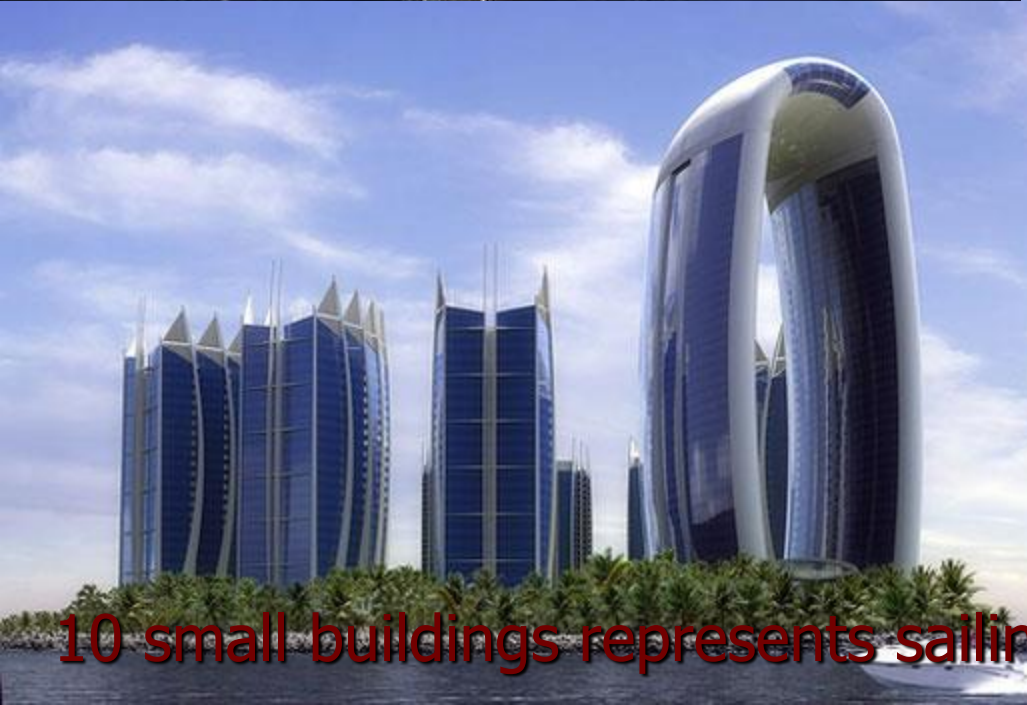
2004-2008



# Regatta Hotel

## Jakarta

Completed  
Nov 2008

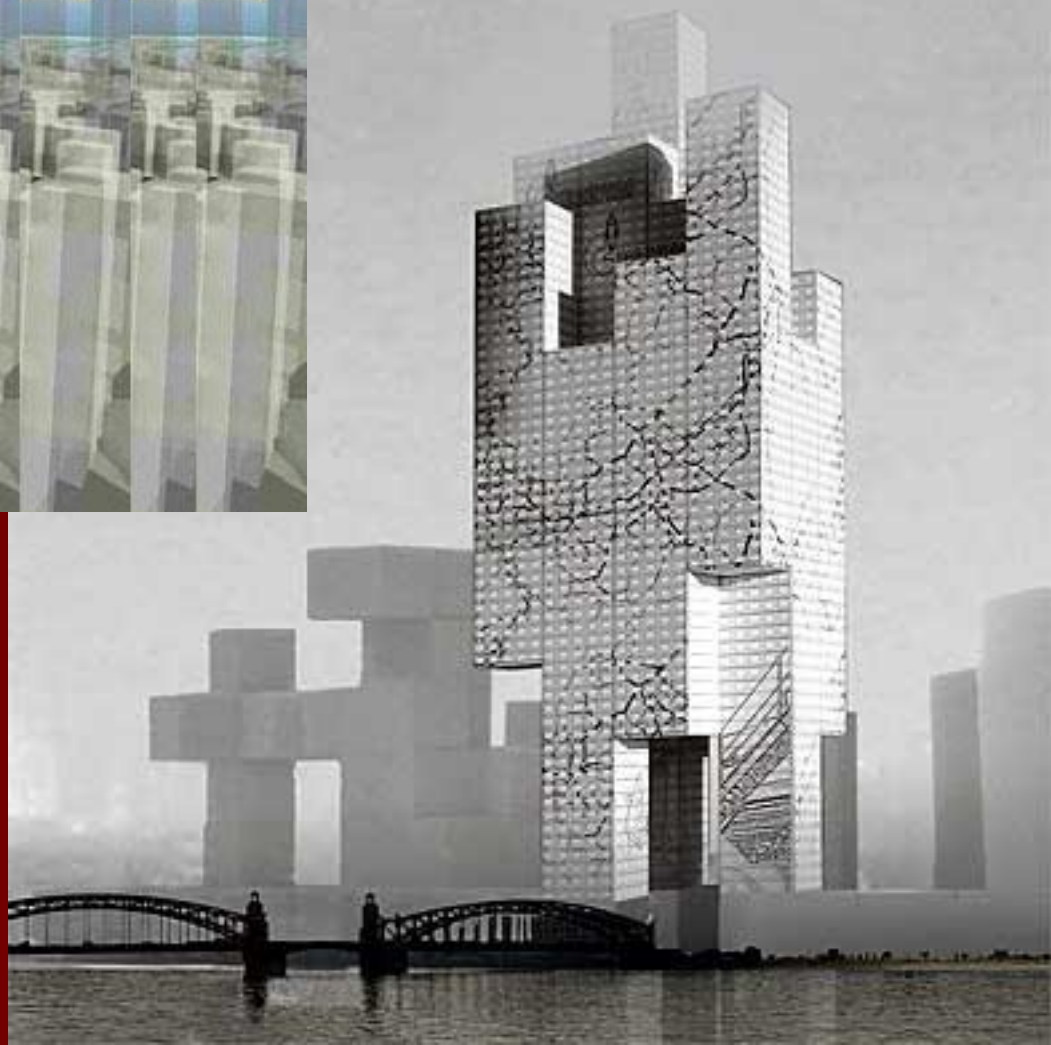


10 small buildings represents sailing and the big one lighthouse

Completed  
Nov 2008



# Residence Antilia India





# Burj Dubai



(Sept 2004-Sept 2009)



Aqua, USA (2006-2009)



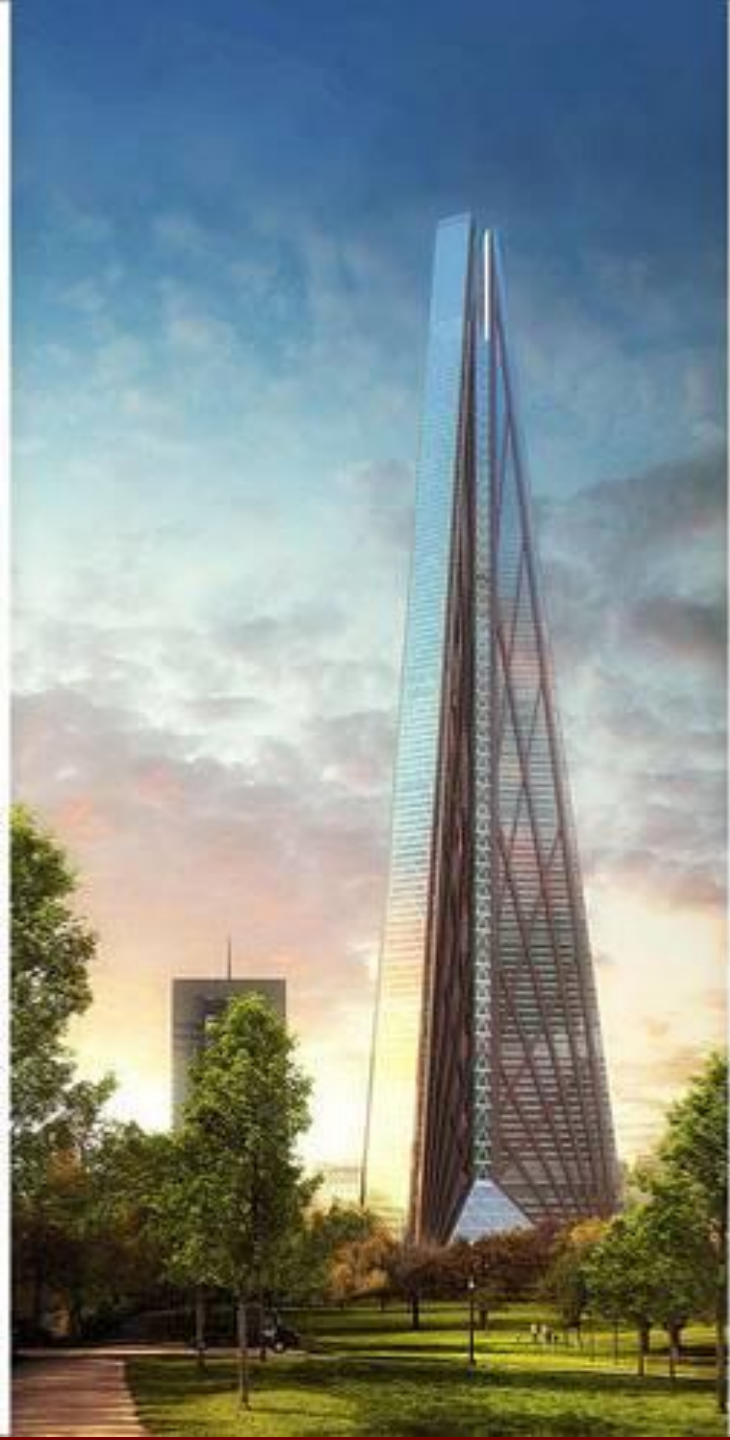


# Chicago Spire, USA



2007-2012

# Russia Tower Russia



2007-2012



# Gazprom City Tower, St Petersburg



okhta-tower-russia (2008-2012)

# Penang Global City Centre Malaysia



(2008 - )



# Functions of Facades



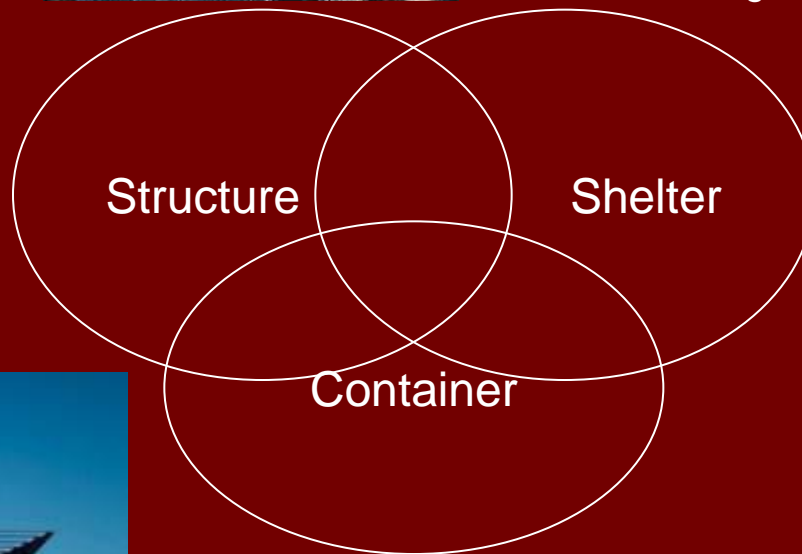
Fawood Children's Centre



Canary Wharf



Chinese American Service  
League, Kam L. Liu Building



Central Library Brighton



BBC



CBX Tower Project, Paris



# Vacuum Insulation Projects

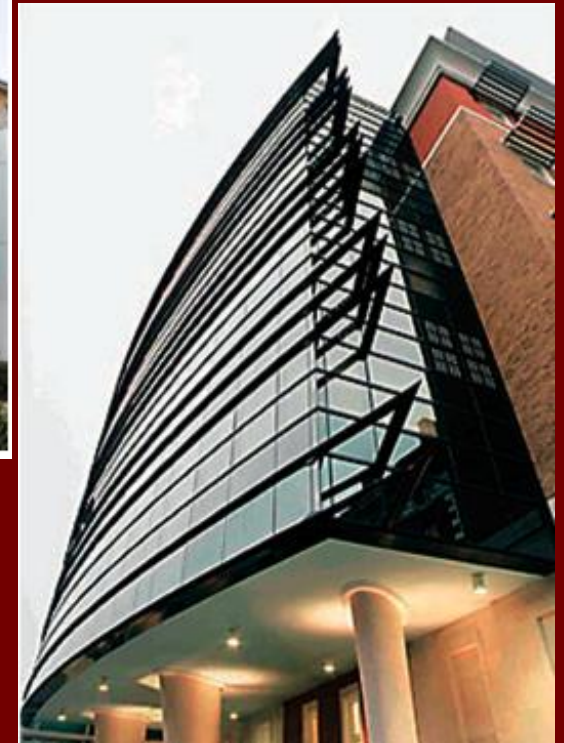
Barratt Green House, BRE



Apartment and office building in



Crossway, Richard Hawkes Architects UK



TuffX Processed Glass's Eco i-panel  
<http://www.vacuuminsulation.co.uk/>

# Building Envelopes Design Considerations BCO Guide to Specification 2009

- Wind Pressures
- Weather Performance
- Integration with Building Services
- Structural Integrity
- Blast proof/ earthquake criteria
- Energy Performance
- Maintenance/ Cleaning/ Recycling



# What parameters to measure?

## Building performance

- Building integrity
- Consumption
  - Electricity
  - Gas
  - Water
- Safety and Security
  - Smoke
  - Gas leak
  - Water leak
  - Security alarm

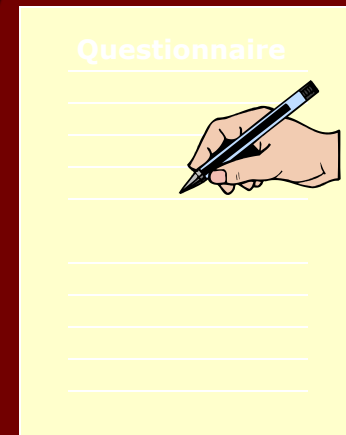
## Occupant satisfaction

- Thermal Comfort parameters
- Air Quality markers
- Light intensity
- Noise intensity
- Occupancy level
- State level (windows, doors)
- Mood
- Well being
- ...

# How to measure?

## Measurements:

- Physical (environmental sensors)
- Physiological (body monitoring sensors)
- Questionnaire (human sensation)



Th.C	T,RH,Tr,vair ----	Met ----	Iclo Thermal vote
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# Facades as Transparent/Opaque Climate Moderators

- Sunlight
- Solar energy
- Sound
- Air
- Moisture
- View
- Temperature

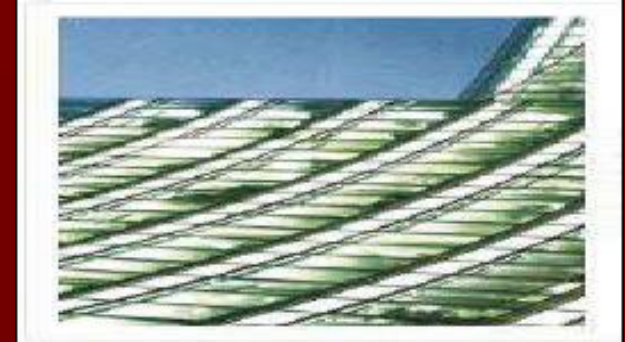
# Desirable Properties for Facades

- Low CO<sub>2</sub> emissions
- Thermal and Moisture Insulation
- Storage
- Solar Isolation
- Natural Light
- View
- Fresh Air
- Sound Insulation
- Sensor system/interact with clothing or skin sensors
- Varying properties (nanomaterials)
- Self cleaning
- Self-repairing
- Security/Safety/Fire Protection
- Aesthetics

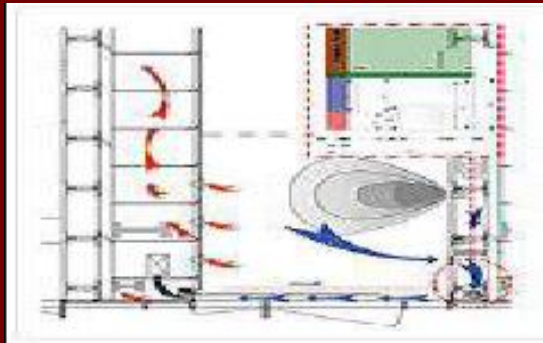


# Building Envelope

- Introduce Double Skin System, Louver and Blind Auto Control, Sunlight Shielding Glass, High Performance Insulation (e.g. Vacuum Insulation) and Window System
- Maximize Building Energy Performance and Comfort Environment



## Air Barrier System

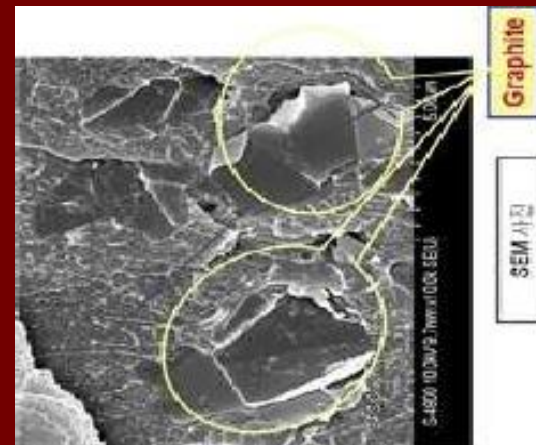
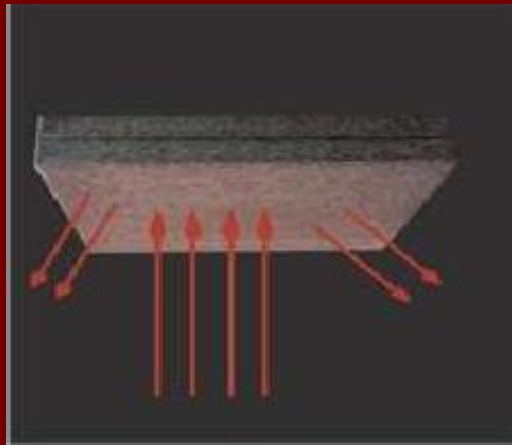


- Eliminating Skin Load from Outer Window Side
- Upward Air Flow from Floor Plenum Between Window and Blind
- Resulting Energy Savings by reducing HVAC Capacity

# Green Materials & Resources

## High Efficiency Insulation Material

- Utilize Reflection of Radiant Heat from Graphite Inside Insulation Material
- Analyze Performance of Insulation Material and Standardize for Practical Use
- Achieving Energy Savings by Improved Performance of Insulation Material
- Other solutions e.g. Vacuum insulation

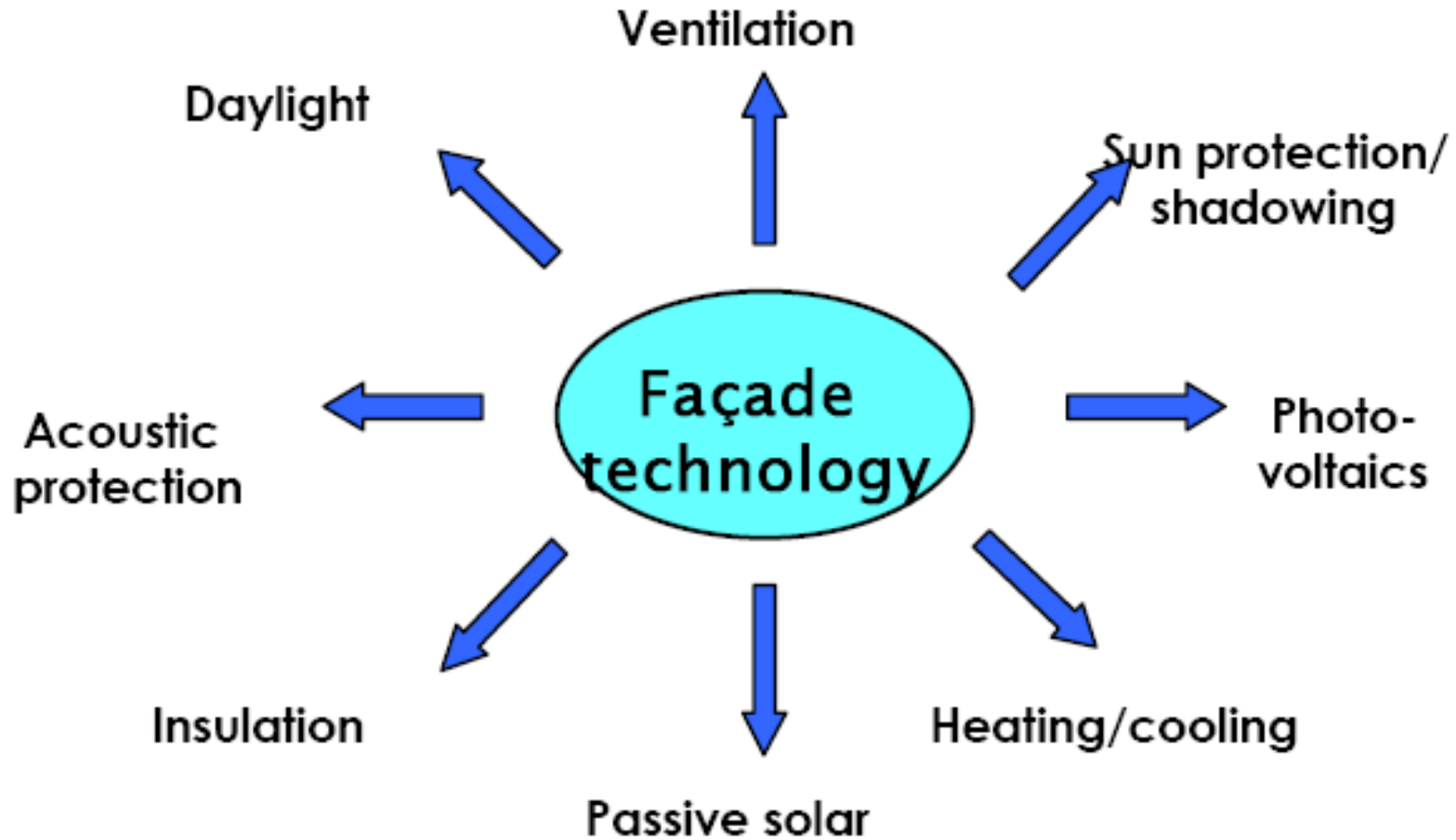




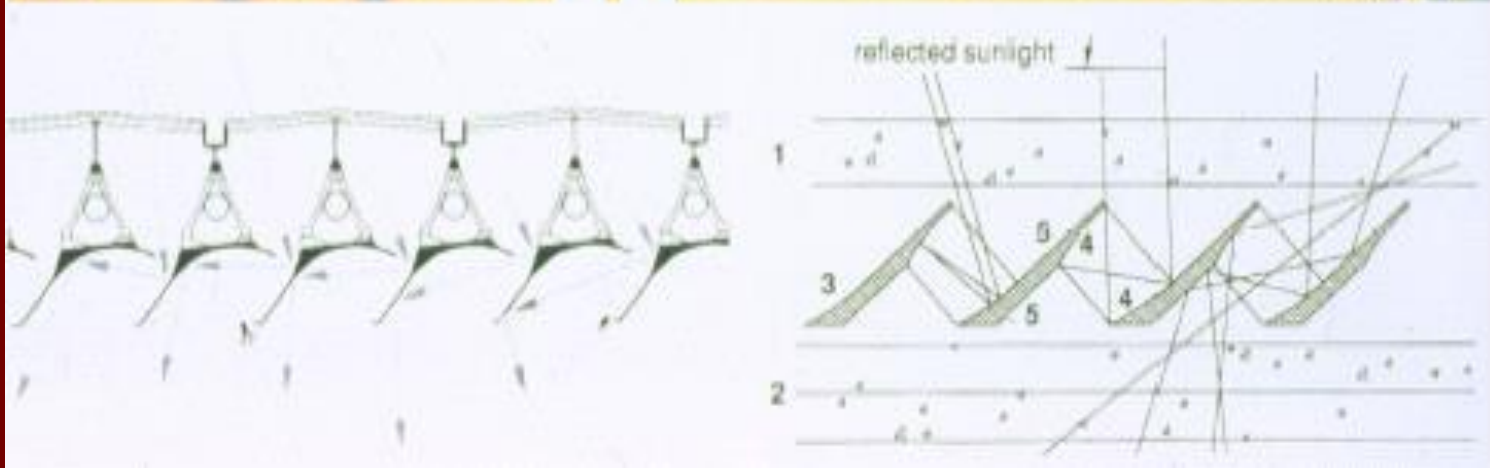
# Facades as Integrators

- Dynamic envelopes
- Nanomaterials
- Windows
- Respond with sensors inside building and occupants

# Possible Integrated Functions



Concrete solar  
Baffles  
for the Menil  
Collection in  
Houston  
Texas (Renzo  
Piano)  
showing how  
form, function  
and aesthetics  
can be  
integrated into  
building  
design.



Behling, 1996

Designer Koster in collaboration with Ocalux arrived at similar forms as they tried to balance shade and daylight control



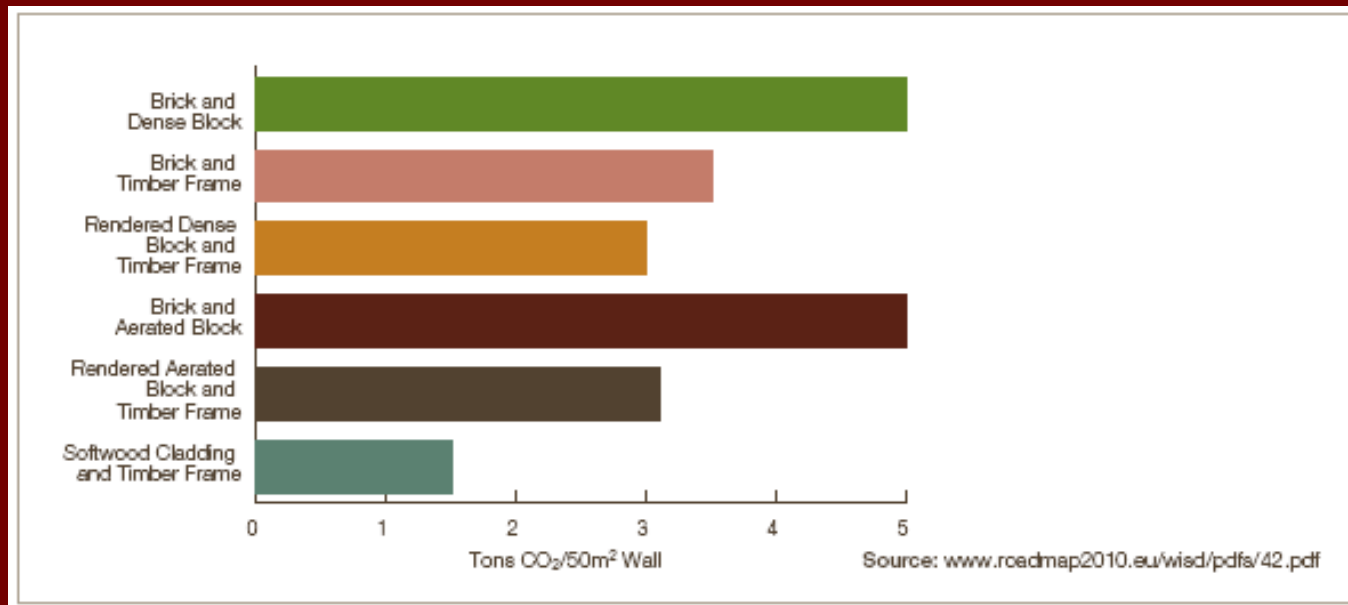
# Facades as Thermal Stores

- Materials
- Mass
- Orientation

# Smart Facades

- Facade is an interactive inside-outside interface
- Reactive materials and surfaces
- Embedded technology can control inputs/outputs
- Low CO<sub>2</sub> emission
- High insulation e.g. vacuum insulation
- Opportunities for nanomaterials
- Lessons from Nature
- Develop new CPD modules for architects, engineers and construction professionals on facade design

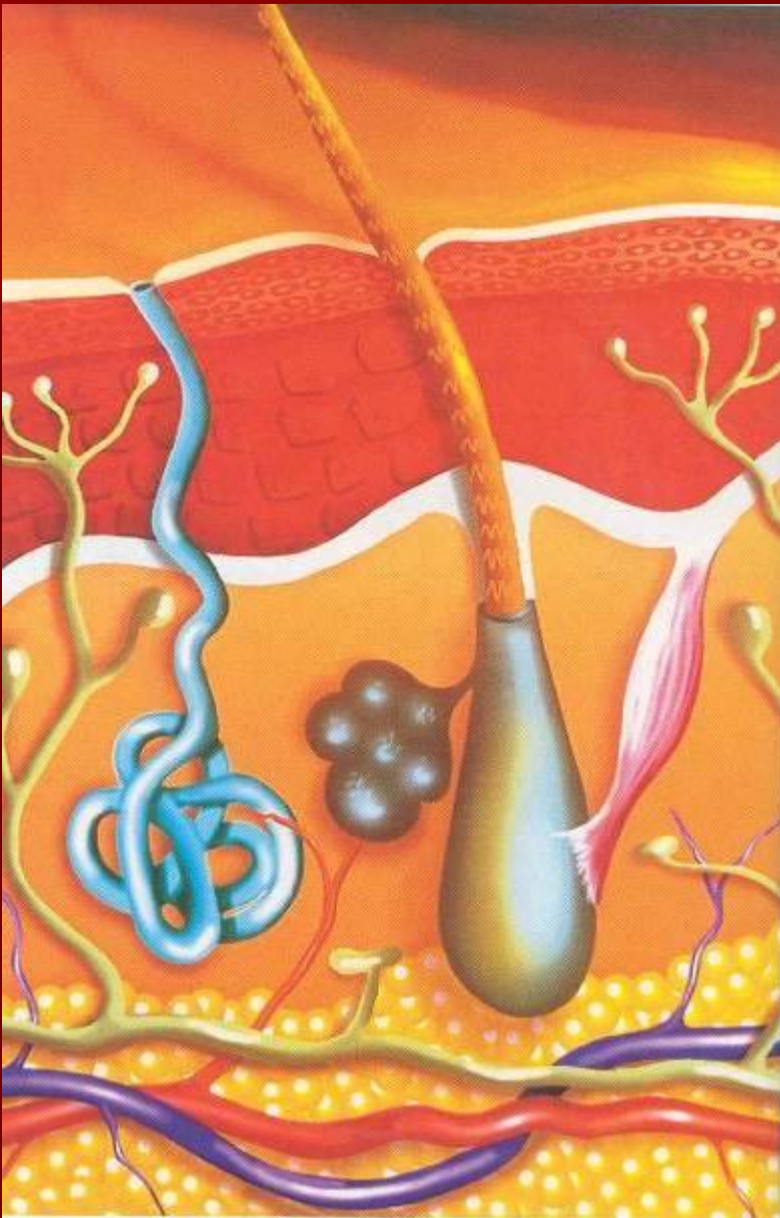
# CO2 Emissions for Different Wall Constructions



World Business Council for Sustainable Development, Policy Directions to 2050, [http://www.wbcsd.org/DocRoot/bdA09BFxjVkjEeXJKjle/int\\_low\\_res.pdf](http://www.wbcsd.org/DocRoot/bdA09BFxjVkjEeXJKjle/int_low_res.pdf), (2007).



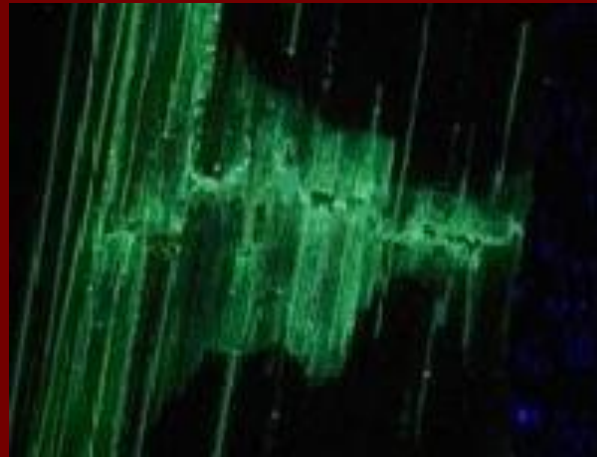
# Lessons from Nature



The human skin is a good model how we would like the building skin to behave. It adapts to temperature and humidity, can feel a breeze or the slightest touch, and can repair itself. It is waterproof and yet permeable to moisture.

# Self Healing Materials

Mimics human bleeding healing process  
Embedded vessels bleed coloured epoxy resin into  
cracks and restore structural integrity.



University of Bristol, Hexcell Composites Ltd,  
EPSRC Annual Report, 2008-2009

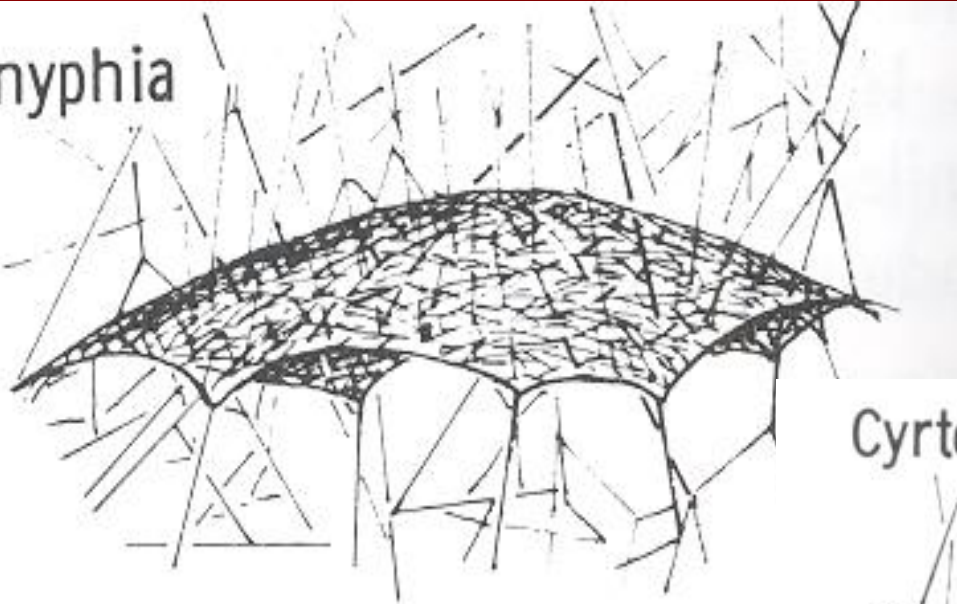


# What can We Learn from Nature?

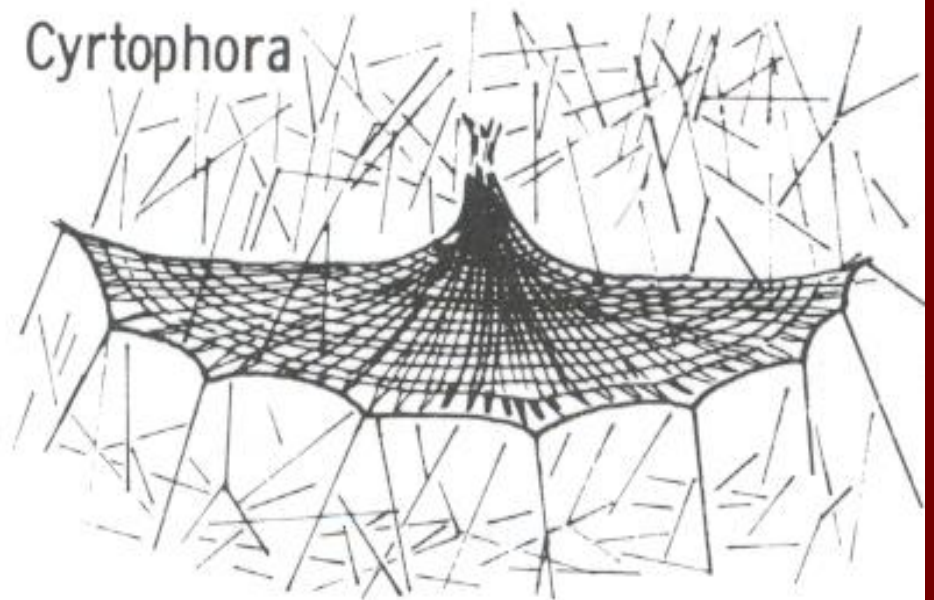
- Human skin: self-repairing, waterproof, heat sensitive
- Animal architecture e.g. termites
- Structures of plants applicable to buildings (self-cleaning lotus leaf)
- Spiders web: waterproof, great strength
- Composites in shell of molluscs (e.g. nacre is strong)
- Wood: strength, low embodied energy, aesthetic
- Feathers: thermal protection (e.g. penguins)
- Fur: thermal protection (e.g. polar bears/reindeers)
- Natural adhesives (e.g. mussels/geeko)
- Rattlesnake: infra red eye sensor for vibration/movement

# Examples of Spiders Webs

Linyphia



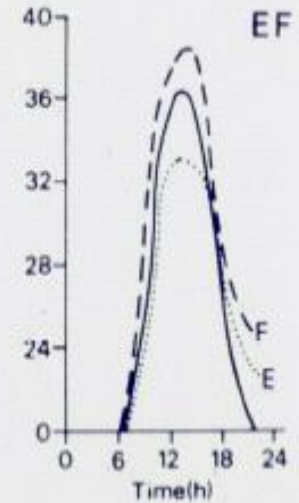
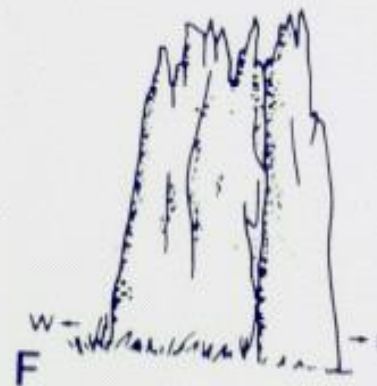
Cyrtophora



## Compass termites in Australia

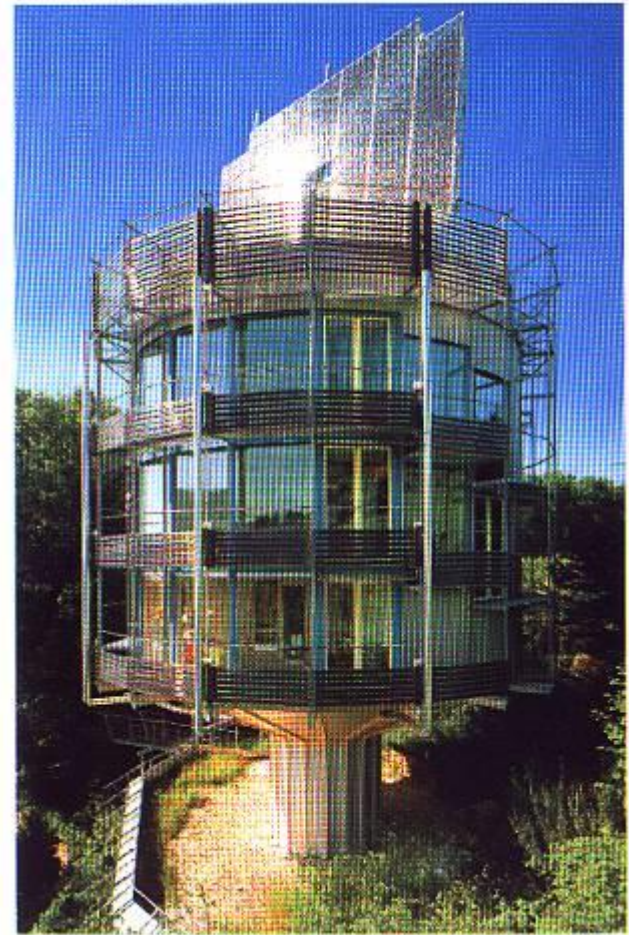


Evolved orientation of termitary for preferred maximum temperature level of about 32°C





# Bio-inspired Architecture

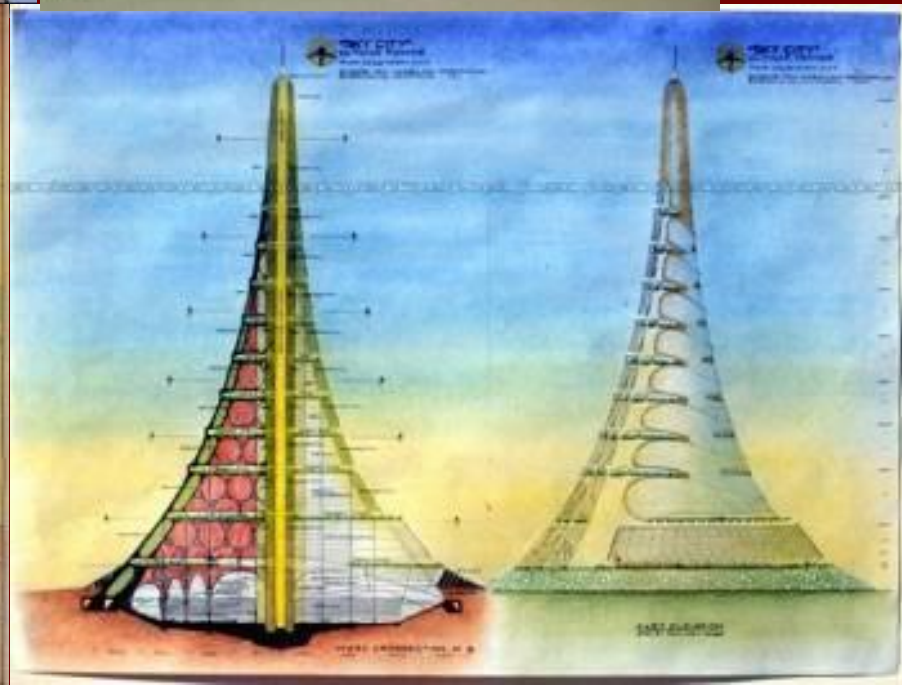


Architecture inspired by termite nests



# Eugene Tsui

## Ultima Tower



The *Podhotel* copies leaves and pods from a flower stalk, the leaves being transformed into solar and shading panels and the pods being prefabricated rooms.



Architect: Dennis Dollens



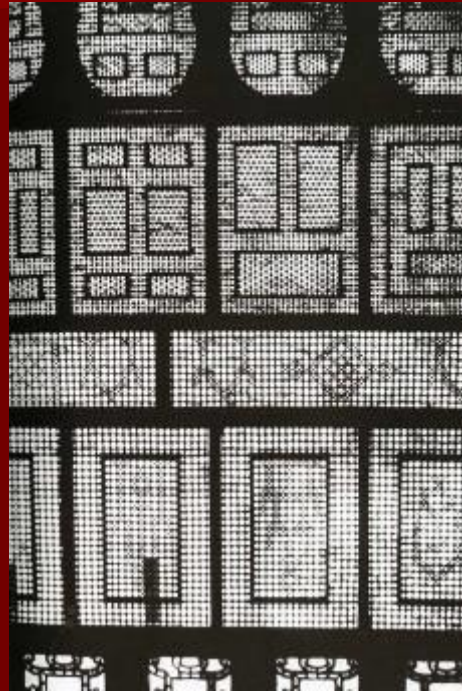
# Vernacular Solutions

# Reed Hut Offers Protection from the Weather: The Primeval House



More highly developed building technology for woven reed hut.

# Middle East

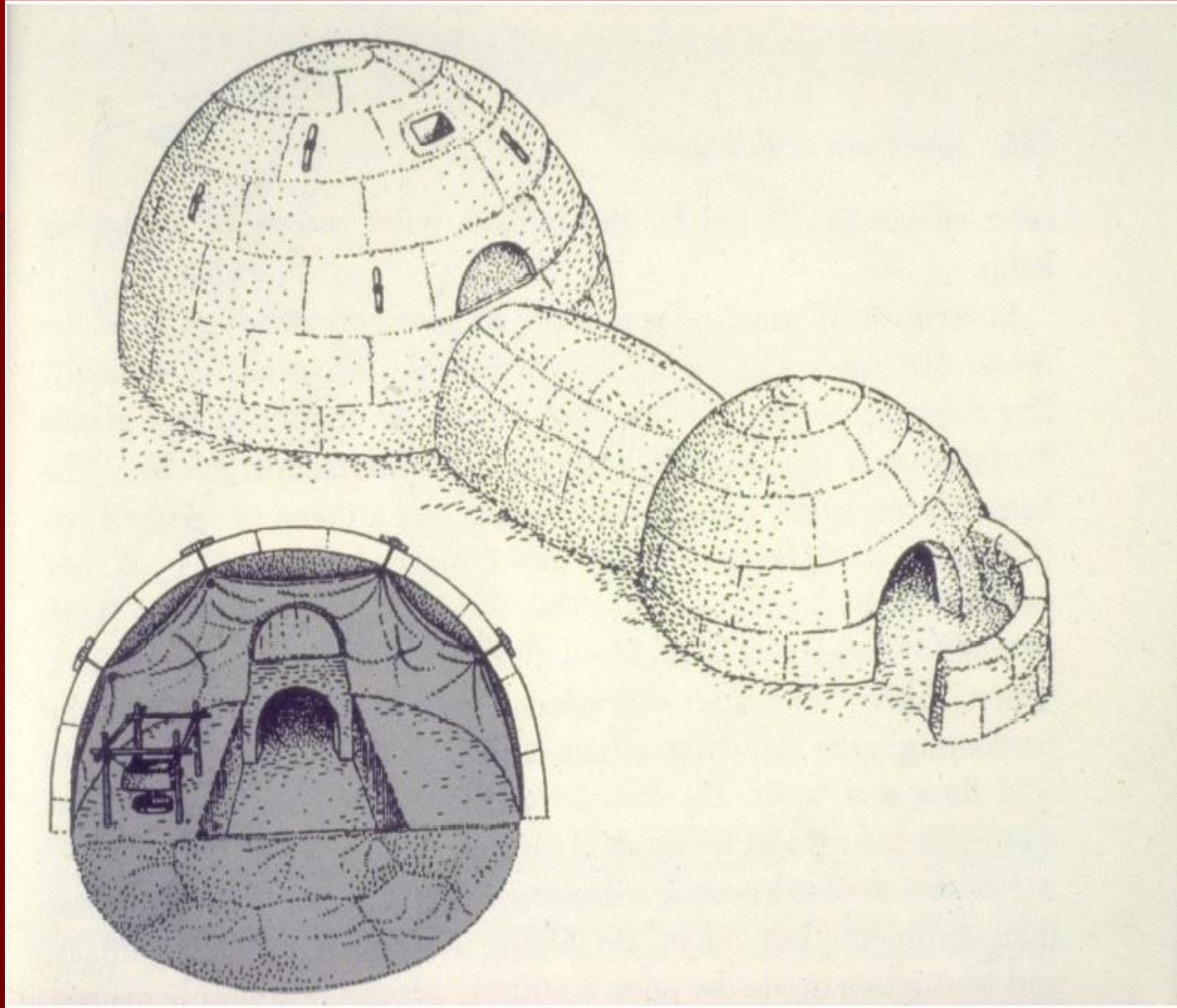




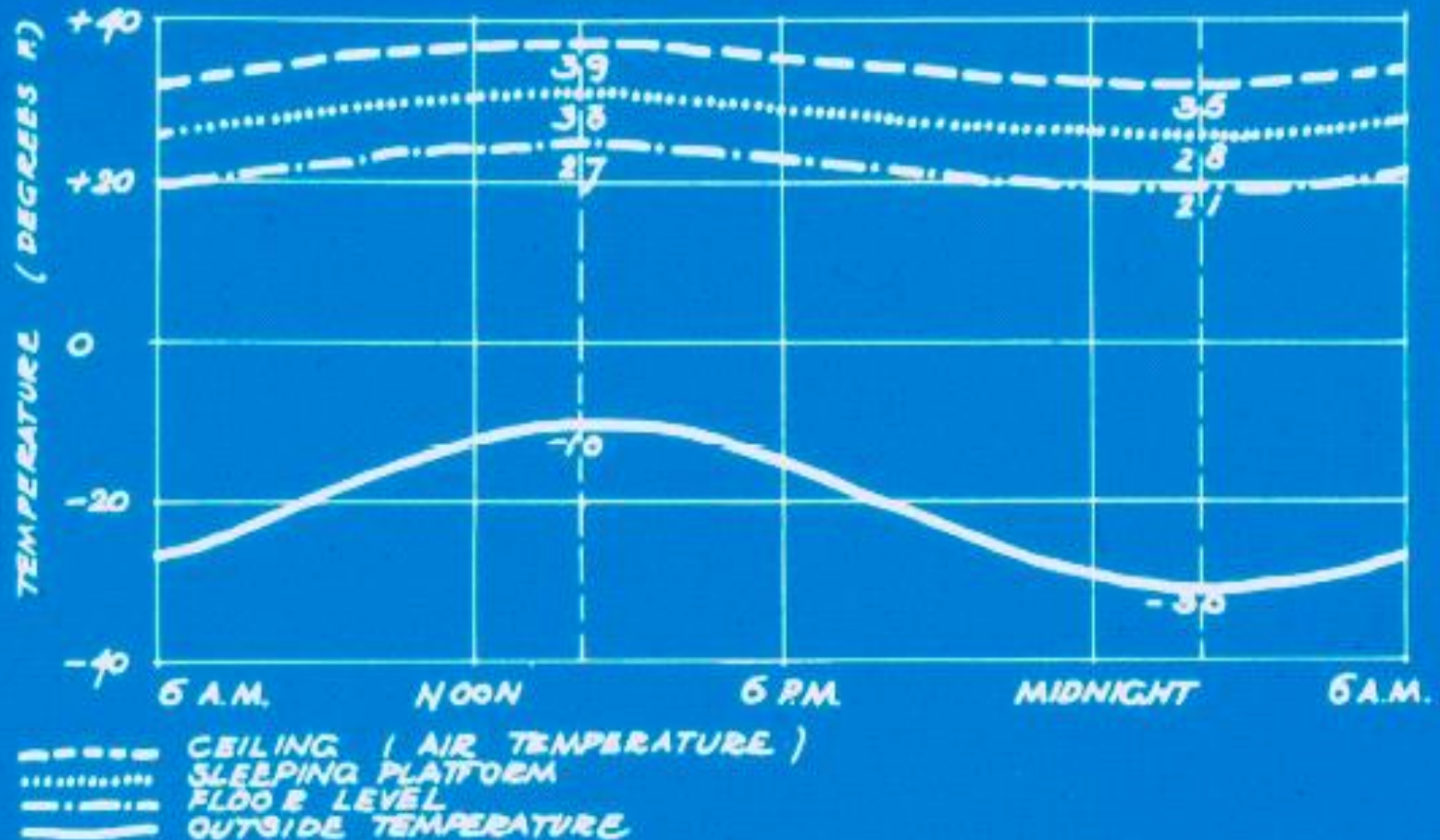
# Indonesia



# IGLOO, Baffin Island, Canada



# Thermal Performance of the Igloo





# Active Environmental Control



**Glass Buildings demand mechanical environmental control systems.**



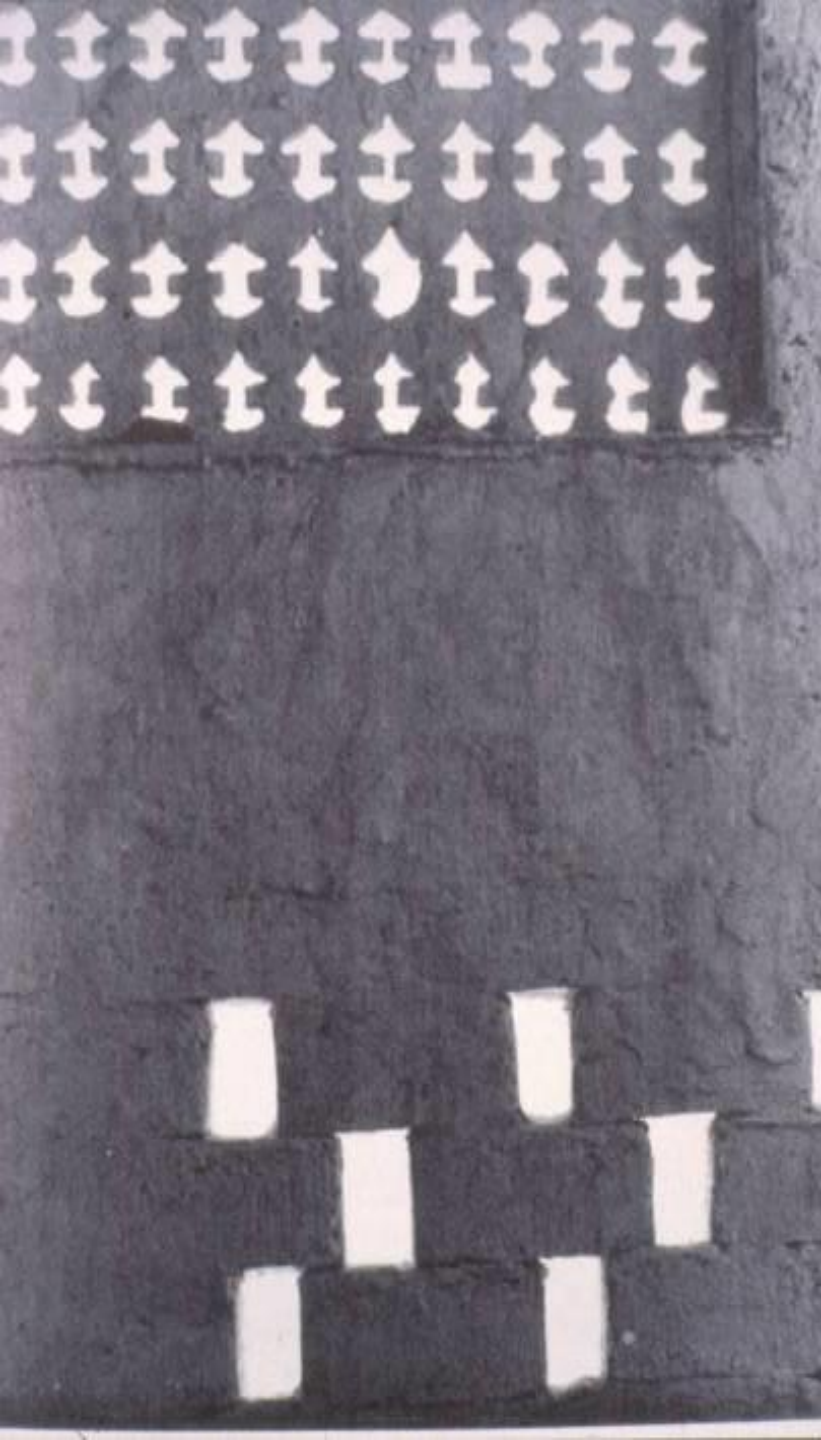
Fortress later monastery in Göreme



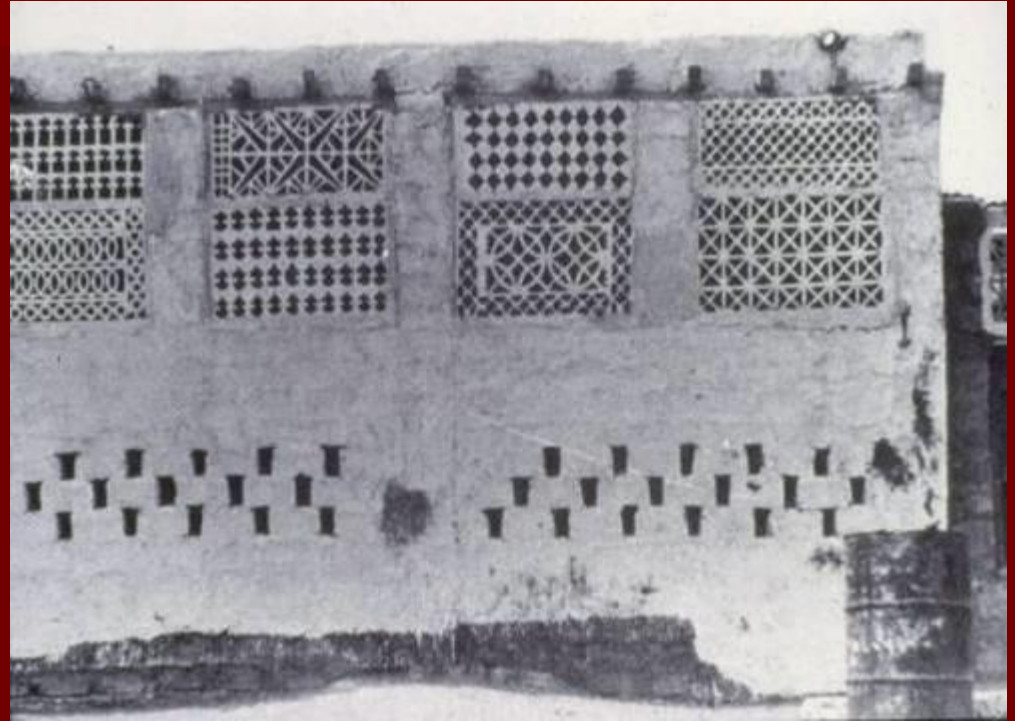
# Yurts / Ghers in Mongolia



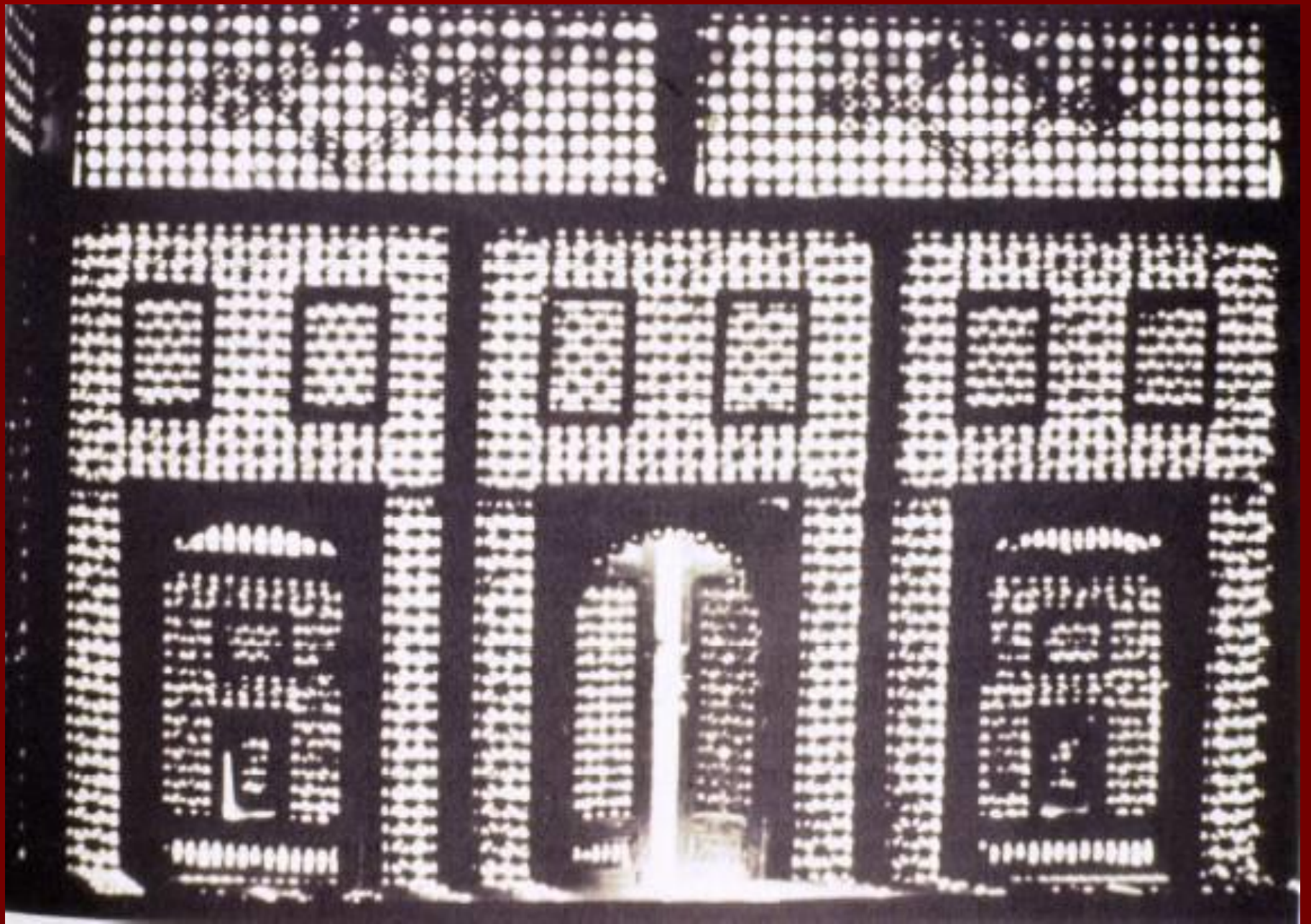




CLAUSTRA (Decorative tracery used for ventilation) in Dubai, United Arab Emirates



Claustra in a parapet wall on the roof of a building in Oman



Brise-soleil in Boke, Ivory Coast

# Modern Trends

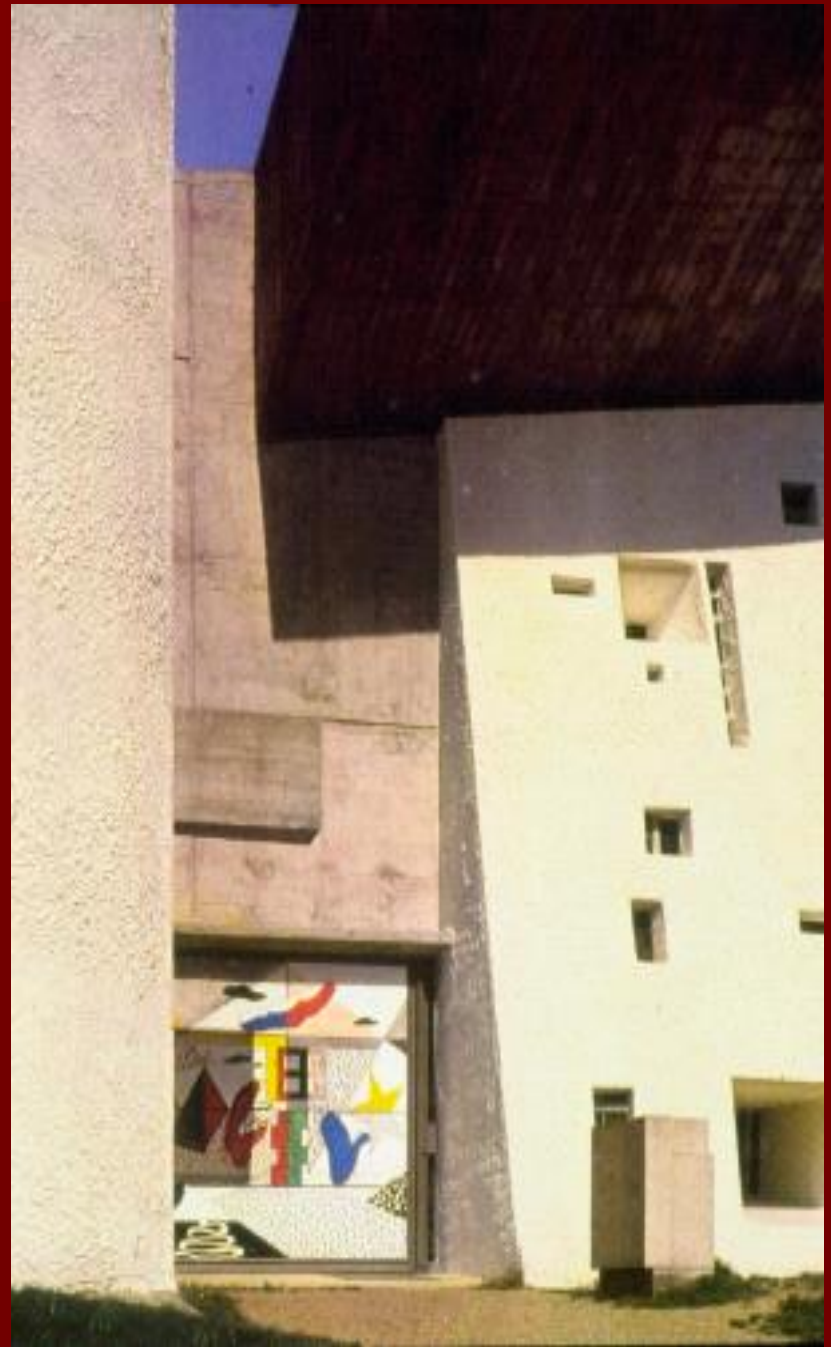
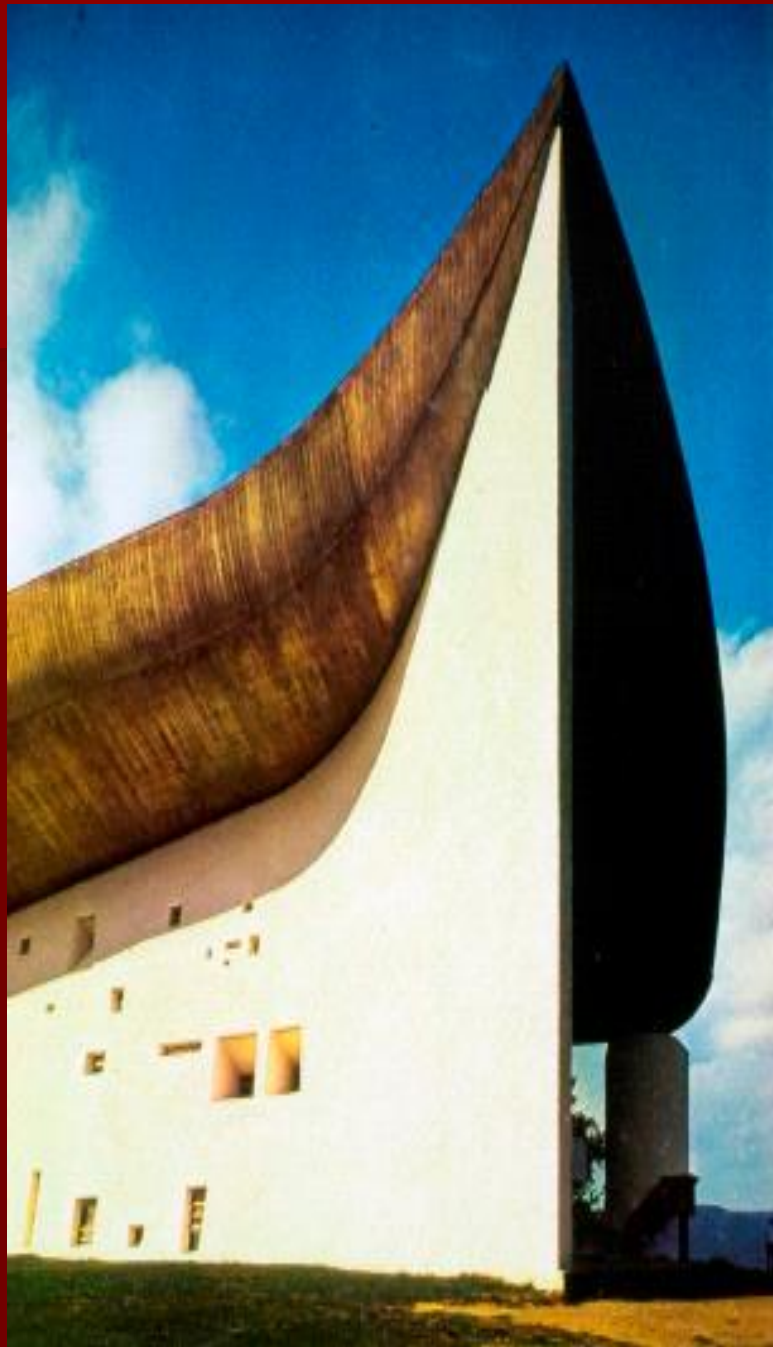


# Vacuum Insulation

- up to 10-fold higher insulation performance compared to conventional insulations
- space saving but highly insulating constructions possible
- cover: high barrier metallised multi layer film
- high quality and long product life time
- Can be transparent
- recyclable

# The Chapel by Le Corbusier at Ronchamps in East France







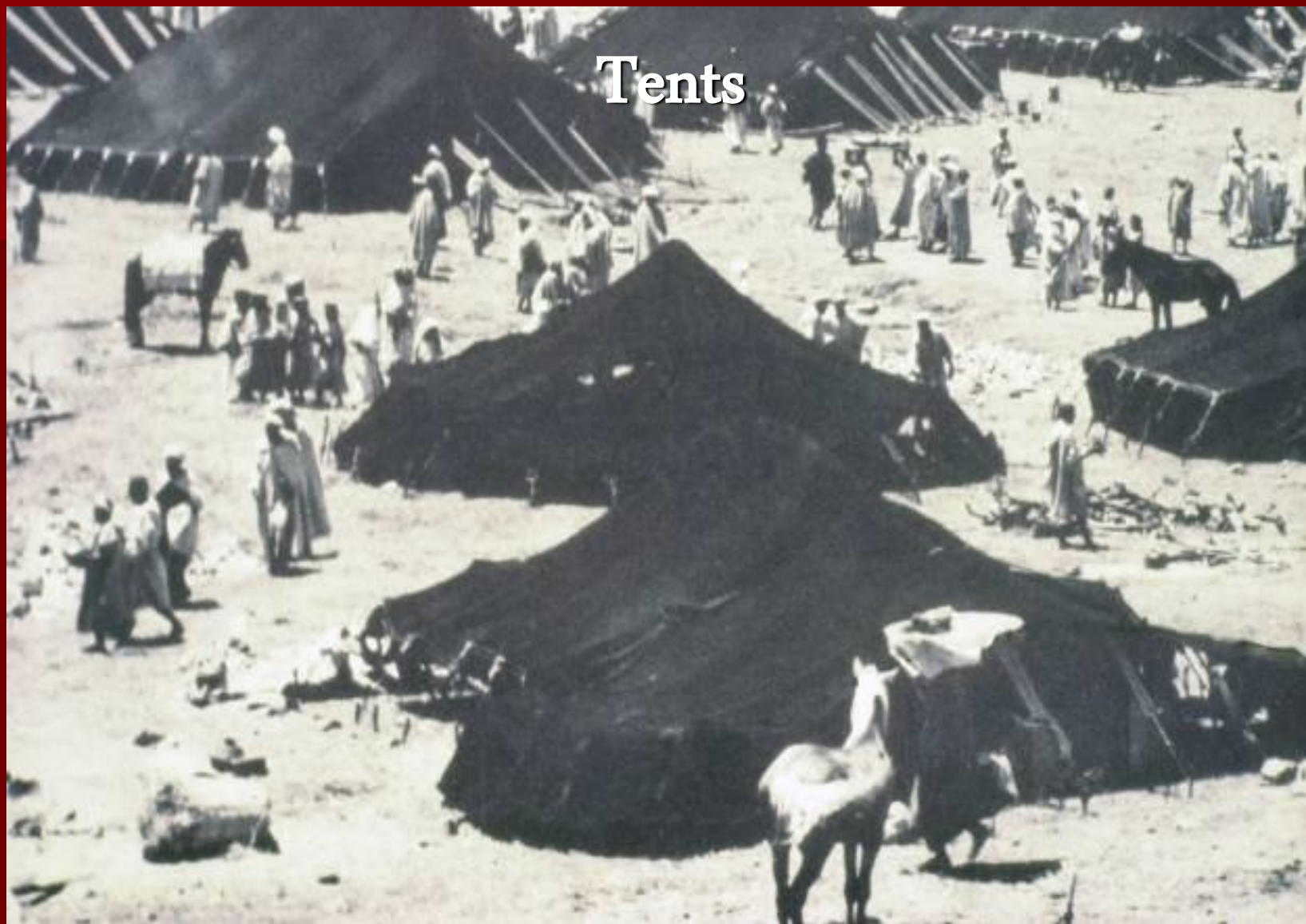


The atmosphere inside the Chapel is one sanctity and peace making it conducive to prayer and meditation. This is brought about by the unusual and highly creative light design echoed by the irregular window shapes and positions.



# Centre Pompidou Paris



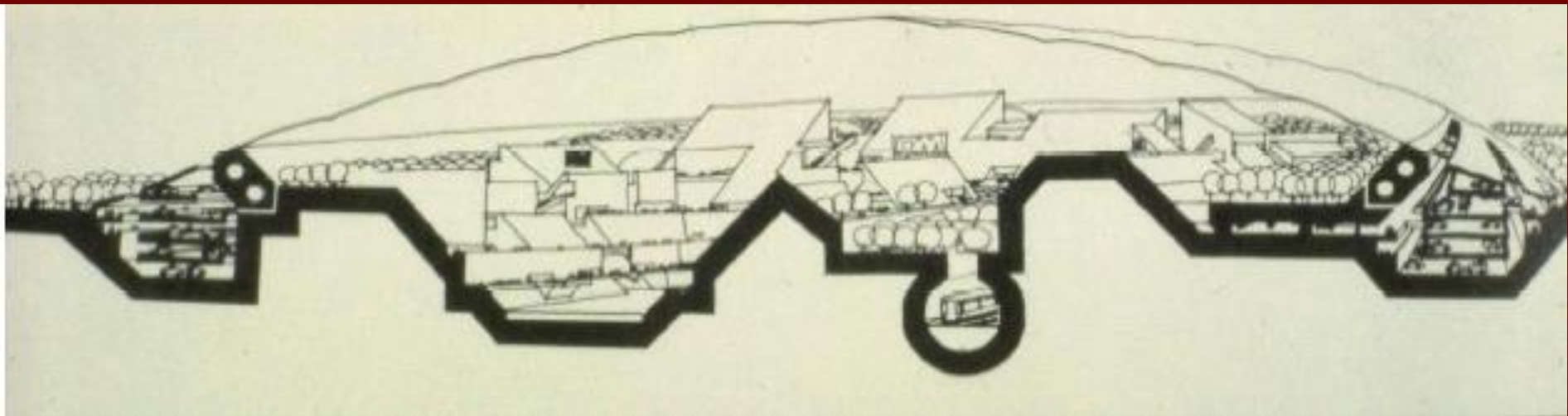


Encampment of Black Goats Wool Tents on Ajdir Plateau in the Middle Atlas Mountains, near the Sahara.

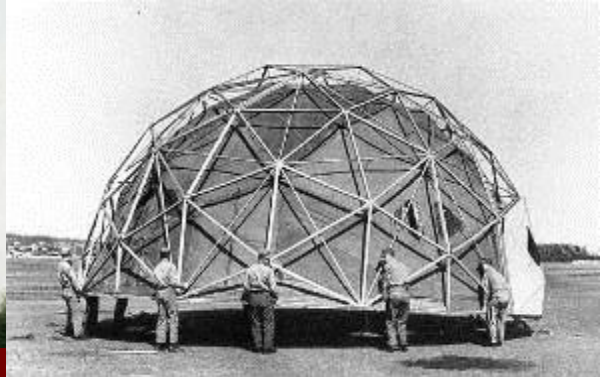


# PROPOSAL FOR ARCTIC CITY BY ERSKINE and OTTO 1952

Technology of air-supported structure ,makes enclosure of entire towns entirely practicable/ this cable-restrained, air-supported technique would be especially useful in Arctic and Antarctic climates, where an absolute deficiency of heath and light plus low temperatures, high winds and heavy snow cover restrict full development of urban life.



# Buckminster Fuller, 'U.S. Pavilion Montreal Expo 67' (1967).





# Lightweight Pneumatic Structure in Alberta, Canada



35 hectare 60mt high township for 10.000 people in moderated environment conditions.



Diplomatic Club complex in Riyadh,  
now known as the Tuwaiq Palace (1988):  
local sandstone and fibreglass tents



Greening

# Greening and Photovoltaics at Unterensingen School



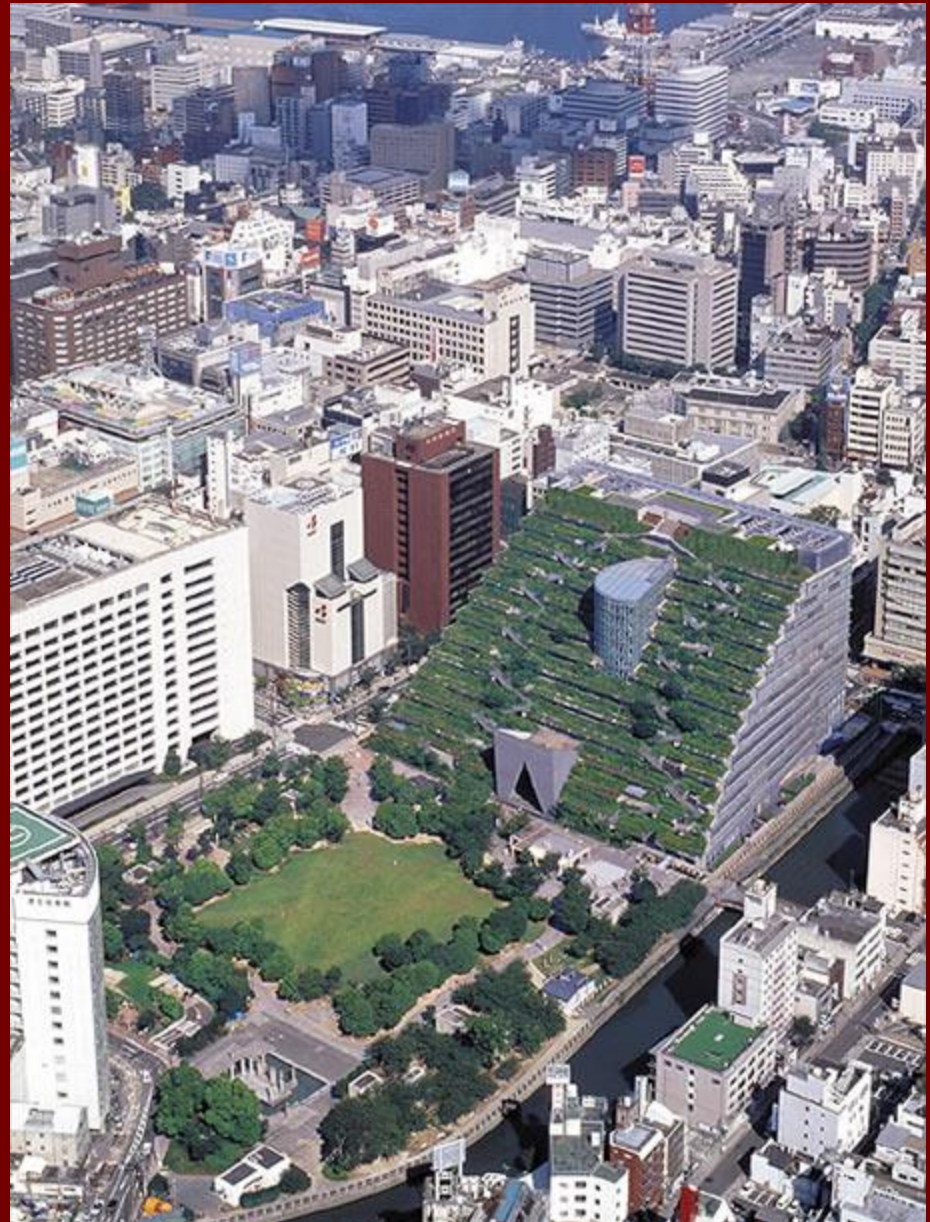
Unterensingen Primary and Secondary School, Germany



# Acros Fukuoka, Japan



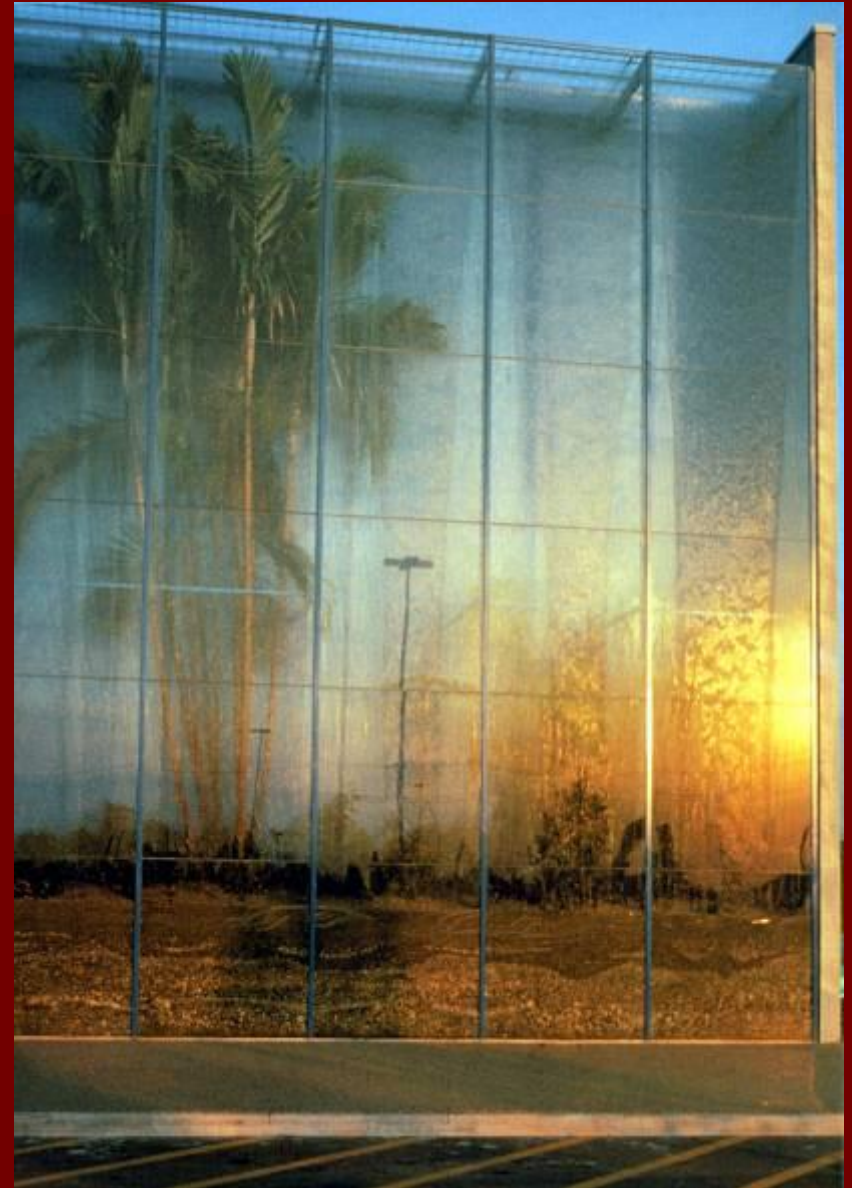
Emilio Ambasz, Fukuoka, Japan







SITE Rain Forest Showroom,  
Hialeah, Florida,



# Green Roofs- Faroe Islands, Denmark

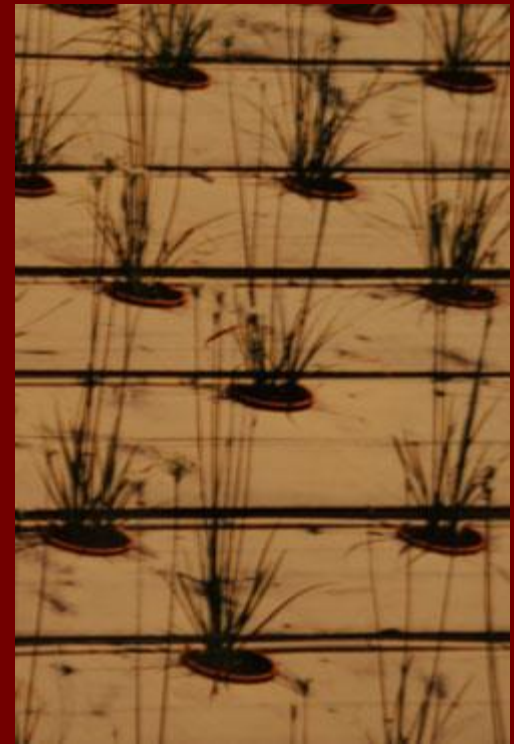




# Seaweed Roof, Laeso, Denmark, 2003



# Green Roofs



Dandelion House by Terunobu Fujimori







# Some Innovations



Use of solar cells for energy generation is growing  
40% per year

# Phovoltaic Solar Cells

Source	Cost (\$ per kWh)
Solar PV	0.30 (current) 0.02 (25 years)
Wind	0.05
Natural Gas	0.03

Generation	Characteristic
First	Single crystal of silicon 18% efficiency
Second	Silicon thin films Other components such as cadmium telluride < 18% efficiency
Third	Quantum dot or nano crystals Efficiency 48% Quantum –well solar cell and Dye sensitised solar cell



# Rules of Thumb for Solar Design

<b>Form</b>	<ul style="list-style-type: none"><li>• create sun spaces, lighting ducts, light shelves</li></ul>
<b>Orientation:</b>	<ul style="list-style-type: none"><li>• main glazing to face 30 degrees either side of due south</li><li>• reduce north glazing</li><li>• minimise tree over-shadowing</li><li>• on housing estates build to a density of <math>\leq 40</math> properties/ha</li><li>• design atriums/roof lighting in accordance with the position of the sun in both summer and winter</li></ul>
<b>Fabric:</b>	<ul style="list-style-type: none"><li>• fabric transmission losses may be reduced by improving insulation or by reducing the mean inside air temperature.</li></ul>

# Colour-Changing Smart Materials

- *Photochromics* -materials exposed to light
- *Thermochromics* -materials respond to temperature changes.
- *Mechanochromics* -materials react to imposed stresses and/or deformations.
- *Chemochromics* -materials exposed to specific chemical environments.
- *Electrochromics* -materials respond to voltage.
- *Related technologies* – electrically active liquid crystals and suspended particle devices

# Smart Window Features

<b>System Type</b>	Spectral response (bleached to coloured)	Input energy	Interior result visual	Interior result thermal
<b>Photochromic</b>	Specular to specular transmission at high UV levels	UV radiation	Reduction in intensity but still transparent	Reduction in transmitted radiation
<b>Thermochromic</b>	Specular to specular transmission at high IR levels	Heat (high surface temperature)	Reduction in intensity but still transparent	Reduction in transmitted radiation
<b>Thermotropic</b>	Specular to specular transmission at high and low temperatures	Heat (high and/or low surface temperature)	Reduction in intensity and visibility, becomes diffuse	Reduction in transmitted radiation, emitted radiation, and conductivity
<b>Electrothropic</b> *	Specular to specular transmission toward short wavelength region (blue)	Voltage or current pulse	Reduction in intensity	Proportional reduction in transmitted radiation
<b>Liquid Crystals*</b>	Specular to diffuse transmission	Voltage	Minimal reduction in intensity, reduction in visibility, becomes diffuse	Minimal impact on transmitted radiation
<b>Suspended particle</b>	Specular to diffuse transmission	Current	Reduction in intensity and visibility, becomes diffuse	Minimal impact on transmitted radiation

\*indicates that a control system and associated electrical supply are required

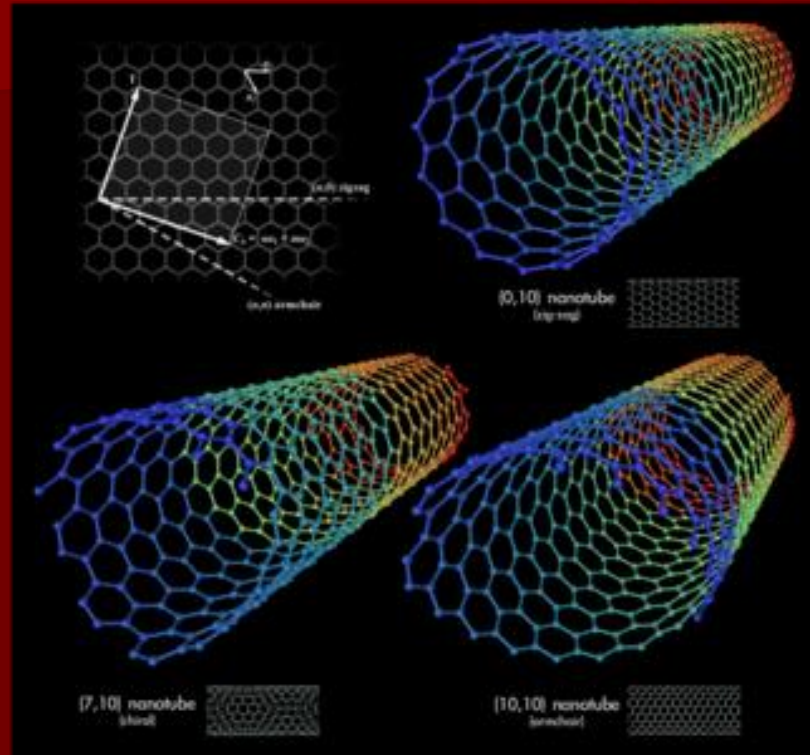


Titanium dioxide nanoparticles with a smooth surface may be used as an anti-adhesive coating for windows or spectacle lenses



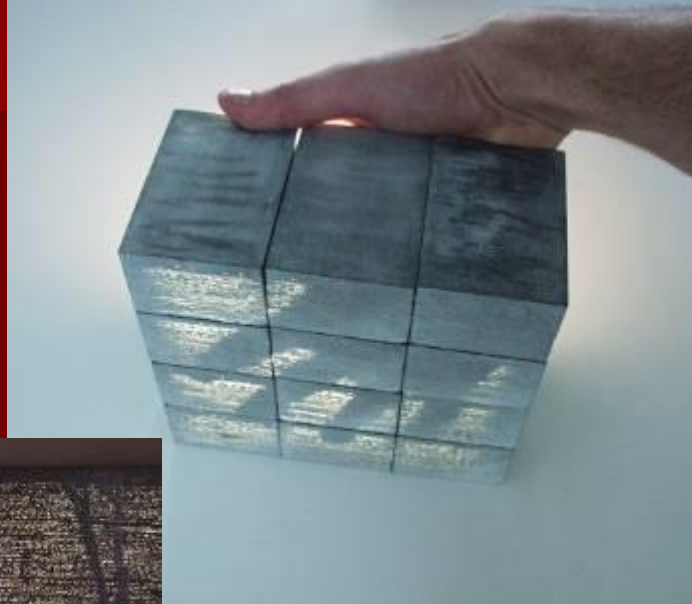
Annabelle Hett, Small matter many unknowns, Ingenia, march 2005, issue 22,

# Carbon Nanotubes



Carbon nanotubes are cylindrical carbon molecules with novel properties that make them potentially useful in a wide variety of applications. They exhibit extraordinary strength and unique electrical properties, and are efficient conductors of heat.

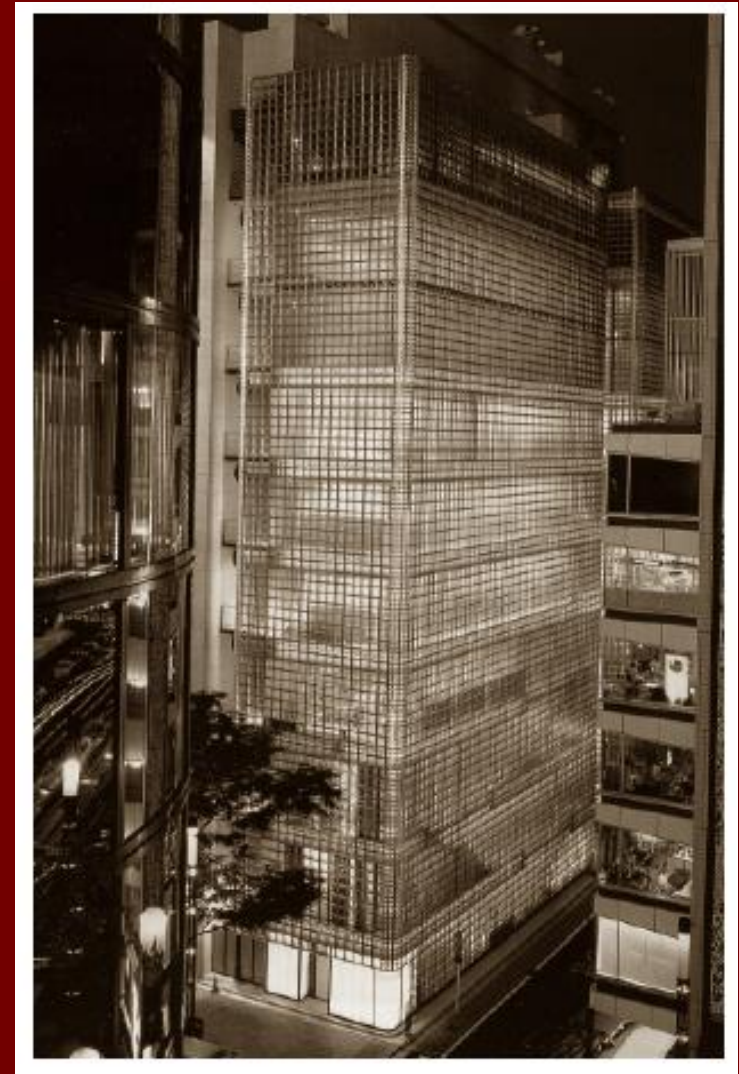
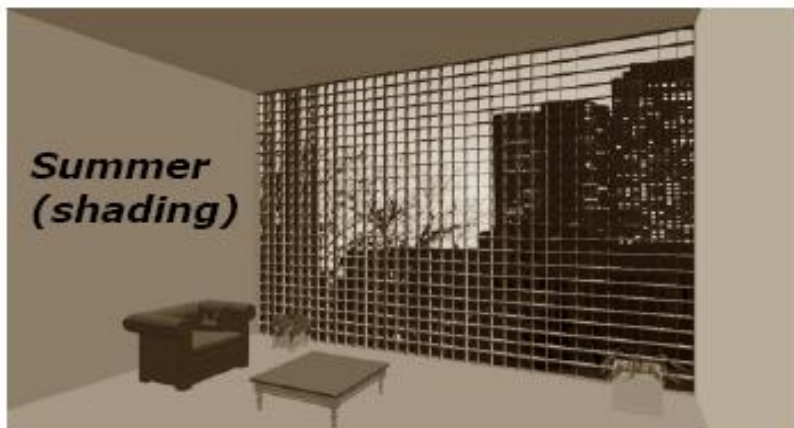
# Light Transmitting Concrete



Wall made of “**LitraCon**” has concrete strength but with embedded array of glass fibres, it displays a view of the outside world. Shadows on the lighter side will appear with sharp outlines on the darker one.

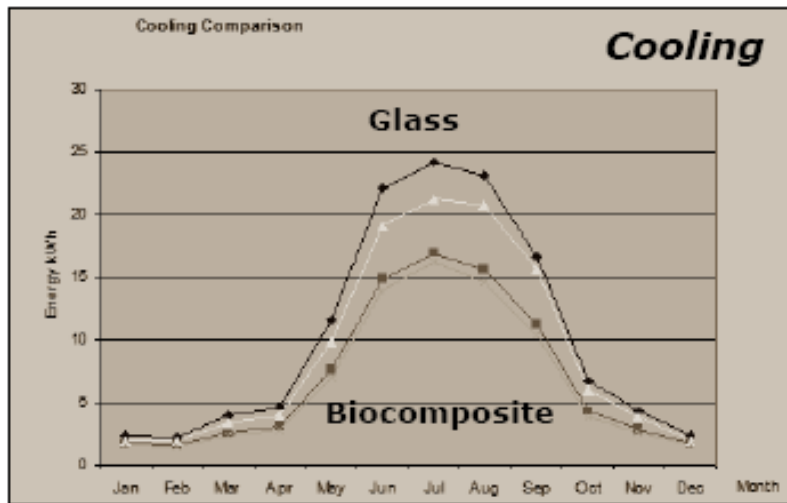
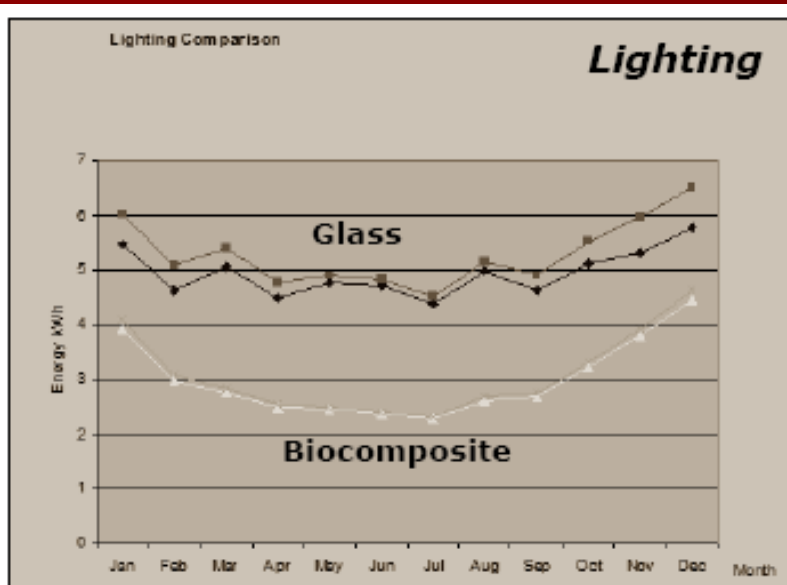
Áron Losonczi. Royal University College of Fine Arts in Stockholm, Sweden.





*Translucent/Transparent Façade application, Hermes, Tokyo, Japan. Source: Architectural Record*

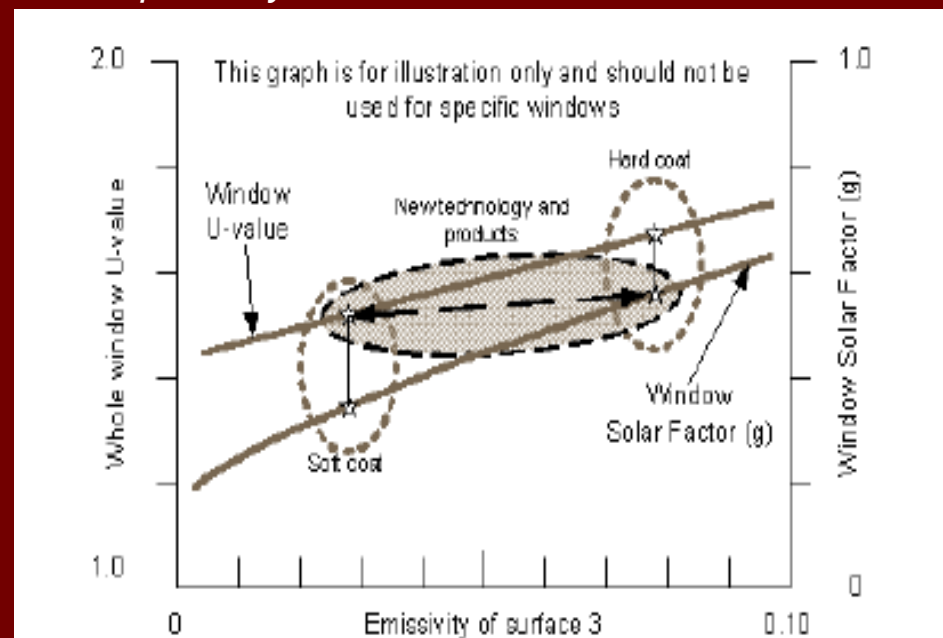
***Application of the biocomposite façade system in passive tempering of solar thermal energy performance –sequence from summer through to winter.***



*Comparison from eQUEST energy analysis over one year, between unshaded low e glass square building (top) and shaded clear glass rectangular building (bottom) showing lower energy consumption – up to 40% savings in lighting and cooling energy.*

Performance value	R	SHGC
Double glazing with low e coating	2.17	0.3
Biocomposite panel clear polymer skins and biocomposite grid core	2.5	varies 0.2 – 0.6 summer – winter

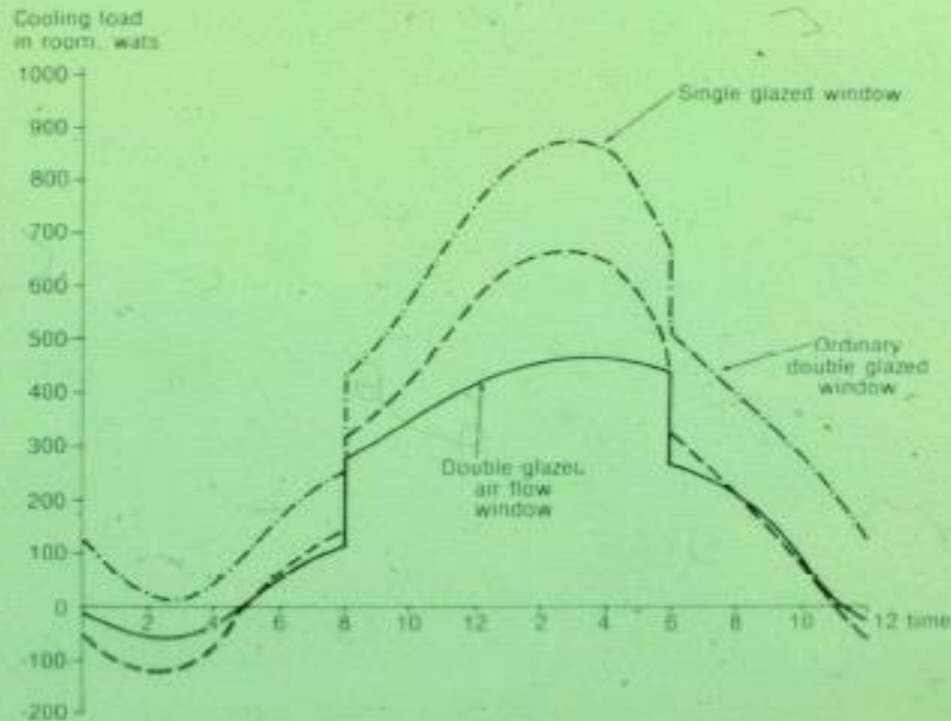
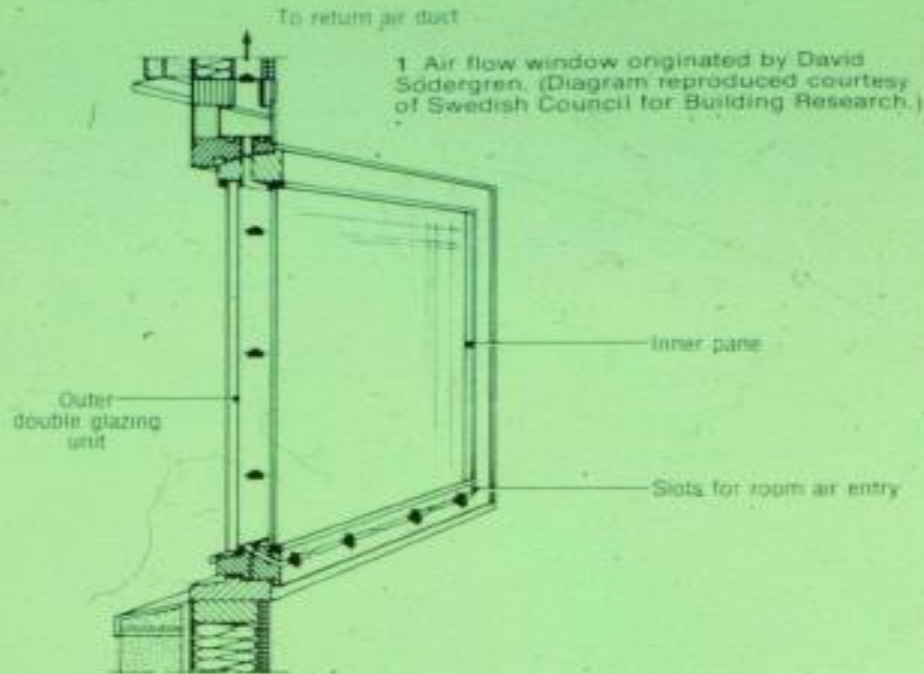
*Performance assessment comparison for glazing and biocomposite system.*



*Relationship between U value (inverse of R value) and SHGC (g) comparing current low e coatings (dotted area) and required new technology products (dashed area)*  
Source: British Fenestration Rating Council

# Solutions





Air V Window with Moving Air Stream in the Gap between the glazing layers.

# Termodeck Hollow Block Floor



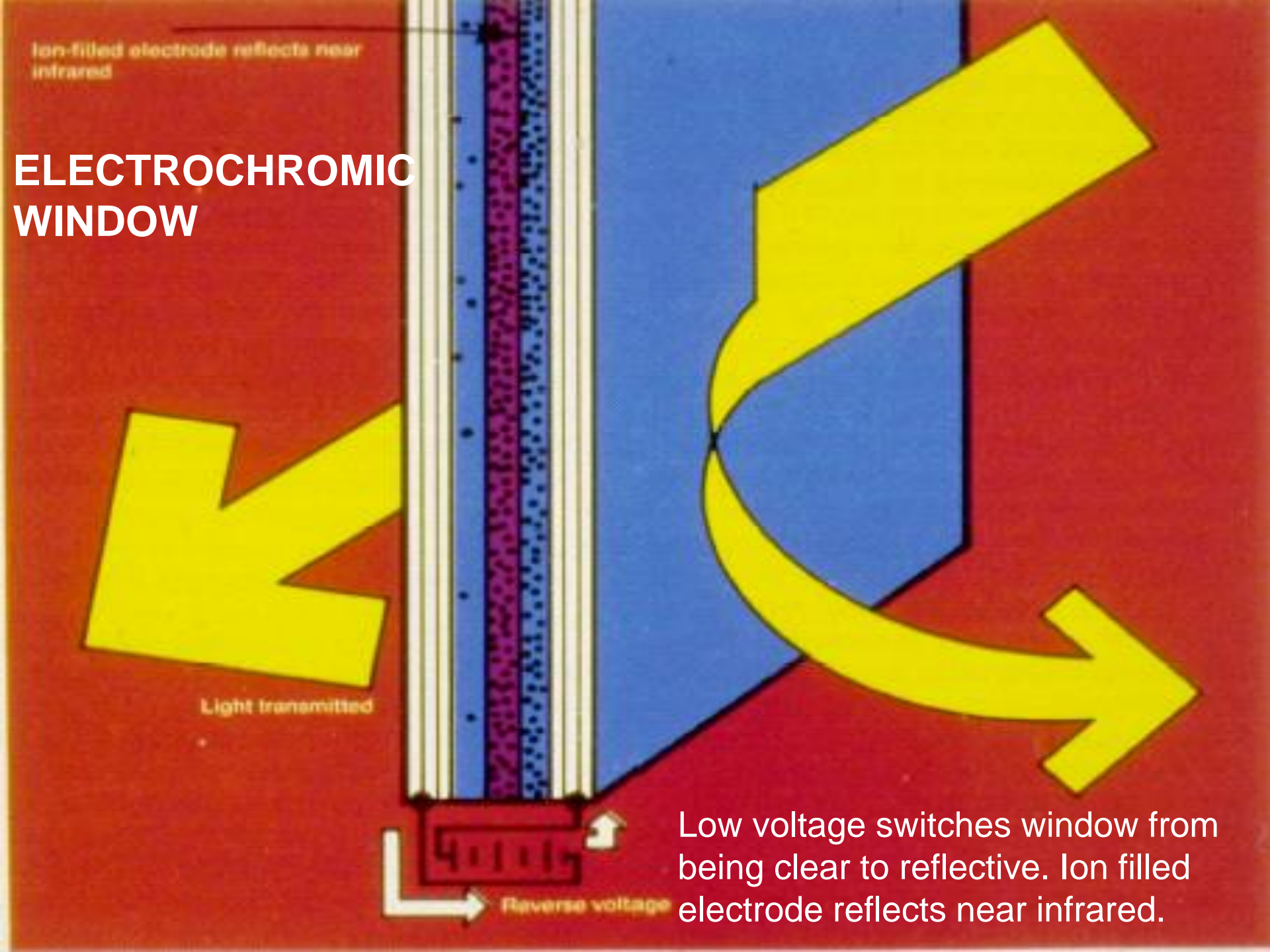
Ion-filled electrode reflects near infrared

# ELECTROCHROMIC WINDOW

Light transmitted

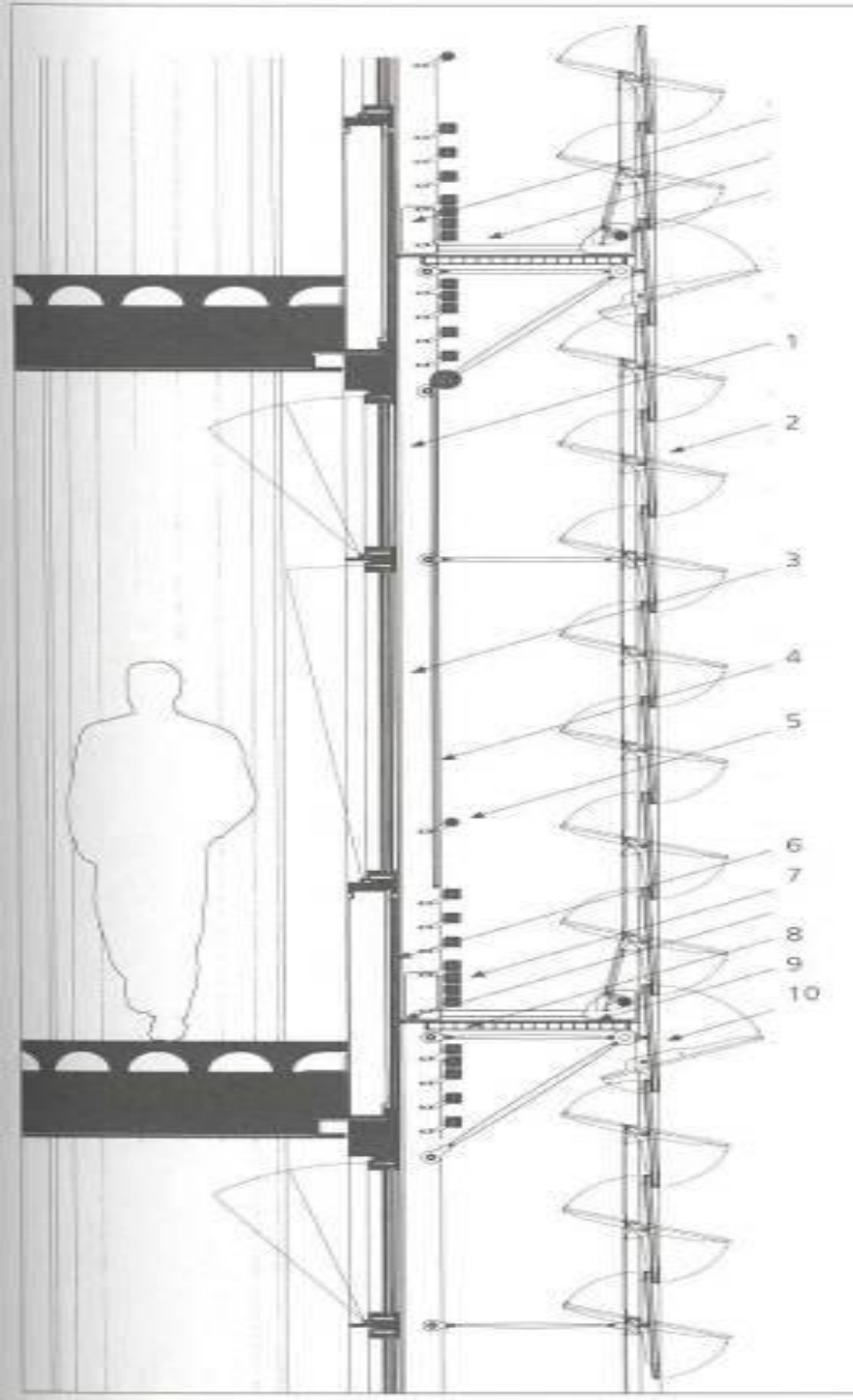
Reverse voltage

Low voltage switches window from being clear to reflective. Ion filled electrode reflects near infrared.





# Fire resistant panels for Debris



→ 1-Tilt-and-turn window

→ 2-Glass slats

→ 3-Tilt-and-turn window

→ 4-Solar shading device

→ 5-Rail, clad in terracotta

→ 6-Fire resistant panels

→ 7-Terracotta façade panel

→ 8-Stainless steel grating

→ 9-Safety glass

→ 10-Fixed pane

# Ventilation Towers with Solar Chimneys at Lancaster University

Ventilation towers with solar-driven chimneys maximises the floor area and exploits the south-facing façade. The towers sit outside the floorplate and provide cooling in the summer and heat recovery in winter





# Bedzed Zero Carbon Home



**Wind-driven ventilation:**  
fresh air drawn from  
outside to ventilate home

**Rainwater  
collection:** used  
to flush toilets

**Solar panels:**  
used to charge  
electric cars

**Walls:** 60cm (23.6")  
thick, concrete lined  
and filled with  
insulation

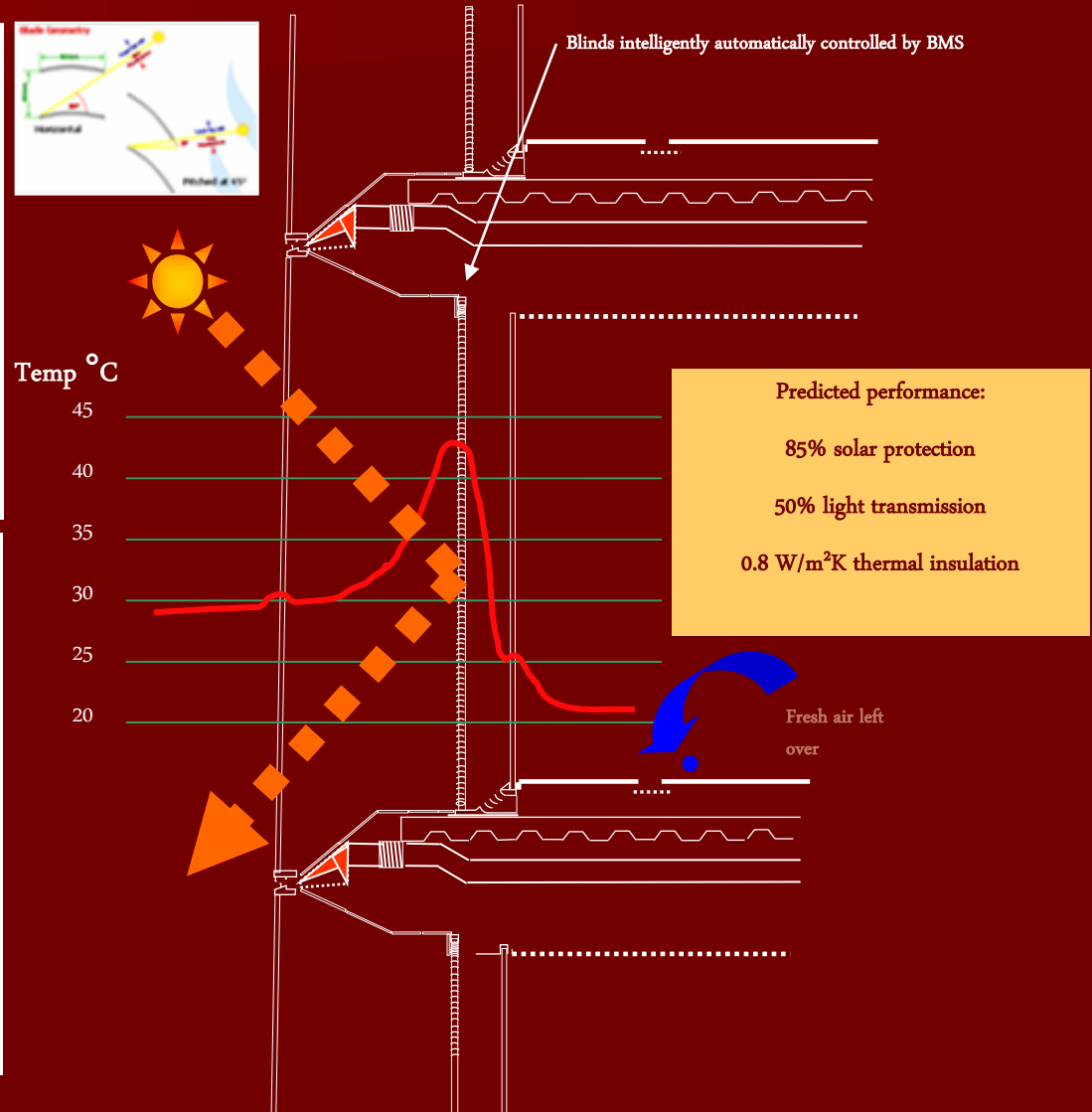
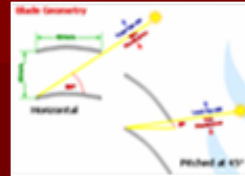
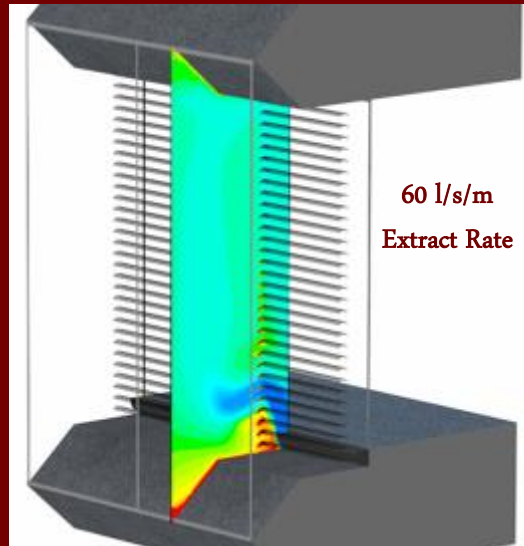
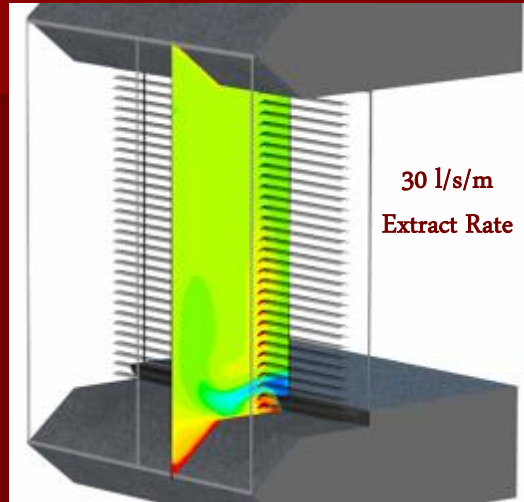
**Triple-glazed  
south-facing  
conservatory:**  
acts as sun trap  
and centrally  
heats house

**Sewage treatment  
system:** waste water  
filtered through reed  
beds but not  
currently used

**Underground  
wood-chip power  
system:** failed to work  
because it caused tar  
that clogged filters



# 30 ST Mary Axe – Façade Design

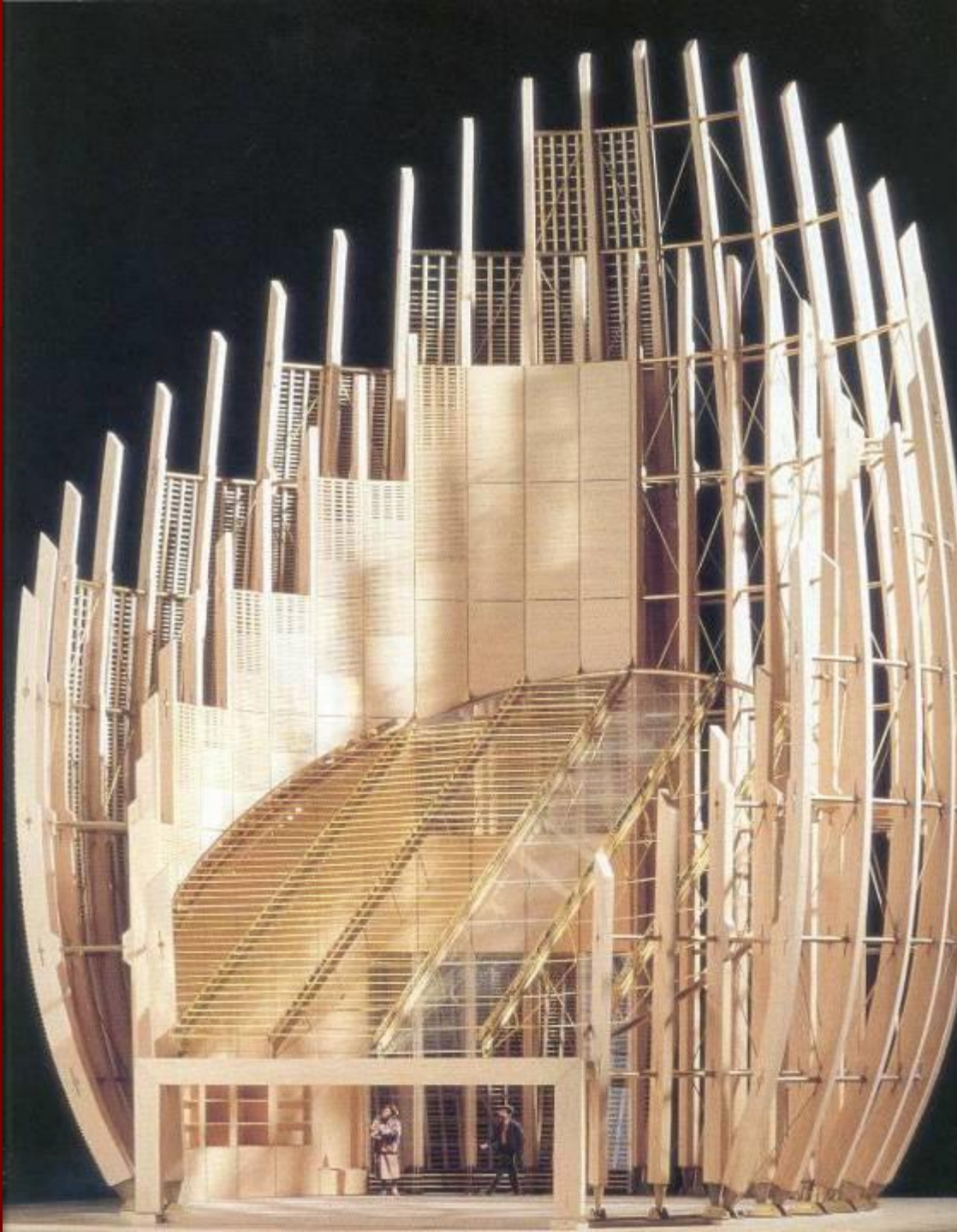


# Jean Marie Tjibaou Cultural Centre, New Caledonia

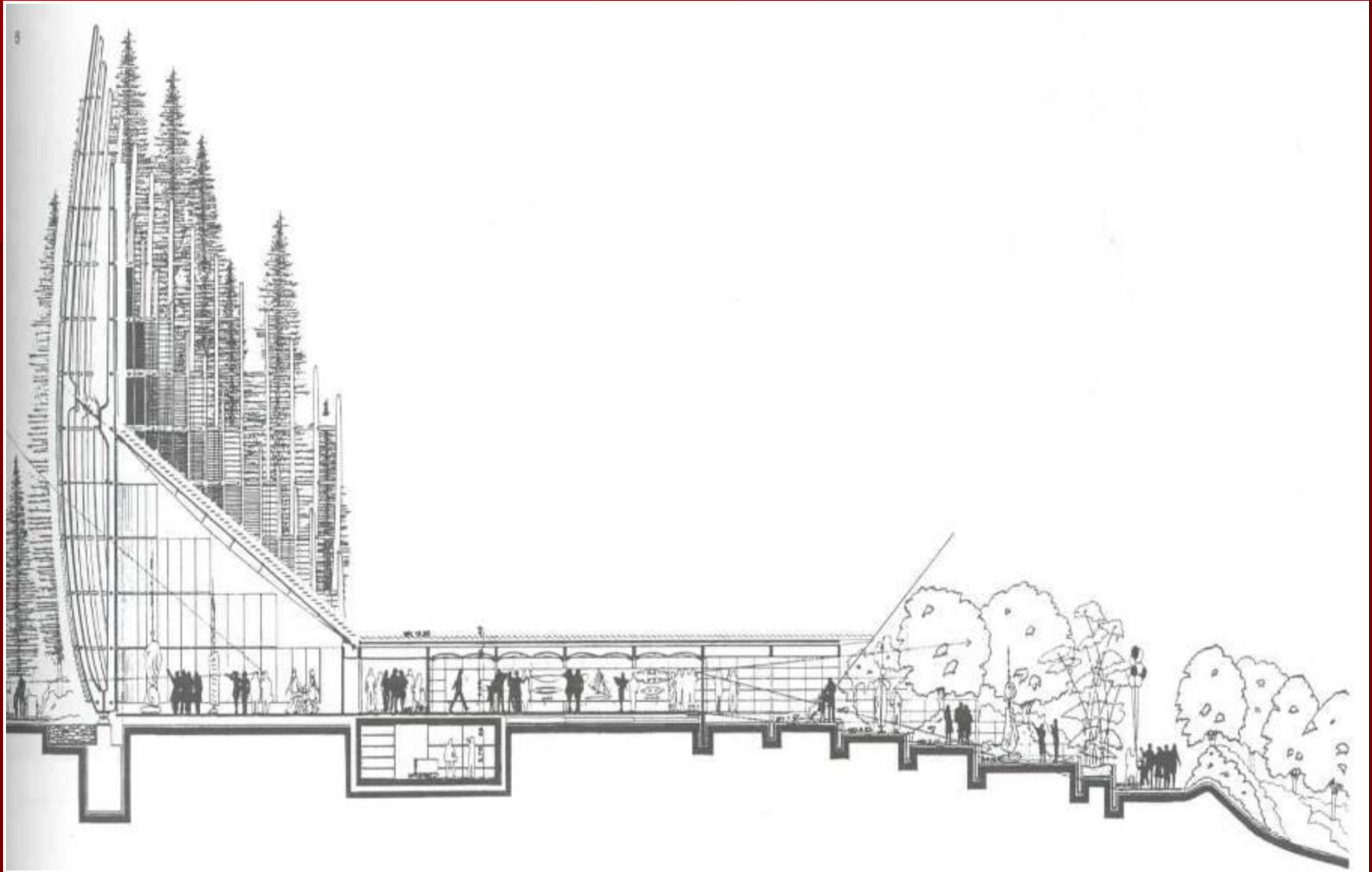


Renzo Piano, 1998









section

# Lloyds City of London, 1986

Rogers-Piano







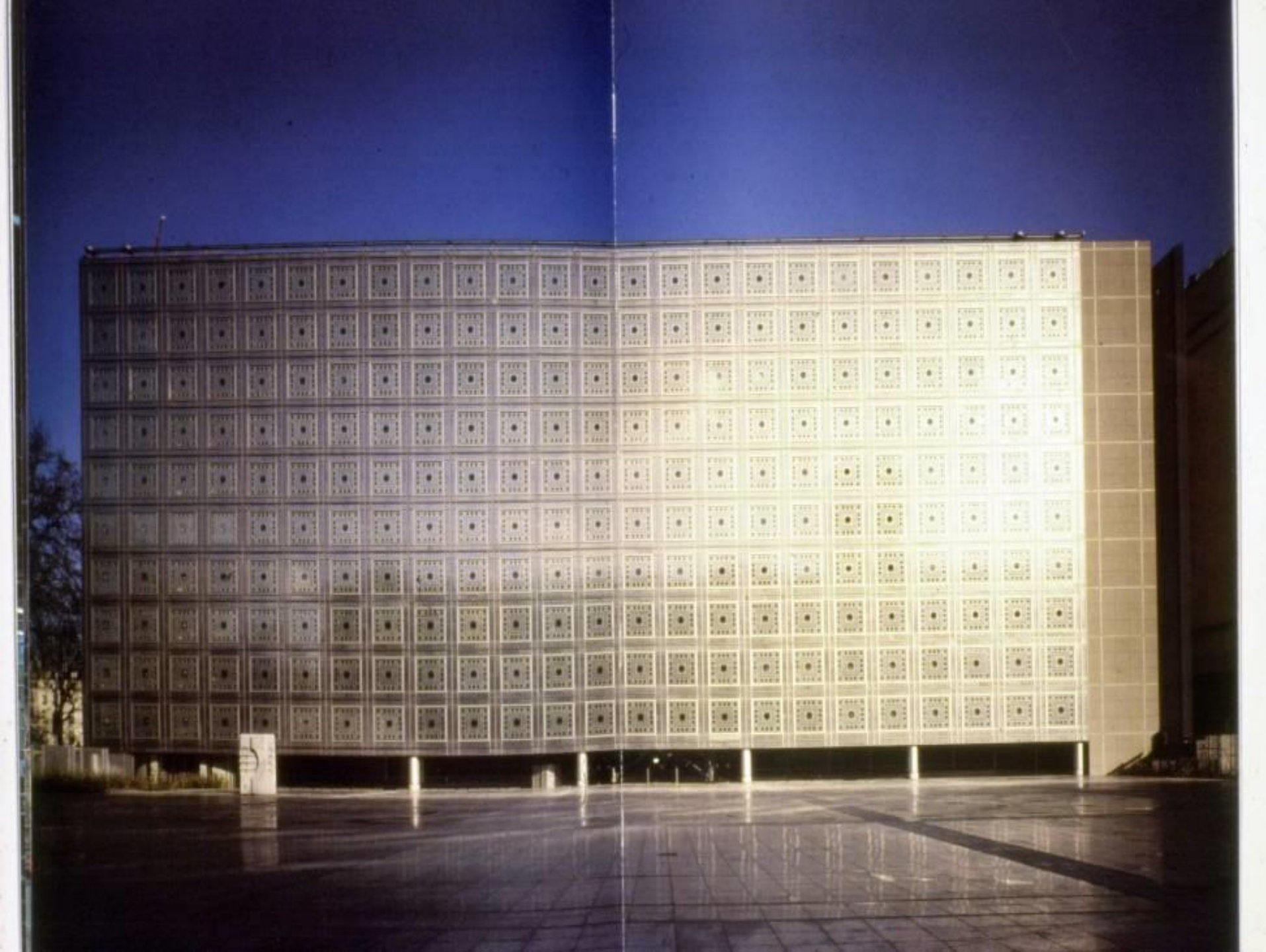
External glazing system consists of triple layered solar control glass with a ventilated cavity through which exhaust air is drawn via the light fittings. The quality of light is further enhanced by optically designed facets in the two outermost sheets of glass to create sparkle making the glass behave as a wall of light.



# Institut Monde d'Arabe Paris

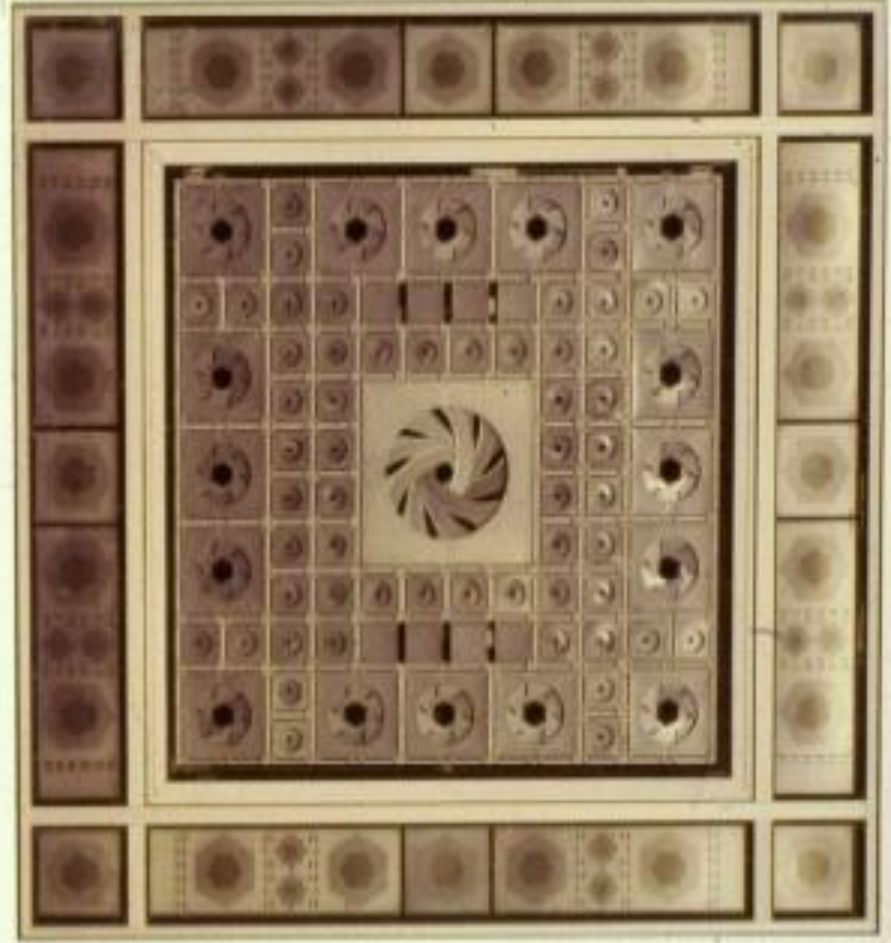


Jean Nouvel, 1987



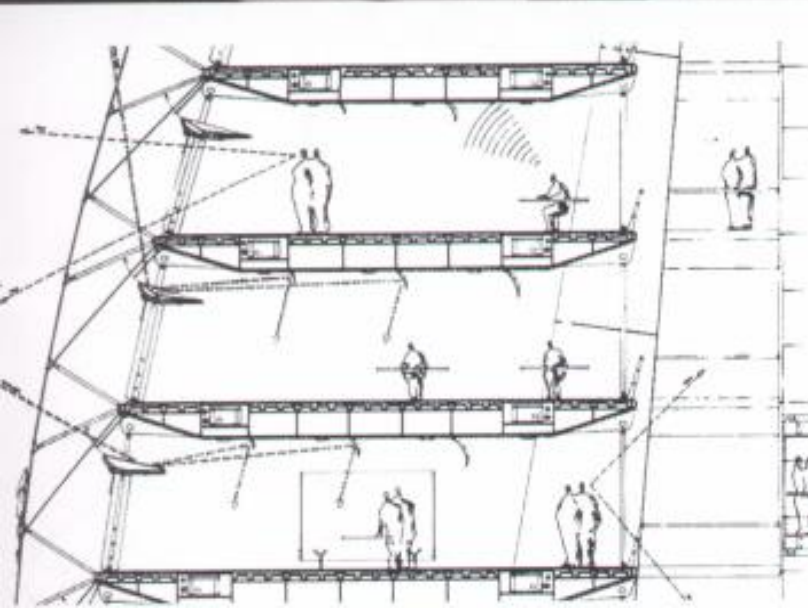


# Solar Control Aluminium Elements in South Facade





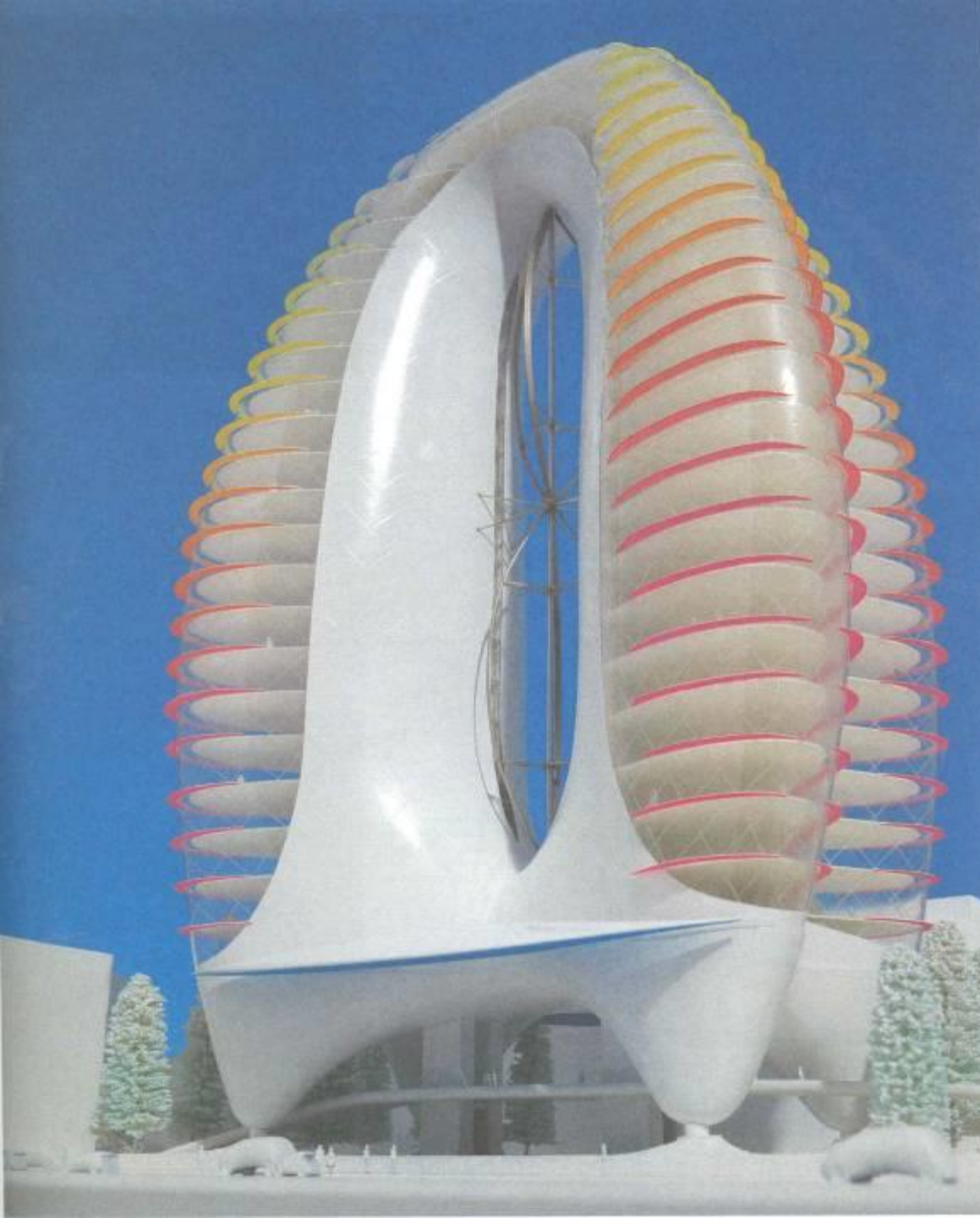
# Future Systems design for Green Building, 1990



Environment is controlled by a passive system using natural ventilation with some night cooling. Heating and cooling systems are only used in extreme conditions.

# Office Building, Project ZED, London

The butterfly-shaped plan of this building has an opening at the centre in which two vertical wind turbines are mounted.



# Biomimicry Green Building Highrise



William McDonough  
Green Tower

<http://sustainabledesignupdate.com>



# Digital Façade (Kunsthhaus Graz, Bix Biomorphic Structure, Austria)

Kunsthhaus Graz's eastern front is a matrix of 930 florescent lamps is integrated into to allow simple signs, images and films in low resolution.



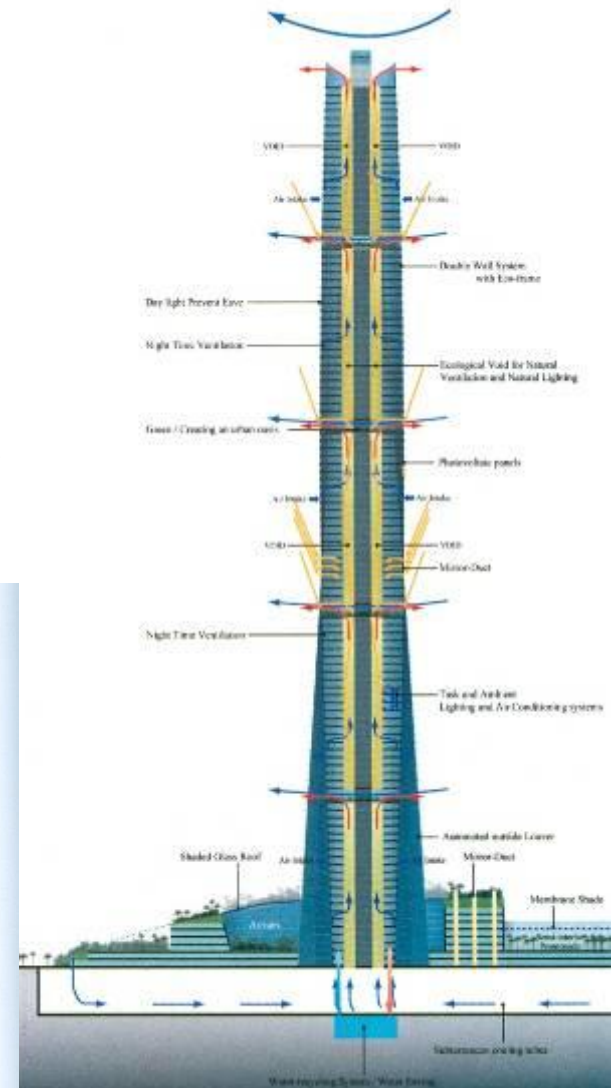
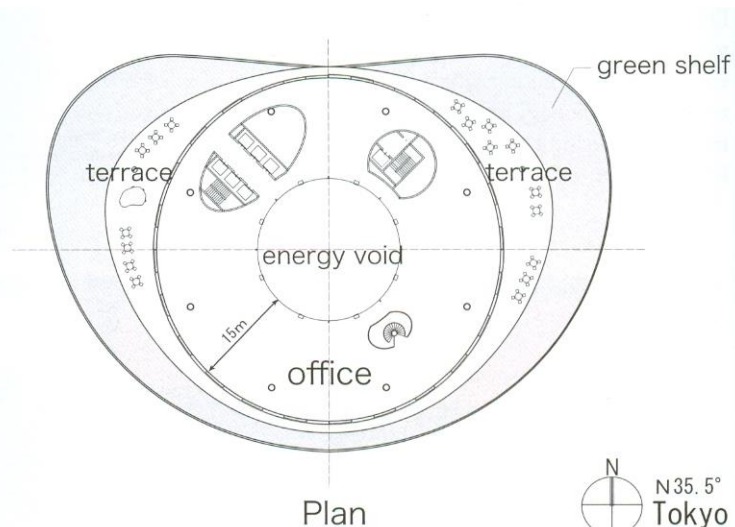
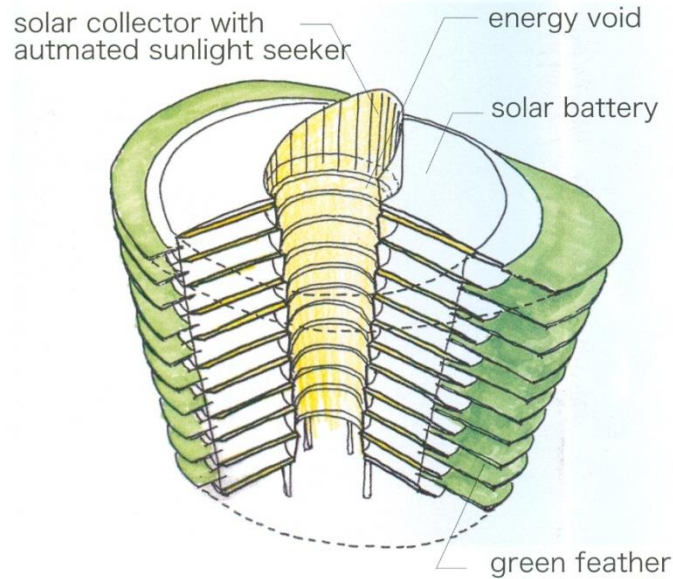
# World's First Revolving Tower Dubai





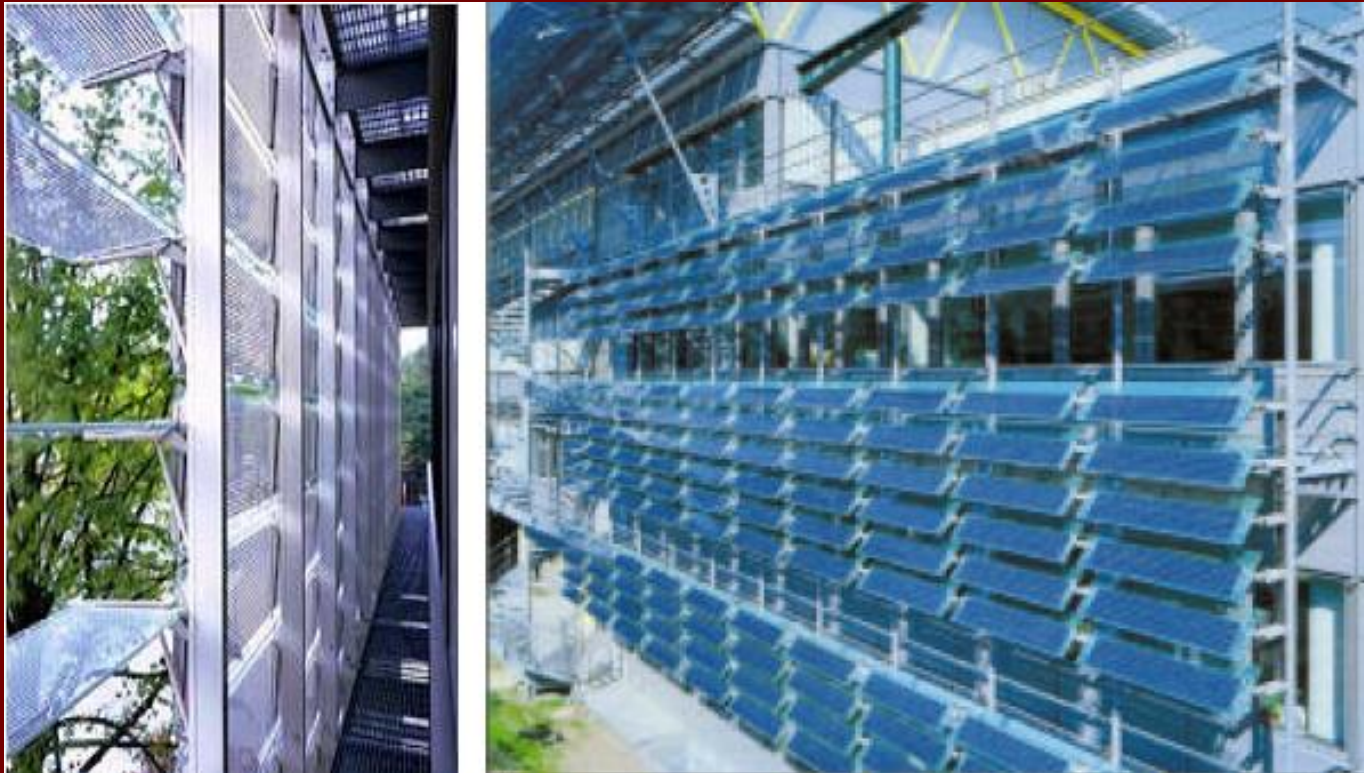
# Lighting and Ventilation Strategies Attempt to Minimise Energy Consumption

Nikken Sekkei,  
Cool City  
Dubai





- New Concepts for sustainable buildings
- Double Skin –facades for office buildings



Left: Multimedia Centre, Hamburg, Germany Foster & Partners

Right: Uni, Erlangen, Germany by UBA Erlangen

# Why Double Skin Facades?

- Reduction of peak wind pressure
- Improvement of energy efficiency of façade by
  - Passive solar heat gain in winter
  - Reducing thermal losses in winter
  - Reducing overall solar heat gain (in summer)
  - Support of natural ventilation (with the stack effect)



Inside view of office in Barcelona



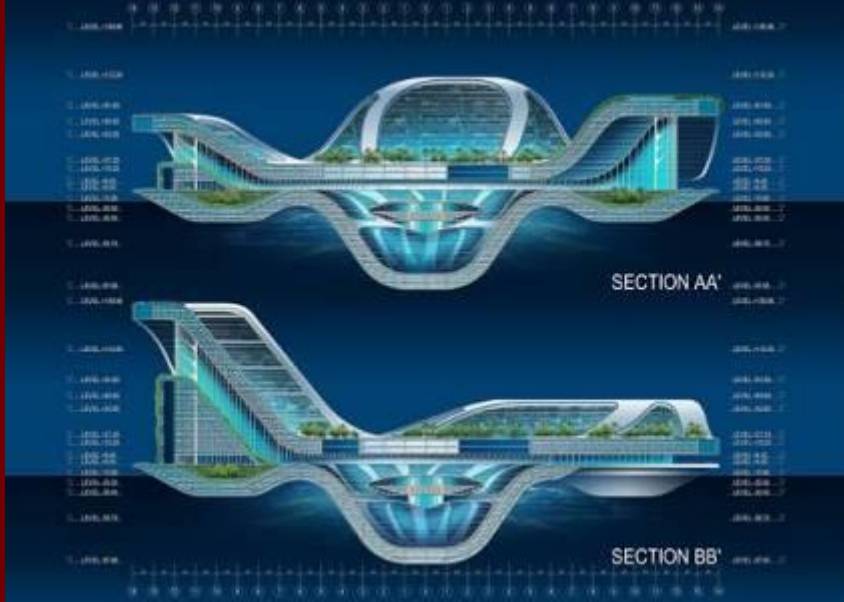
Outside view of office in Barcelona

The PV installation contributes positively in the field of daylight use, sun protection, visual relation to the exterior, thermal behaviour of staircase and building and last but not least as a corporate identity element for the company.

Masseck T, 2005, Transparent Amorphous Silicon PV-Façade as part of an Integrated Concepts for the Energetic Rehabilitation of an Office Building in Barcelona, 20th European Photovoltaic Solar Energy Conference, 6-10, Barcelona, Spain

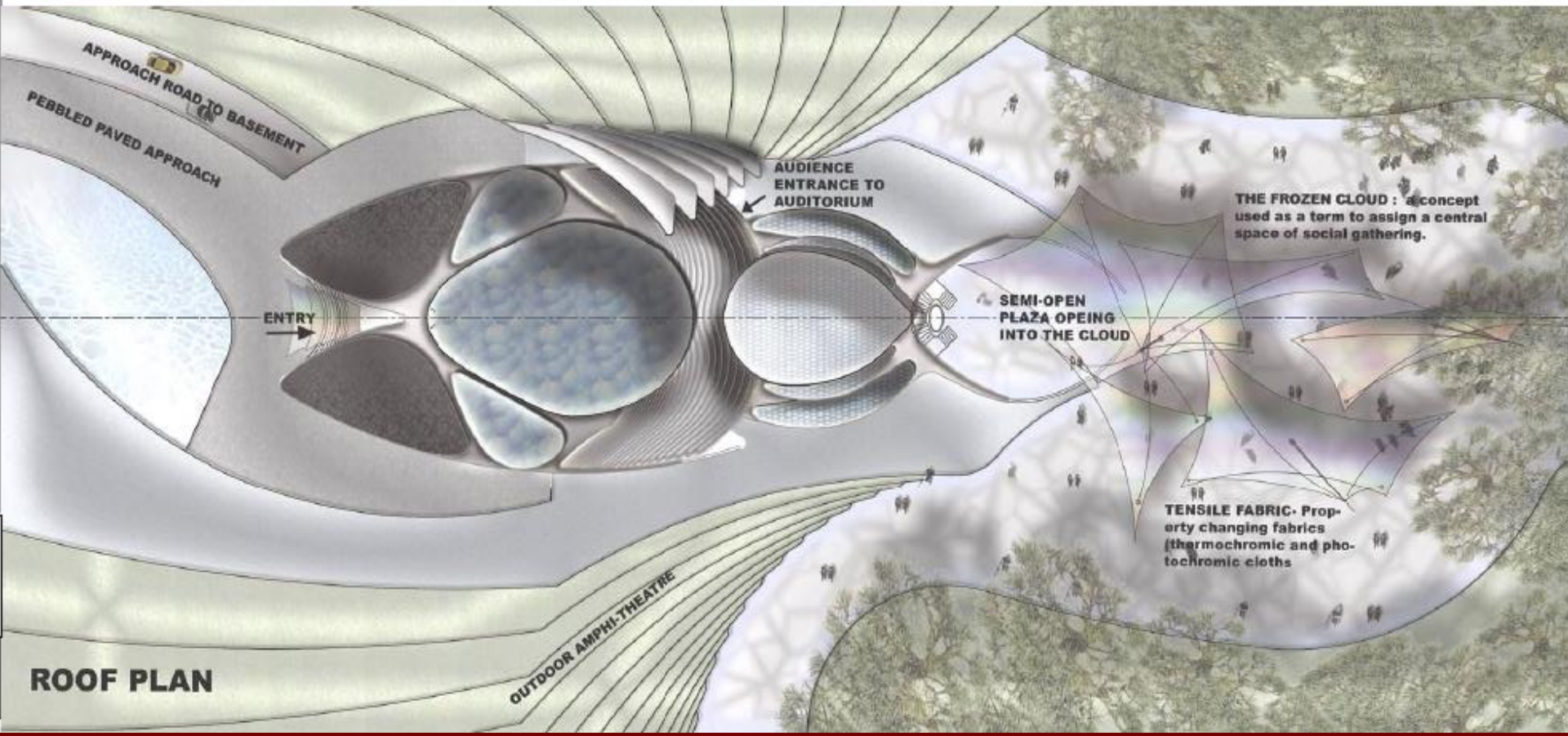


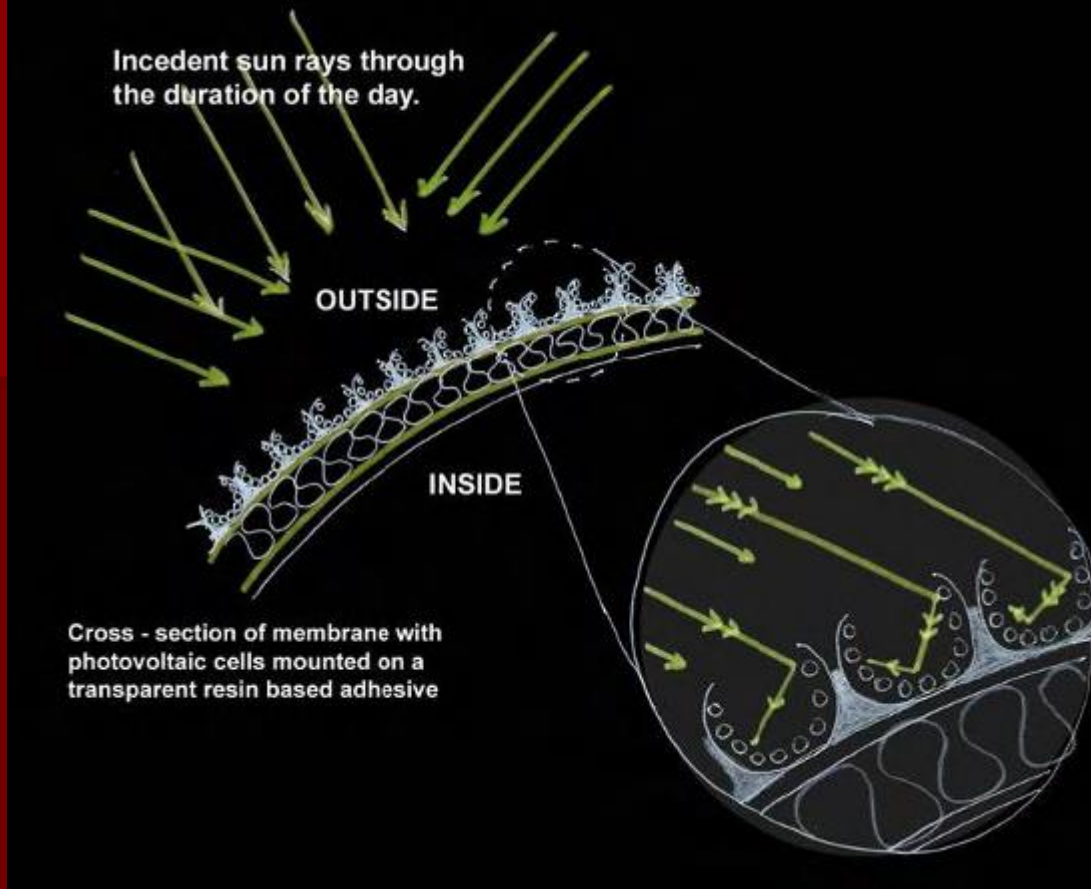
# Lilypad, a Prototype of Auto-Sufficient Amphibious City



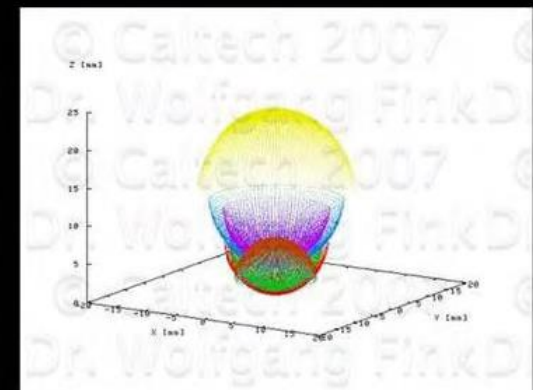
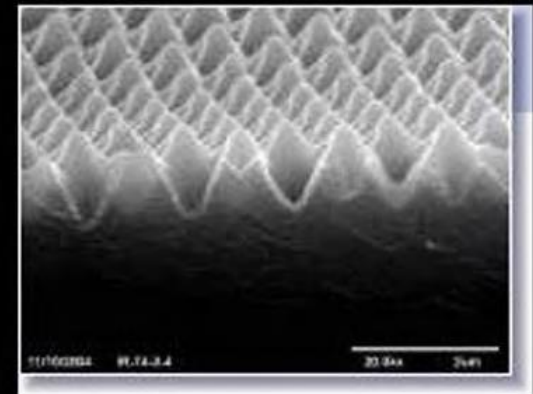
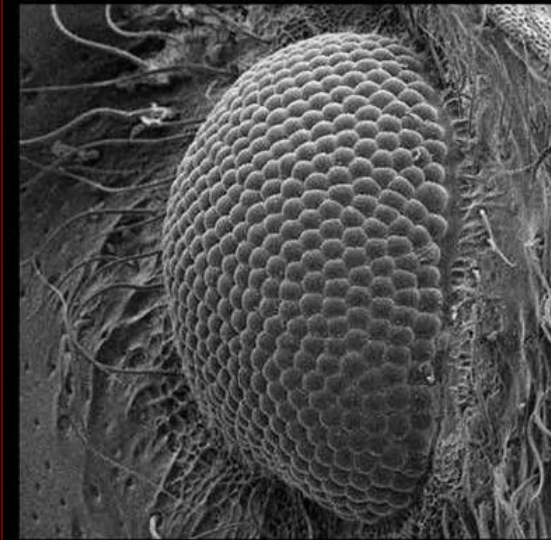
Architect Vincent Callebaut







- A cross sectional sketch of the proposed photovoltaic cell over the membrane absorbing sunrays from all directions.
- Derived inspiration – the eye structure of the moth.





# The Heritance Kandalama - Eco Hotel in Sri Lanka



# The Heritance Kandalama Eco Hotel in Sri Lanka

The property embraces a philosophy of sustainable development that encompasses the following areas:

- Energy efficiency, conservation and management
- Reduction of freshwater consumption
- Waste water management
- Minimization of waste, reuse and recycling
- Air quality protection and noise control
- Land use planning
- Social and cultural development
- Ecosystem conservation
- ENVIRONMENTAL AND SOCIAL POLICY
- RESOURCE CONSERVATION

# Tenets for Intelligent Buildings Design and Management

- Plan and design with an **integrated team** so that clients, consultants, contractors, facilities managers all develop a commitment to the project and want to fulfil the environmental, social and economic aims.
- **Systems and holistic thinking** are key.
- Assess the **impacts** of the buildings on occupants and communities nearby.
- **Occupants behaviour** has a large effect on the consumption of energy and water so try to increase awareness of occupants to the impact of their actions on resources.



- Smart metering is a start but sensor technology is rapidly becoming applicable in building operation and for the use by consumers of equipment..
- **Data management systems** are important to give feed back on the performance of different spaces in the building. Use continual post-occupancy evaluation process.
- Use a **whole life value** approach to ensure quality as well as whole life costs are taken into account.
- Aim for **simplicity** rather than complexity in operation.
- Think about **well-being and freshness** rather than comfort and consider all the senses and how air, view, daylight, sound, colour, greenery and space affect us in the workplace.

- **Connectivity** is important so there is interoperability not only between the systems and the building but also between the occupant and the building
- Design for **flexibility and adaptability**
- Think of an intelligent building as **an organism** responding to human and environmental needs but also one that needs to 'breathe' through the facade between the external and internal environments. The façade transfers light, solar radiation, air, noise, and moisture but also links occupants to the outside world so intelligent or smart facades allow these aspects to be controlled in a way which is functional but also enjoyable to those working and living inside the building.

- Plan the **facilities management** so the building is cared for
- **Balance efficiency with effectiveness.** An air supply system for example can deliver the “right” amount of air to a space and be deemed efficient but may not be effective in the space because it has no impact on the breathing zone where the people are.
- **Design beyond the expectations defined in Regulations.**
- **Keep abreast of the relevant fields of knowledge.**
- **Learn from other sectors and disciplines**